# OPTICAL MAGNIFICATION FOR SUBNORMAL VISION: HISTORICAL SURVEY [a,b,c]

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Early attempts to provide optical magnification to compensate for subnormal visual acuity used small galilean telescopes, mounted in spectacle frames, giving magnifications ranging from 1.3 to 3×. They were seldom helpful in distance vision because of the restricted field, change of apparent distance, and inadequate magnification. Many used them only for reading, and obtained additional magnification from a reading cap of high dioptric power which permitted a close viewing distance. After about 1955, the interest in telescopic magnifiers was almost entirely replaced by two other developments. One emphasized the use of simple reading spectables of high power. A second involved the search for inexpensive optical aids such as jeweller's loupes, thread counters, magnifiers for inspection of coins or stamps, and similar devices developed for the normal eye. Trial-and-error prescription of these devices as reading aids was later superseded by more-systematic procedures based on measurement and classification of the available aids as to magnifying power and type. This led to the development of new optical aids to supplement those already available. Examination procedures were also devised to assist in selection of aids of the required power and type for each user.

INDEX HEADINGS: Vision; Optical systems.

The subject I have chosen is an elementary one for an audience that includes lens designers and manufacturers of highly sophisticated optical instruments. However, there is need for closer cooperation between those who design or manufacture the magnifiers used by the partially sighted and those whose job it is to prescribe suitable reading aids for individual patients. A paper by Ellerbrock (1), published in the December 1946 Journal of the Optical Society, gave a comprehensive review of the sub-

[a] Reprinted with permission from the Journal of the Optical Society of America, 62 (2) :162–168, Feb. 1972.

[b] Tillyer Medal Lecture delivered at 1971 Annual Meeting, Optical Society of America, Ottawa [J. Opt. Soc. Am. 61, 1574A (1971) ].

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ject. I will therefore confine myself largely to development since that time.

## TELESCOPIC READING AIDS

Prior to about 1955, the most frequently used devices for compensation of subnormal vision were spectacle magnifiers based on the principle of the galilean telescope. The design of a telescope to be worn in a spectacle frame requires a compromise with the various conflicting requirements of size, weight, freedom from aberrations, and degree of magnification. For distance vision, the magnifications that proved feasible in spectacle form range from about 1.5 to 3×. Among the better-known telescopic spectacles are those of Zeiss (with magnification of 1.3 and 1.8×), Kollmorgen (1.7 and 2.2×), Bier (1.8,2, and 2.3×), Keeler (2×), Univis (1.5 and 2×), and Feinbloom (1.3, 1.7, 2.2, and 3×). Some of these are full-field telescopes; other smaller units provide both a magnified and an unmagnified field of view. Dr. Gerald Fonda, an ophthalmologist who prescribed telescopic spectacles prior to 1955, was soon convinced that they were of little help for distance vision (2). The major problems are insufficient magnification, a restricted field of view, a change of apparent distance of objects, and an apparent movement of stationary objects when the head is moved. In driving a car, riding a bicycle, or walking, a wide field of view and a correct location of objects are usually of greater importance than ability to discriminate fine detail. For momentary needs for magnification of distant objects—e.g., to read bus numbers, street signs, or blackboard material—and to watch sporting events such as ball games or horse racing, hand-held binocular or monocular telescopes such as are used by those with normal vision are also helpful to the partially sighted. Most of the latter group find a monocular telescope more convenient because they usually have unequal degrees of visual impairment in the two eyes. Figure 1 shows a Selsi 2.5× Sport Glass in binocular

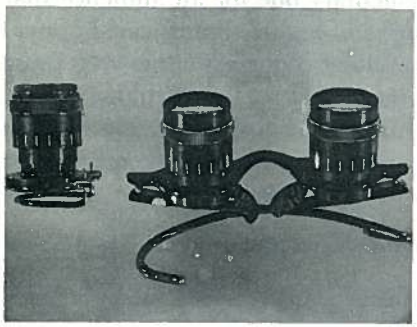

FIGURE 1.—Selsi 2.5X Sport Glass. Binocular and monocular versions.

