A broad view of the science and technology of optometry past and future

Hindsight and Foresight

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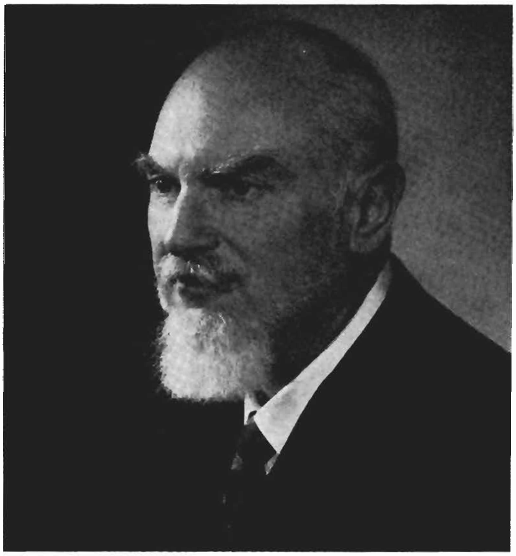

Introduction

Predictions of advances in science and technology generally have been notable for their inaccuracy.

One of the primary problems in acquiring foresight in optometric development is a definition of the role of optometry and of new demands on the profession. Will they be static or will they be modified along with continuing new developments in the science and technology of vision? Is optometry ready, able and willing to redefine the boundaries of its activities in order to embrace new opportunities generated from the laboratory?

A chronological table of milestones in the science and technology of vision and optometry is presented from prehistory through the present and extrapolating into the future. For the next decade, several developments are imminent. First, new clinical instruments including the use of automation. Second, the prevention of certain visual neural anomalies by the examination of infants during their sensitive period of neural development. The data obtained would be used to prevent stimulus deprivation which leads to amblyopia and strabismus. Other developments are expected in contact lens materials and techniques as well as improved diagnosis and therapy of

Reprinted from the Journal of the American Optometric Association

eye and systemic diseases.

Role boundaries

Before one can discuss the effects of developments in science and technology on optometry, it is essential to define its role. This may be the most difficult task of all because of diverse views within the profession and because of the absence of a coordinated division of activity with ophthalmology and other overlapping professions.

Looking back to the Middle Ages, when surgeons were barbers, optometrists were opticians selling spectacles in the market place. With the coinage of their name around the turn of this century, optometrists became professionally oriented. The examinations, both refraction and screening for eye disease were emphasized along with the professional provision of spectacles. Gradually over the years to the present day, the selling aspects of spectacles have been de-emphasized although, by and large, the dispensing aspects have not. This has been and can be justified in order to provide a complete service, especially when the examination fee is separate, distinct and not included in the cost of the spectacles. Furthermore, with professionalization new services have been offered such as thorough screening for eye disease, and with advances in technology, contact lenses. How far should an optometric examination and prescription go beyond these now established boundaries? Will the role of the optometrist remain as it is now or will the sweep of science and technology change his activities?

Milestones in the science and technology of vision and optometry

Let us look backward through a reversed telescope, compressing the view, and paint the picture we see in bold strokes, avoiding fine detail in order to encompass the whole picture at a glance. For an organized and economical presentation of optometric milestones a table (Table 1) is presented arranged with a non-linear time scale. Most entries mark discoveries, some practical application, through technological developments or inventions. The historical data have been obtained from a number of sources but the single most complete one is Duke-Elder.[1] Catoptrics, the science of reflection, may reach back several millenia before Christ. Dioptrics, the science of refraction, was known as a technology by the Romans who used glass spheres filled with water as burning glasses, but the principles were not understood until Kepler's time. Wheatstone discovered binocular stereopsis in 1838, which marks the entry of binocular vision, but binocular vision was more generally and fully explored by Donders in 1864. Contact lenses were originally conceived by Da Vinci, but are placed in our chart at 1949 when the invention of the corneal lens made them widely practicable. Hubel and Wiesel's now classical papers on selective visual deprivation started in 1963 but the clinical harvest from these concepts in the prevention of visual anomalies probably will not be available for another decade. Improvement in the diagnosis and therapy of eye and systemic diseases is a continuous process and is placed in the table at a time in the near future to emphasize its importance. Better diagnosis and understanding of a disease often makes its early detection critically important in order to cure or arrest it to prevent its deleterious effects.

