min point, the difficulty of back-diffusion to the cornea from either the aqueous humor or the iris-ciliary body, and the known resistance to penetration of the cornea by water-soluble organic compounds like pilocarpic acid.

That extensive metabolism should occur in the cornea is not surprising. Anderson et al. demonstrated esterase activity in the cornea of the albino rabbit in the study of conversion of the prodrug dipivalyl epinephrine (DPE) to epinephrine. The metabolism rate constant in that study was 0.17 min⁻¹. What is surprising is that the corneal metabolism of pilocarpine should be so much greater in the pigmented than the albino rabbit. It is possible that either a specific esterase was involved in the corneal conversion of DPE to epinephrine or that a specific esterase for pilocarpine is present in pigmented but not albino rabbits. A third possibility may relate to the permeability characteristics of DPE and epinephrine as contrasted to pilocarpine and pilocarpic acid; that is, esterases may be membrane-bound, and their accessibility is controlled by the mechanism of drug permeation. This issue will be resolved in subsequent studies.

Numerous issues need to be addressed as a result of this finding of extensive corneal metabolism of pilocarpine. Such issues include the site of metabolism in the cornea, corneal permeability mechanism for pilocarpine and its metabolites, binding of pilocarpic acid to pigments, and the total anterior segment disposition of pilocarpine and its metabolites.

One point that is worthy of note is the possibility that the increased dose of pilocarpine1 needed in dark-iride patients is due not exclusively to drug-pigment binding but also to increased metabolism in the deeply pigmented patient.

From the School of Pharmacy, University of Wisconsin, Madison. This study was supported by a grant from Allergan Pharmaceuticals, Irvine, Calif. Submitted for publication May 30, 1979. Reprint requests to Joseph R. Robinson, Ph.D., School of Pharmacy, University of Wisconsin, 425 North Charter St., Madison, Wis. 53706.

Key words: pilocarpine, corneal metabolism, pigmented rabbits, pilocarpic acid, anterior segment metabolism

REFERENCES


A new rapid test of contrast sensitivity function utilizing spatial bandwidth equalization. J. S. DOBSON* AND P. A. DAVISON.

The clinical potential of tests of spatial contrast sensitivity function (CSF) has been limited until recently by the time taken to administer them. A new method for the rapid measurement of CSFs is described, utilizing the principle of spatial bandwidth equalization (SBE). The method involves electronic generation on a cathode ray tube (CRT) of a sinusoidal grating pattern of increasing spatial frequency in the horizontal meridian and decreasing contrast in the vertical meridian. The observer has separate control of 10 vertical segments of pattern containing different spatial frequency bands; he is required to adjust the rate of change of contrast of each band until each grating pattern disappears at the same vertical height on the CRT. The SBE method is far more rapid than conventional methods, taking only about 6 min, and has the advantage over other recently described methods of allowing simultaneous comparison of the apparent contrast of a wide range of spatial frequencies, thus minimizing problems of criterion shift during the test. The SBE method is shown to produce comparable results with those obtained with the conventional method and is thought to have application to a wide range of clinical conditions in which CSF tests have been reported to have advantages over visual acuity tests.

In recent years a growing interest has developed in the application of the contrast sensitivity
function (CSF) to the evaluation of a variety of clinical conditions (including amblyopia, cataract, glaucoma, cerebral lesions, and corneal edema). In addition, the CSF has been used as a measure of visual performance through contact lenses.

In order to obtain a patient's CSF it is necessary to obtain the reciprocal of threshold contrast separately for many spatial frequencies. This "conventional" procedure is difficult for untrained or poorly motivated observers and is too time-consuming for many clinical purposes. However, several systems have recently been described which permit simplified rapid testing of CSF. Thus Sekuler and Tynan have described an automated bracketing system in which the contrast of a sinusoidal grating on a cathode ray tube (CRT) is automatically decreased or increased at 4 dB/sec according to whether the observer depresses controls indicating that the grating is visible or invisible respectively, spatial frequency of the grating is automatically doubled every 52 sec. A simpler system described by Arden and Jacobson uses photographs (one for each of six discrete spatial frequencies) on which contrast of a sinusoidal grating decreases continuously towards the upper edge, the observer's task being to indicate the height (on a vertical scale at the side of the photograph) at which the grating becomes invisible.