FIGURE 2.—Monocular telescope with interchangeable objective lenses giving magnifications of 8 and 6X.

form, and its monocular counterpart, which can be clipped on the user's spectacles or held in the hand. Figure 2 shows another inexpensive monocular, also made in Japan, which provides either 6 or 8× magnification. Both of these telescopes can be focused to correct for small amounts of myopia or hyperopia. The emmetrope or corrected ametrope can use this same adjustment to focus for closer distances, i.e., up to about 4, 2, and 1.6 m, respectively, for the 8, 6, and 2.5× telescopes. For closer distances, auxiliary lenses of 0.5, 1.0, and 2 diopters are supplied with the 2.5× monocular.

Although telescopic spectacles were not widely accepted by partially sighted patients for improvement of their distant vision, many were able to use such a device as a reading aid when a suitable convex lens was added in the form of a reading cap. It is important to remember that when a telescope, focused for distance, is used to view a near object, there is an enormous increase of the divergence of the emerging light and consequently an increase of the amount of accommodation required. Boeder (3) derived a formula which shows that the divergence of light from a near object is increased by a factor approximately equal to the square of the magnification. For example, when a 2.2× telescope is used to view reading material at a distance of 33 cm., the accommodation required is increased from 3 diopters to 4.8×3 or 14 diopters. This formula gives only approximate values but serves to explain why everyone becomes presbyopic when viewing near objects through a telescopic spectacle. When such a device is used for reading, it is therefore necessary to place over its objective lens a reading cap consisting of a convex lens.

When the magnifications of 1.5 to 3× provided by telescopic units are not sufficient to compensate for the impairment of vision, a reading cap of high dioptric power can be used so that the closer-than-normal reading distance provides additional magnification. When, for example, a +10-diopter lens is worn over a 2.2× distance telescope, the user holds his book at the principal focal distance of 10 cm. from this lens. The magnification of the retinal image provided by the combination of telescope and reading cap is the same as that which the user would obtain if he wore a simple 22-diopter lens and held the book at its principal focal distance of 4.5 cm. It is obvious from this example that the compound lens consisting of distance telescope and reading cap provides about a twofold increase of working distance. This increase is sometimes helpful when it is not feasible to use a very short viewing distance. Telephone operators, for example, who must see a switchboard dial have a special need for a long working distance.

It should be recognized, however, that though the working distance can be doubled approximately by the commonly available telescopic reading spectacles, there is no corresponding improvement of depth of focus associated with this longer working distance. One of the reasons

why the patient finds it difficult to read with, for example, a simple +22-diopter reading lens is not the short viewing distance of 45 mm. that it requires but rather the small depth of focus. With only a 5-mm. decrease of this distance, the light reaching the eye is no longer parallel but has a divergence of 3 diopters. The older presbyopic patient who cannot compensate for this diverging light by lens accommodation is usually the one who finds it most difficult, because of tremor or general weakness, to hold the book steady in the principal focal plane of the reading lens. Methods of meeting this difficulty will be discussed later. For the present, I wish merely to emphasize that the compound telescopic reading lens has the same principal focal length as the equivalent thin lens and therefore has the same depth of focus.

## READING SPECTACLES OF HIGH POWER

Fonda (4) and a few other ophthalmologists began to suspect that the reading cap of high dioptric power, not the telescope, was contributing most of the magnification in the case of patients who were successfully using telescopic spectacles to read ordinary print. Striking illustrations of the use of a short reading distance to obtain a magnified retinal image are given by students attending schools for the blind because of retinal damage associated with high myopia. Many of them are able to read standard print at a close distance simply by removing the high-minus distance glasses worn to correct the myopia. Patients with subnormal vision who are not myopic can be made myopic artificially by wearing a convex lens for reading. Its dioptric power may be only slightly stronger than the maximum of 2.5 or 3 diopters prescribed for the elderly patient to read at a normal distance of 40–33 cm., or it may be as high as 20 diopters or more for patients with severe visual impairment.