The future becomes more speculative the further we go. New instruments are here, but for the most part, still under development in the laboratory. The "artificial eye" or phosphene visual prosthesis is under development. In England two different models have been implanted in the heads of human subjects with promising results, and phosphene producing electrodes have been implanted in blind subjects in North America. Direct stimulation of the visual cortex can bring light and form to those blinded from eye, retina, or optic nerve trauma or disease. When these devices are developed, people, presumably optometrists because of their rigorous training in vision, will be needed to match (in programmable-read-only-memories) visual-field image space and brightness with visual cortical-space and electrical thresholds with the aid of computers.

Beyond this point we approach science fiction. There we step beyond vision and perhaps become visionary.

Physiological modifications of refractive state[2] could have a profound effect on op-

TABLE I
MILESTONES IN THE SCIENCE AND TECHNOLOGY OF VISION & OPTOMETRY

Year A.D. (non-linear scale)	**Scientific Concept**	**Technological Advances**
<1300	Catoptrics	Mirrors Spherical lenses
1300		Reading glass (Roger Bacon, 1266) Spectacles (in Venice, 1270)
1600	Myopia, dioptrics (Johannes Kepler, 1604)	Prisms (Kepler, 1604)
	Refraction in the eye (Christopher Scheiner, 1619)	
	Optical correction for myopia & aphakia (Daza de Valdes, 1623)	
	Law of Refraction (Willebrord Snell, 1637)	
	Anisometropia (Johann Zahn, 1685)	Refractor (Zahn, 1685)
	Hyperopia (Isaac Newton, c. 1700)	
		Bifocal (Benjamin Franklin, 1775)
1800	Astigmatism & optical constants of eye. Accommodation in lens. (Thomas Young, 1801)	
		Cylindrical lenses (Airy, 1827)
	Binocular vision, stereopsis (Wheatstone, 1838; Donders, 1864)	Crossed cylinder (Gabriel Stokes, 1849)
	Compound optical system (Gauss, c. 1841)	
	Dioptrics of eye (Helmholtz, 1856)	Retinoscopy (Bowman, 1859)
1900	Eye disease examination	Opthalmoscopy (Helmholtz, 1851) Slit-lamp microscopy (Gullstrand, 1911) Tonometry Visual fields
1950	Contact lenses	Corneal contact lens (Touhy, 1949) Hydrogel contact lens (Wichterle, 1960)
past → 1960	Visual neural development (Hubel & Wiesel, 1963)	
1970	New instruments for eye examinations	Automated retinoscopes Automated perimeter (Octopus) Guyton astigmatic optometer (refractor) Humphrey refractor Computer refractor Visual evoked potential examination

TABLE I CONTINUED

Year A.D.	Scientific Concept	Technological Advances
present		Contact lenses, new materials & techniques, intraocular lenses
1980		Prevention of visual neural anomalies (based on knowledge of visual neural development and perception)
← future	Improved diagnosis and therapy of eye and systemic diseases	Continuous progress. Expected to make additional demands on optometry
1990	Artificial eye—phosphene visual prosthesis (Brindley, 1968)	Packaged integrated circuits, non-noxious electrode array, neural basis of perception
2000	Biological modification of refractive state	Current attempts unsuccessful (Keratomileusis, J. I. Barraquer, 1964)
>3000	Regeneration of eyes and visual pathways	Currently may be considered as science fiction
	Selective genetic modification of eyes and visual pathways	
	Interactive direct brain-computer coupling. Electronic sensors input	

tometry should it become a successful and widespread procedure. If optometry does not become qualified to make this modification, it may have to change its emphasis from refraction to other aspects of vision and health care in order to serve the public and survive.

Interactive brain-computer systems is science fiction today. Yet computer peripherals could do all the sensing and processing could be accomplished before transmitting the information to the brain. Aside from our ignorance of the basic code of the brain (although progress is being made in this direction) the fundamental barrier today is knowing how to build a safe and effective interface between the computer and the brain. Current electrode systems for the striate cortex are neither fine enough for adequate channels for high resolution nor free of noxious effects. Interfaces without electrode contact would be more desirable, but none are as yet in sight. (At this point in considering future possible developments in computers, one might question if the computer would find any advantage being coupled to a brain, or if the brain, coupled or not, could maintain control of the computer.)

Let us now retreat from the highly speculative, going to the near certainty, and discuss those developments which, on the basis of current work in the laboratory, optometry is very likely to be concerned with in ten years: new instruments for eye examinations including visual evoked potentials and the preventing of visual anomalies through deprivation avoidance (developmental stimulation) in infants.