A new test is described here for determining CSF/s by means of a spatial bandwidth equalization (SBE) method (subject to United Kingdom patent application 7908598). It has the advantage of enabling simultaneous comparison of subjective contrast of the complete range of spatial frequencies of interest.

The new test. The SBE method uses a test pattern (generated on a CRT) in which spatial frequency increases continuously from left to right while contrast decreases continuously from bottom to top (Figs. 1 and 2). In this respect the pattern resembles an earlier pattern used for demonstration purposes. The unique feature of

*Defined conventionally as $L_{\text{max}} = \frac{L_{\text{max}}}{L_{\text{min}}}$ where $L_{\text{max}}$ is the maximum luminance of the test target and $L_{\text{min}}$ is the minimum luminance.
the present test is that it enables the profile of the CSF (the upper boundary of the area of the screen perceived by the observer as being striped) to be measured in terms of the adjustments of physical contrast which he makes in attempting to convert the appearance of the pattern from that of Fig. 1 (for normal observers) to that of Fig. 2.

The observer adjusts contrast by means of 10 potentiometers, each of which controls a different band of spatial frequencies, until the boundary (between the patterned and apparently homogeneous areas) is a straight horizontal line bisecting the screen. He is instructed to fixate directly on the band of which he is adjusting the contrast. Once he has adjusted the contrast of all 10 bands he is invited to make fine adjustments to the potentiometers; when comparing the apparent contrast of any two adjacent bands he is instructed to alternate direct fixation from one to the others. The observer's contrast adjustments are converted into contrast sensitivity values by means of calibration tables.

The method by which the test pattern is generated on the CRT and adjusted by the observer is shown schematically in Fig. 3. Uniform screen luminance is achieved by applying a 60 Hz sawtooth waveform to the x-input of a large screen CRT and a 150 KHz triangle wave to the y-input.

A truncated triangle wave is generated from the y-input waveform, the base width of which can be varied while the amplitude is kept constant. This is applied to one input of a four-quadrant multiplier, the other being derived from a swept sine-wave oscillator controlled by the time-base sawtooth. The output applied to the z-axis results in the grating shown in Fig. 1, which reduces to zero contrast at a point up the screen proportional to the ratio of truncated triangle base width to its period.

The screen is electronically divided into 10 vertical bands, each band having a separate “observer's control” for altering the triangle base width and hence zero contrast height. Once the contrast at the base of the screen has been measured by telephotometry, the contrast halfway up the screen for each band can be derived from the observer's setting of the appropriate control.

Evaluation. CSF data have been obtained for
Fig. 3. Schematic diagram of electronics circuitry used for production of SBE pattern and for its adjustment by an observer.

eight subjects from both the conventional and SBE methods in order to establish the relationship between functions obtained by the two methods. In all cases space-averaged screen luminance was 3.0 cd m⁻², and the same CRT was used (Hewlett-Packard 1321A x-y display with P31 phosphor, gain-corrected z-axis amplifier and transistor-transistor logic blanking; subsequent design modifications enabled a much higher screen luminance to be used). Viewing distance was 2 m, at which the screen subtended 12.9° horizontally and 9.7° vertically and the surround subtended 33.8° by 27.8°. Surround brightness and colour were approximately matched to the appearance of the CRT screen. Natural pupils were used. Conventional CSF data were obtained with a combined ascending and descending method of adjustment (5 + 5 threshold determinations per spatial frequency). The frequencies selected were the midpoints of each of the 10 spatial frequency bands used in the SBE method. The method of generating grating patterns for conventional CSF thresholds was essentially that of Campbell and Green.10