The three most important difficulties associated with the use of strong convex lenses worn as reading spectacles are: 1. lens aberrations, 2. inability to maintain the required object-to-lens distance, and 3. difficulty in getting enough light on the reading material when it is held close to the eye.

In attempts to minimize aberrations, a few manufacturers have designed lenses or lens systems specifically for use as reading aids by the partially sighted. These include best-form spherical lenses with specially chosen front and back curves, aspheric lenses, either of glass or of plastic, and compound lens systems using either spherical or aspherical surfaces.

It is difficult to evaluate the relative merits of the available types of reading spectacles. This is partly because patients who require essentially the same magnification of the retinal image nevertheless differ widely in tolerance to the various aberrations introduced by lenses of high dioptric power. Some, for example, see no difference between a simple bicon-

vex lens and a specially designed aspheric lens of the same power. Others are more critical but differ with one another as to which type of lens is the best. It is not surprising, therefore, that at the present time there is no general agreement as to which of the many aberrations should be minimized in order to meet the needs of the greatest number of users of reading spectacles of high power.

The importance of aberrations is fortunately much less in the smaller-diameter lenses used when a bifocal spectacle is prescribed. When the patient has no useful vision in the poorer eye, he often prefers a bifocal correction for the better eye so that he will have both distance and reading vision when wearing the glasses. The main disadvantage of the bifocal, as compared with a single-vision reading glass, is the smaller field of view. Figure 3 illustrates this for single-vision Hyperocular lenses as compared with Keeler bifocals.

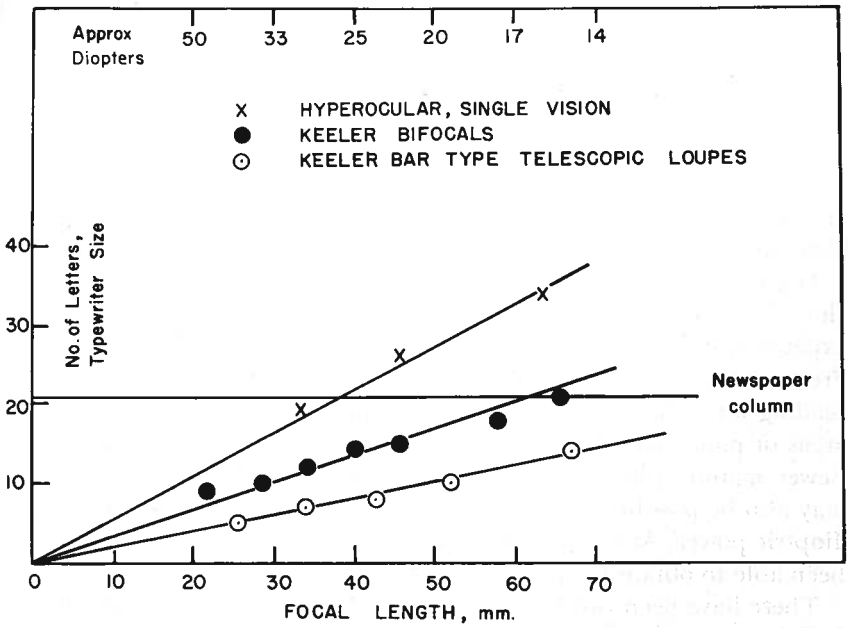


FIGURE 3.—Comparative fields of useful vision of three types of reading aid worn in spectacle frame (5). ×, Hyperocular, single vision; •, Keeler bifocals; ⊙ Keeler bar-type telescopic loupes.