New instruments for optometry

In this section I have been somewhat selective, including instruments which are, or show promise of becoming commercially available. The literature contains many instruments which for various reasons have not been of sufficient interest and usefulness to be used clinically on a broad scale, and they are omitted here.

Automated retinoscopes

In the past few years, three automated retinoscopes have become available at about twenty thousand dollars each: Safir's

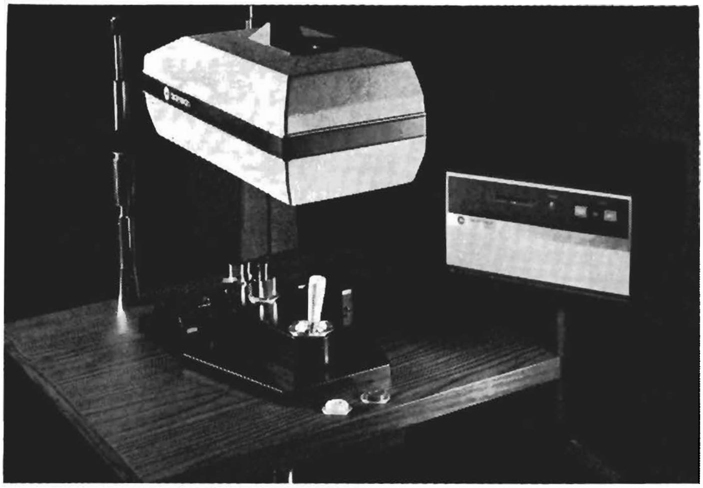

FIGURE 1—The Dioptron, an automated retinoscope made by Coherent Radiation, Inc. of Palo Alto, California.

Ophthalmatron (Bausch & Lomb, Inc.) Cornsweet's (Acuity Systems, Inc.) 6600 Auto-Refractor, and the Dioptron (Coherent Radiation, Inc.) Figure 1. While there are differences in their modes of operation, these clever instruments essentially automate retinoscopy. Like retinoscopy, their findings are useful as a guide to the refractive state of the eye. They are not the same as, and an unsatisfactory substitute for, a subjective examination which when available is almost always used as a basis for prescription of spectacles.[3] The primary end-point or desired finding of the subjective examination is that combination of lenses which provides maximum visual acuity without activating accommodation. This criterion is not possible with retinoscopy, automated or manual.

Computer perimeter

Although some attempts have been made in the past to automate the measuring of perimetric fields, a computer-controlled perimeter called Octopus has been devised by Spahr and Fankhauser[4] in Switzerland. It is expected to be commercially available this year. (Figure 2, Interzeag AG, Schlieren, Switzerland.) The need for and cost of this instrument will probably confine it to large health centers (rather than to small group practices) where full utilization would provide an opportunity to make it economically viable. Future development along with the falling cost of computation could make it less expensive and therefore more widely useful.

Guyton astigmatic optometer (refractor)

A new subjective optometer which is to be used as a refractor has been patented by Guyton[5,6] and is expected to be commercially available in about two years (American Optical Co., Inc.). Figure 3 shows the

FIGURE 2—Spahr-Fankhauser computer-controlled perimeter including computer, digital magnetic tape, display terminal and eye position monitor. This figure is taken from reference 5 with the permission of the author and publisher.

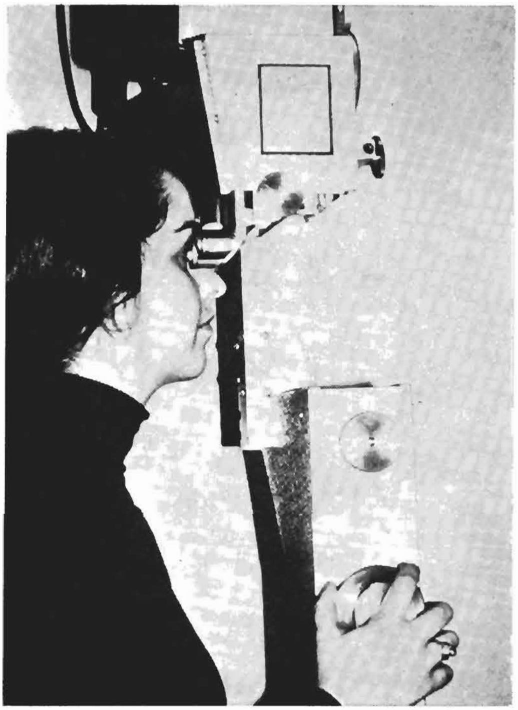

FIGURE 3—The Guyton Astigmatic Optometer which is used as a refractor. The production model of this instrument by the American Optical Co. will be much more compact and will differ in appearance.