Fig. 4 illustrates representative data from both methods for an emmetrope and for an uncorrected myope; their visual acuities from a British Standard (BS 4274: 1968) chart were 6/4-1 and 6/9-2, respectively. It is clear that, broadly speaking, the two methods gave similar results, although the SBE method tended to yield lower contrast sensitivity values for both subjects at all but the highest spatial frequency band. However, these differences are probably at least partly due to the slight nonuniformity of CRT screen luminances; under such conditions it is to be expected that observers would make use of the optimum region of the CRT screen during testing with the conventional method, whereas such a strategy is less applicable with the SBE method. In addition, in any given spatial frequency zone in the SBE method, observers are likely to be most strongly influenced by the most visible single frequency within the zone; this frequency will not generally be the mid-point of the zone as plotted in Fig. 4.

Discussion. Selective depression of sensitivity to low spatial frequencies is evident in Fig. 4 for the SBE method. This is to be expected because the number of cycles per frequency band is much more restricted than when the full width of the screen is available for each discrete frequency, as in the conventional method, and because contrast sensitivity is known to be dependent on number of cycles in the case of small fields.11 It is therefore necessary to obtain normative data for any given variant of the SBE method rather than to rely on normative data obtained by the traditional method; fortunately this presents no problem because of the rapidity of the SBE method.

Other possible sources of difference exist between CSF data obtained by the two methods: for example, contrast sensitivity is known to be affected by grating height11 (the height being 50%...
less in the SBE method than in the conventional method used here).

The SBE method described above for determining CSF is capable of rapidly providing repeatable data which can be directly related to those obtainable by the time-consuming conventional method; the new method takes only about 6 min for 10 spatial frequency zones, including instruction time. It has the advantage over previously mentioned rapid methods* of presenting the entire spatial frequency range of interest at the same time, thereby enabling the observer to make direct comparison between the contrast gradation for different spatial frequency zones. Consequently the new method eliminates possible criterion shifts between presentations of gratings of different discrete spatial frequencies. An additional advantage is that observers have little difficulty in understanding or completing the test, in fact the method has been successfully demonstrated with two 6-year-old children.

The method has recently been used for over 40 subjects in a study of the influence of visual factors in driving behavior in fog (in which drivers' speeds on a motorway in fog were found to be rather more strongly correlated with their CSFs than with their visual acuities) and may have ergonomic as well as clinical applications.

We thank Mr. A. Irving of the Transport and Road Research Laboratory (TRRL), who first encouraged the idea that a rapid test of CSF could be devised. Thanks are also due to Drs. F. W. Campbell and J. G. Robson of Cambridge University for their advice and encouragement; the CSF pattern referred to in ref. 9 was devised by Dr. J. G. Robson. Several colleagues at TRRL contributed to the design of the test, including S. Rainsbury and I. Carter.

The work described in this paper forms part of the research program of the Transport and Road Research Laboratory, and the paper is published by permission of the Director.


Key words: contrast sensitivity function, spatial frequency, visual acuity

REFERENCES


Stability of measures of the dark focus of accommodation. DONALD H. MERSHON AND THOMAS L. AMERSON, JR.

Without visual stimulation, the eye tends to assume an individually-determined intermediate state of accommodation (the "dark focus"). The present study examined the stability of these individual dark focus values over time. Two sets of measurements were obtained with a laser-Badal optometer for each of 39 college-age subjects. For 19 subjects the second test occurred during the same experimental session as the first; for 20 subjects the retest was conducted in a separate session 1 week later. Eye dominance was determined by a pointing task. High correlations between test-retest values were found for both immediate and delayed retest. The average change between the tests was less than ±0.3 diopter, even when the retest was a week later. These results indicate a definite stability in individual dark focus values. Eye dominance and subject's sex were both irrelevant.

Accommodation is the process by which the crystalline lens undergoes a change in power to focus images clearly upon the retina. When the eye is provided a well-lighted display exhibiting adequate temporal or spatial changes, the power of the lens approximately complements the distance of the display from the observer. The state of