Clip-on jeweller's loupes are used as reading aids by some patients. Figure 4 shows two of the most popular types, the Selsi Loupe from Japan and the Ary Loupe from Switzerland. The Selsi loupes range in power from 8 to 21 diopters, the Ary loupes from 10 to 32 diopters. The Ary Loupe can be quickly flipped up to give a full field of distance vision. Both types use simple biconvex lenses. Even in the highest powers there

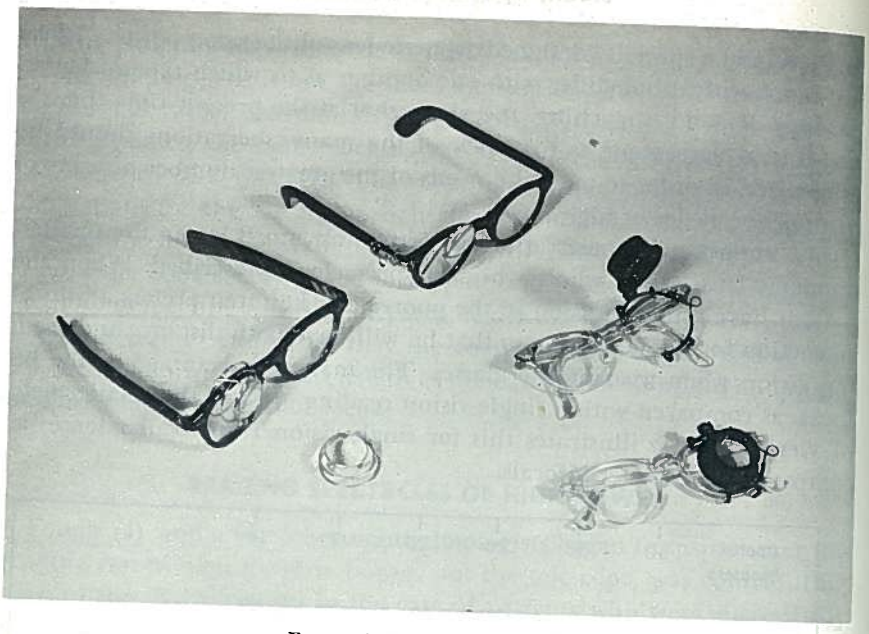

FIGURE 4.—Jeweller's loupes.

are no obvious aberrations, because of their small diameters (about 25 mm.).

High-power bifocal corrections are also available in permanent spectacles. They are less conspicuous than the hook-on loupes but are more expensive. A recent promising development is the use of press-on plastic Fresnel lenses. They can be prescribed either as single-vision or as bifocal reading aids. Early versions of the Fresnel plastic lenses had irregular areas of poor definition and an overlay of diffuse scattered light. With newer manufacturing methods these defects may be minimized, and it may also be possible to correct for spherical aberration in lenses of high dioptric power. At the present time, 20 diopters is the strongest we have been able to obtain for use as a spectacle correction.

There have been two attempts to meet other problems connected with the use of a very close reading distance. Figure 5 shows a device developed in England to assist the reader in maintaining his book at the required distance from the lens. I am not convinced that a single rod is adequate to maintain the page steady and exactly parallel to the reading lens. Another British device, Figure 6, attempted to meet both the problems of maintaining the page in the correct location and of illuminating it adequately. Because it is heavy and bulky, patients to whom we have shown this device prefer to use it as a stand magnifier by letting it rest on the reading page, bringing the eye close and moving the magnifier along the line of print.

FIGURE 5.—Rod of adjustable length to assist reader in maintaining correct distance from lens.

FIGURE 6.—Keeler illuminated spectacle magnifier.