FIGURE 4—The Humphrey Refractor is now being made by Humphrey Research Associates, Inc., Berkeley, California. It features Alvarez-Humphrey continuously variable sphero-cylindrical lenses. The production model will appear somewhat differently.

instrument in its original form. The production model will be much more compact and will appear entirely different. Subjective refraction is accomplished in two meridians independently by continuously variable astigmatic lens systems. This device may be partially automated and if it proves to be a practically useful clinical instrument it no doubt will be subsequently fully automated. It is expected to cost around five thousand dollars.

Humphrey refractor

A desk-sized refractor also incorporating continuously variable-power lens systems[7,8] has been devised and production prototypes are now being built (Humphrey Instruments, Inc., Berkeley, California) and are expected to be available this year at $18,500. It features a large concave mirror (Figure 4) through which images, including correction lens vergence, are projected to the eye of the patient. No apparatus or lenses are needed in front of the patient's face. The instrument is particularly adaptable for binocular testing. Visual acuity is tested in the conventional way. The validity of the instrument is still to be determined in relation to conventional clinical subjective refraction methods which are slower and more difficult to perform. Attachments are planned for manual retinoscopy, ophthalmoscopy, and fundus photography. A micro-computer, an integral part of the instrument, provides a readout of the powers and corrects for lens effectivity.

Computer refractor

A computer could perform a subjective eye examination just as an optometrist does if it could control the lenses in a refractor, the slides in a projector and communicate with the patient. We have done this and it works well in the laboratory.[9] Basically conventional tests are used which have been the basis of clinical subjective refraction for a century. Figure 5 shows our latest computer-actuated refractor, Refractor III, which is run by a minicomputer (PDP-8E). It is scheduled to be installed for clinical trials at the Optometry Clinic at Letterman General Hospital in San Francisco later this year.

By automating the case history, visual acuity, objective refraction (by visual evoked potentials) and subjective examination, it is calculated that an optometrist

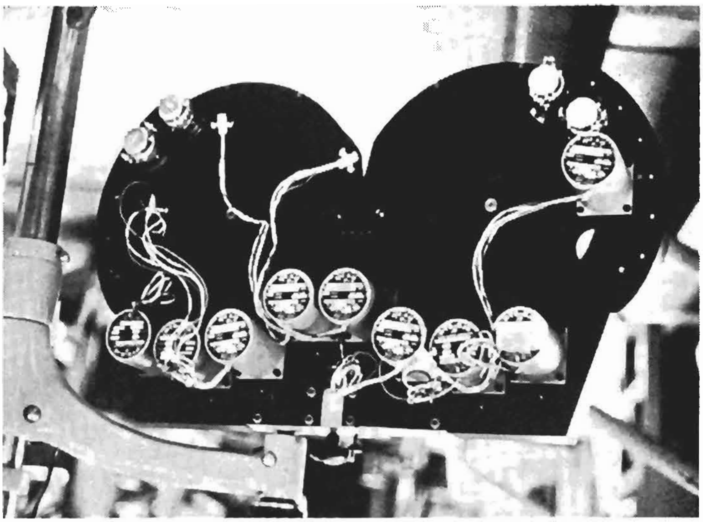

FIGURE 5—Computer-actuated refractor, called Refractor III because it is the third experimental model, being assembled in the machine shop. The large projections are stepping motors which control the positioning of lenses. Smaller projections are shaft encoders which feed the computer data on the position of cylinder and prism axes.

could take care of four to six times as many patients with no decrease in the quality of the service.[10] A computer-assisted optometry clinic designed to be computerized for this goal is shown in Figure 6. Such a system could increase access to eye examinations (particularly if saturation occurs because of developments in third party payment for public health services such as through a national health act) and reduce costs while improving the economic standards of the optometrist.