## HAND-HELD MAGNIFIERS

When a convex lens is held in the hand at its principal focal length above the reading page, the magnification provided is the same as that obtained when the reading material is in the principal focal plane of a lens of the same power worn in a spectacle frame. Although a longer working distance is obtained by moving the lens and the reading material as a unit away from the eye, the possible advantages of this may be offset by the decrease of the field of view with increasing distance between eye and lens. The problem of critical depth of focus is the same with a hand lens and a head-borne lens of equal power. Hand-held lenses are usually self-prescribed. The user is likely to choose a large lens too weak for his needs, in order to obtain a wide field of view and to continue a hopeless search for a lens that is "bigger and stronger." Hand-held lenses are nevertheless useful for tasks such as the reading of a dial, if a short viewing distance is inconvenient and a wide field of view is not important.

## STAND MAGNIFIERS

Several difficulties in the use of strong convex lenses as reading spectacles or as hand magnifiers are solved by the use of stand magnifiers. In these, the lens is supported in a mount that rests on the reading page

and maintains the desired object-to-lens distance. A focusing adjustment for varying this distance and an attached illuminating device can easily be provided. Aberrations can be minimized by the use of compound lens systems that would be too bulky for insertion in a spectacle frame.

In the years between about 1955 and 1960, there was a growing interest in the use of inexpensive stand magnifiers that were originally designed for such tasks as thread counting, inspection of fingerprints, coins, stamps, etc. Most of those devices have excellent optical properties but a somewhat limited field of view for use as reading aids. Examples are the Bausch & Lomb Tripod and the Pre-cop-tic Magnifiers, the illuminated Flaw-Finder, Adisco Magnifier, and Agfa Loupe. All but the last two are focusable. All give high magnifications, about equal to those provided by spectacle lenses of 20 to 40 diopters. As with the spectacle reading aid, they are used with the eye close to the magnifier lens.

A great deal was done to stimulate the use of commercially available inexpensive optical devices by Ritter (5) when he was a member of the staff of the American Foundation for the Blind. A large assortment was available for inspection at their New York office or could be ordered by mail from their catalogue. This service, discontinued in 1961, was taken over by the New York Lighthouse in 1967 (6).

A series of focusable stand magnifiers designed specifically as reading aids for the partially sighted, developed in my laboratory, were described in a paper published in 1964 (7). Lenses of wide diameter are employed to secure as large a field as possible without introducing optical aberrations of significance to the partially sighted reader. These magnifiers use doublet lenses and have equivalent powers of 18, 24, 29, 37, 44, and 53

FIGURE 7.—Sloan focusable stand magnifiers and illuminating attachments.

diopters. Aspheric plastic lenses are used for the two strongest magnifiers. The others use plano-convex lenses with their curved surfaces facing inward. The magnifiers and illuminating attachments are shown in Figure 7.

Another type of stand magnifier is designed for use with the eye at a considerable distance from the lens. Representative devices in this group are shown in Figure 8. Because the fixed distance of the reading page behind the magnifier lens is less than its principal focal length, a magnified virtual image is formed at a short distance behind the lens. When used as intended, the reader's eye is located at about 40 cm. from this virtual image. He must, therefore, either exert about 2.5 diopters of accommodation or wear spectacles with a suitable reading addition. The optical characteristics of this class of magnifier are illustrated in Figure 9. In this example, the object is located 4 cm. from a 20-diopter lens, which therefore forms an enlarged virtual image 20 cm. behind the lens. If the user's eye is at a normal reading distance of 40 cm. from this image (20 cm. from the lens), he must supply 2.5 diopters, either by accommodation or by wearing a 2.5-diopter reading addition. The formula for the equivalent power of two lenses separated by an interval shows that the 20-diopter magnifier lens and the 2.5-diopter reading addition, when separated by 20 cm., have an equivalent power of 12.50 diopters. For convenience in comparing magnifiers in this group with spectacle reading aids, we may assume in every case a viewing distance of 40 cm. from the virtual image, because this corresponds to the reading distance for which the presbyopic patient with normal vision is usually corrected. Under these conditions, presently available reading aids of this type provide

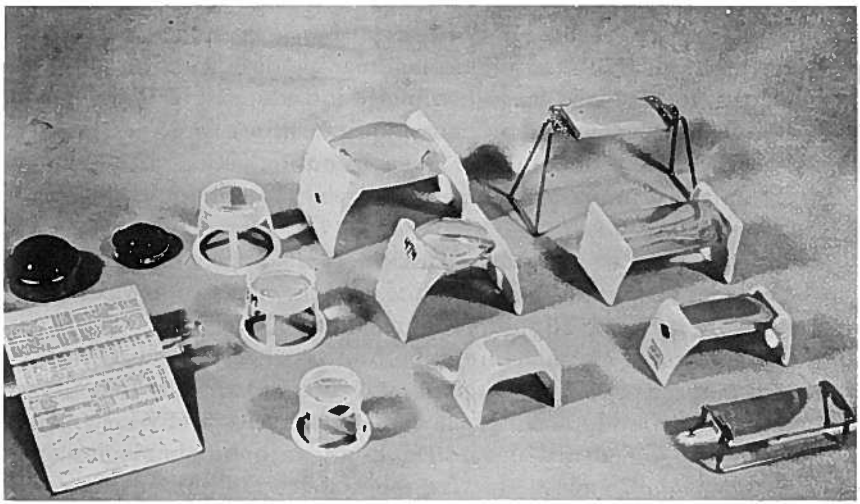

FIGURE 8.—Several types of fixed-focus stand magnifiers for use with eye at a distance.

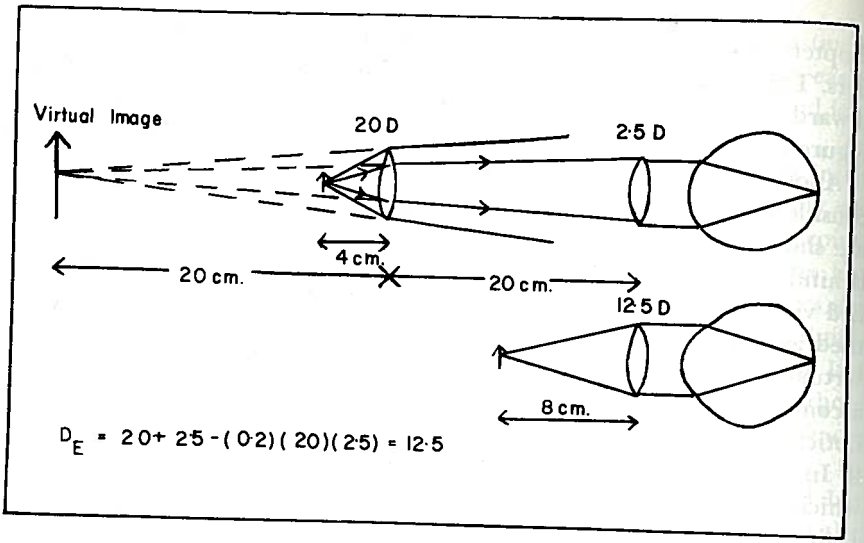


FIGURE 9.—Optical characteristics of fixed-focus stand magnifiers used with eye at normal reading distance from the virtual image (5).

magnifications equivalent to those of spectacle lenses ranging in power from about 3.50 to 17.50 diopters. The stand magnifiers have the advantage of longer working distances but provide smaller fields of view than their equivalent spectacle-lens magnifiers.

## PROJECTION MAGNIFIERS AND CLOSED-CIRCUIT-TV READERS

In another class of reading aids, the user views a magnified real image projected on a screen located at a normal reading distance. The substitution of a real for a virtual magnified image introduces several problems. First, the viewing screen and accessory equipment are large, heavy, and not easily portable. Second, there is an enormous reduction of luminance when the enlarged image of the reading page is projected optically onto the diffusing screen.

Two such devices are the American Optical Co. Projection Magnifier, which provides magnifications of 3 or 5×, and the Megascope which provides 12 or 22×. Figure 10 shows the magnified image of newsprint on the 12× Megascope. Manufacture of both of these devices has been discontinued because of limited demand.