Visual evoked potential

The visual evoked potential is just emerging from the laboratory. Already it can be useful in the clinic.[11] In ten years it may be almost as indispensable for objective examination (unlike the electroretinogram and electrooculogram) as an ophthalmoscope. These very feeble waves from the brain are amplified and processed in a small averaging computer. With the proper stimuli it can provide objective measures of visual acuity, stereopsis and color vision. It can measure objectively the refractive state of the eye. Currently it may be no more accurate for spherical lenses than retinoscopy, and for astigmatism perhaps less, but the method is capable of being improved. Visual evoked potential can provide a different diagnosis of functional vs. organic amblyopia as well as determining the patency of visual pathways. It promises to provide objective information on higher cognitive visual functions and their anomalies such as dyslexia. Current research in the field indicates that it may provide early diagnosis of certain neurological diseases such as multiple sclerosis. One of the questions that optometry should consider is, does it wish to do screening or diagnostic tests for conditions or diseases of no direct concern to the visual examination as some have advocated, e.g., the measuring of blood pressure? And how far does it wish to go in taking objective tests of functions which may require special skills and technology that are not generally considered important in the de-

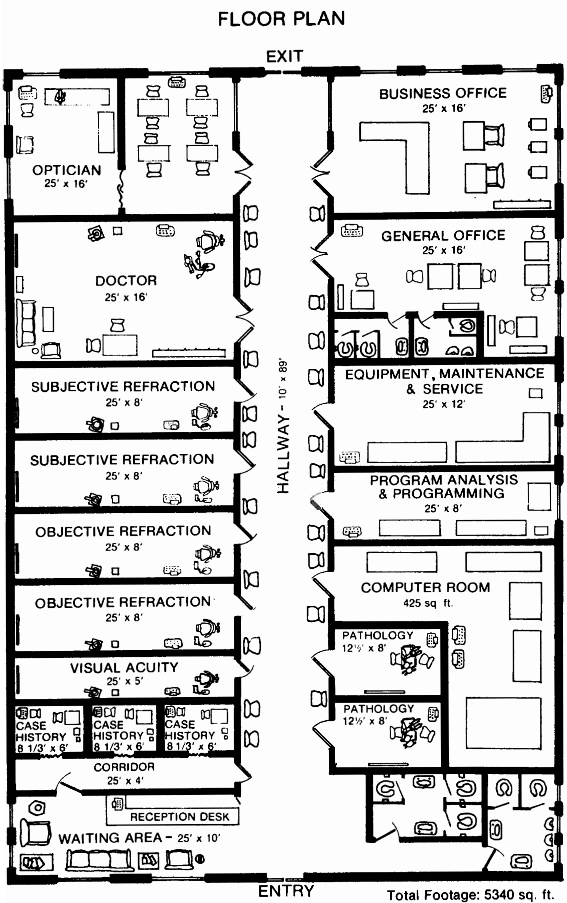

FIGURE 6—Floor plan of a modular computer-assisted eye examination facility. It is designed for a flow of up to six patients per hour with one optometrist, one receptionist, one dispensing optician and several technicians.

termination of the visual prescription, but may be of diagnostic importance systemically?

Prevention of visual neural anomalies (deprivation avoidance in neurovisual development)

Since the classical work of Hubel and Wiesel a decade ago, we have been learning more and more about the development of neural pathways in the visual system after birth.[12] Basically, there is a sensitive susceptible or critical period (in kittens lasting until three months of age) during which the visual environment critically influences the development of visual synapses in the brain.[13] These influences can account for much of amblyopia and associated strabismus. The results of this visual-deprivation research call for eye doctors to go into nurseries to prevent any deprivation of visual stimulation from anisometropia, astigmatism, squint, high ametropia or for any other reason during the sensitive period The duration of the sensitive period in infants is not yet known, but it has been estimated as lasting somewhere between three months (as in kittens) and six years but it is probably much closer to the former. It is not necessary to wait for definitive answers from the laboratory before attempting to prevent amblyopia and squint. On the basis of current knowledge an examination including visual acuity by visual evoked potentials can be justified within the first few months of life. As a result of the findings, the prescription of lenses, prisms, contact lenses or surgery may be strongly indicated to maintain binocular vision with good acuity.

Conclusion

In conclusion, optometry has a scientific and technological challenge which is an opportunity. Such challenges and opportunities have been grasped in the past. Optometry was quick to adapt the refractor, the tonometer and the contact lens. It is now seeking and obtaining the use of topical drugs for better detection of disease. With new concepts and instruments emerging from the scientific laboratory and the instrument shop, it can offer its patients new or better and more extensive vision health care than ever before. **AOA**

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