A more recent development is the use of closed-circuit-TV systems to produce the magnified real image. Dr. Potts, an ophthalmologist, and his co-workers, Volk and West, were the first to publish a description of such a device, in 1959 (8). Their TV reader provides only one level of

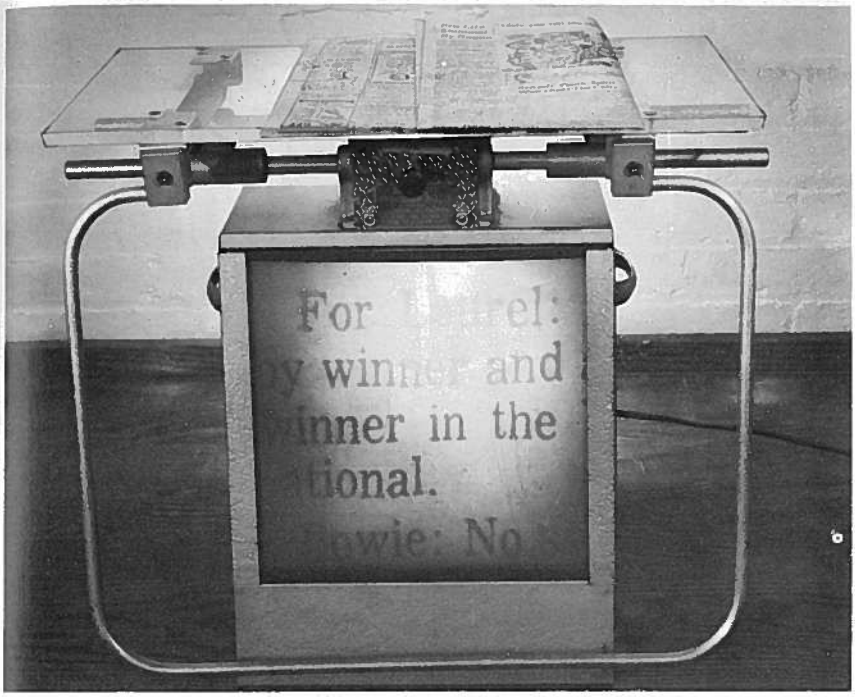


FIGURE 10.—Showing newsprint as seen with 12X Megascope.

magnification, 10×. There are now at least three commercially available TV readers. They employed zoom-lens systems to obtain the wide range of magnifications required to meet the needs of different users. One such device is shown in Figure 11.

By suitable electronic enhancement, TV readers can provide high luminance of the white areas and good contrast between black and white. This should overcome one of the disadvantages of magnifiers using simple optical projection. It is claimed also that the TV magnifiers can be used for tasks other than reading, e.g., writing, sewing, assembly of small objects, etc. An adequate depth of focus supplemented by provisions for easy adjustment for larger changes of object distance is an important requirement in meeting such special needs.

## TESTING PROCEDURES AND PRESCRIBING

The two principal reasons for the past lack of interest in prescribing optical aids for the partially sighted have been, first, the absence of a consistent system of rating these devices as to the magnification they provide and, second, the use of time-consuming trial-and-error procedures to find a suitable device for each patient.

FIGURE 11.—A closed-circuit-TV reader.

A 1959 paper by Sloan and Jablonski (9) showed that all of the types of reading aids can be specified in comparable units, equal to the dioptric power of the spectacle lens that gives the same magnification. That paper included data on the equivalent power, size of useful field, and other pertinent optical characteristics of more than 200 devices, including head-borne, hand, and stand magnifiers and projection readers. Trial of these devices in our clinic led to publication in 1966 of a handbook, distributed by the National Society for the Prevention of Blindness (10). This booklet gives specifications and sources of supply for recommended devices, whose selection was based primarily on acceptance by our patients.

To simplify the prescribing of a suitable strength of reading aid for each patient, we developed (11) a set of reading cards composed of samples of continuous text ranging in size from that of ordinary newsprint to text twenty times as large. The reading cards are shown at a fixed distance of 40 cm. to determine the amount of magnification required for easy reading of ordinary print. The size of print read with ease at the standard test distance determines the dioptric power of the required reading aid. If, for example, at a distance of 40 cm. the patient requires, for easy reading, print that is five times the size of newsprint, then he will be able to read newsprint at 8 cm., one-fifth the standard distance. As-

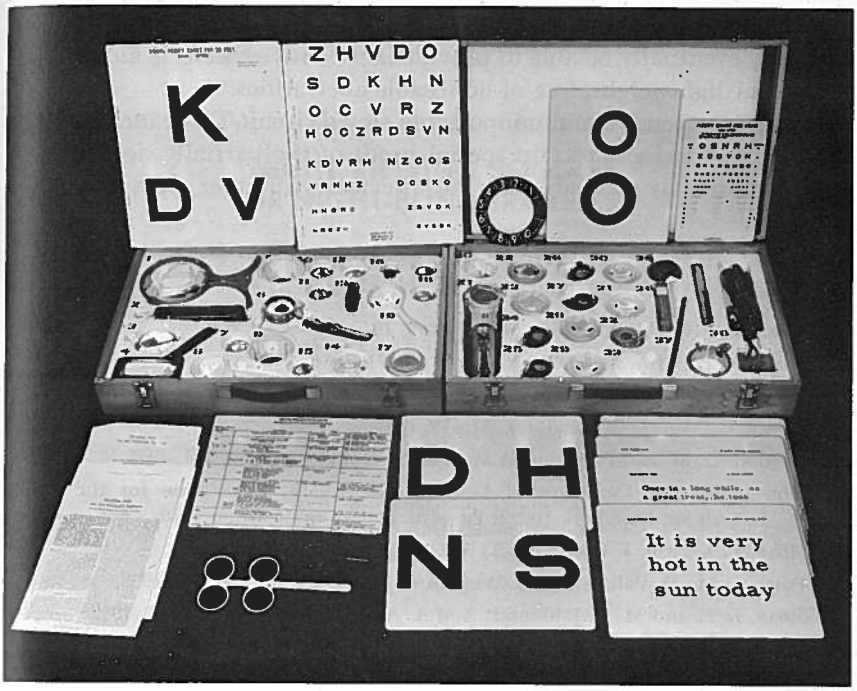


FIGURE 12.—Basic test kit. Includes nonspectacle magnifiers in wide range of powers, and accessory testing equipment (10). Photograph by permission of the National Society for the Prevention of Blindness.

suming that his power of accommodation is negligible, he will require a spectacle reading addition of 12.50 diopters to read newsprint held at a distance of 8 cm. The most suitable type of reading aid for the individual patient is next determined by showing him for comparison a series of spectacle, hand, and stand magnifiers equivalent to one another as regards the magnification they provide.

We have also developed a test kit that contains nonspectacle optical aids previously found useful in our Low Vision Clinic. The kit includes special equipment for examination of the patient with subnormal vision. The complete contents are shown in Figure 12. The mail order service initiated by the New York Lighthouse in 1967 is of assistance in securing optical aids other than those prescribed in spectacle form. Their catalogue (6) has excellent photographs of each device and gives specifications of their equivalent dioptric powers, based on measurements made in our laboratory.

## FUTURE NEEDS

This survey suggests that the most urgent need is for improvements in the design of high-power reading aids in spectacle form. Recent develop-

ments in the manufacture of press-on plastic Fresnel lenses suggest that they may eventually be able to provide inexpensive spectacle aids of high power but lightweight, free of noticeable aberrations.

Whether expensive and nonportable closed-circuit-TV readers provide the best way to meet certain special needs of the partially sighted must be determined by comparison of such devices with other types of reading aid.

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