GLOSSARY

accommodation (positive accommodation): The increase in the refractive power of the eye as a result of ciliary muscle contraction, which moves its focus from a distant to a near object. *Decrease in accommodation (negative accommodation):* The act of reducing the power of the eye to move its focus from a near to a more distant object.

accommodative convergence-to-accommodation ratio (AC/A): Because in binocular vision the visual axes of the 2 eyes must converge to obtain single vision for near objects, the convergence and accommodation systems are linked, a change in one producing changes in the other. The AC/A ratio indicates the amount of accommodative convergence (AC in prism diopters) stimulated by a change in accommodation (A diopters). It is usually measured in terms of the accommodation stimulus (the stimulus AC/A ratio), but it can also be measured in terms of the accommodation response (response AC/A ratio).

accommodative vergence: Vergence (convergence) occurring as a result of accommodation.

adaptive optics: Techniques to improve the performance of optical systems, such as the human eye, by eliminating or reducing aberrations. The technique usually involved in ophthalmic optics instruments uses a mirror, which, through feedback from a wavefront sensor, is deformed to compensate for the aberrations of the eye.

alternating image (vision): A form of presbyopic contact lens correction that mimics the design of spectacle bifocals in that they are manufactured with 2 distinct sectors of different refractive power, 1 for distance and 1 for near, respectively. On downgaze to view near objects, the lens is displaced vertically on the cornea so that light passes through the near section of the lens. Although *alternating vision* is the term commonly used in the literature, according to International Organization for Standardization (ISO) standards, it is now deprecated, being substituted by *alternating image*.

amplitude of accommodation: The range of stimulus vergence over which there is no noticeable image blur, with respect to the spectacle plane, the entrance pupil, or some other reference point of the eye, expressed in diopters.

aniseikonia: A condition where there is a significant difference in the size or shape of the visual images from the 2 eyes as a result of either spectacle correction of anisometropia or inequality of the cortical representation of the 2 images.

Pallikaris IG, Plainis S, Charman WN.
Presbyopia: Origins, Effects, and Treatment (pp. 299-306).

anisometropia: The condition in which the 2 eyes have unequal refractive power; that is, are in different states of myopia, hyperopia, or in the extreme, antimetropia, wherein one eye is myopic and the other is hyperopic.

apodization: In any aberration-free optical system with a circular pupil, having uniform transmission across this pupil, the monochromatic point-spread function (PSF) is an Airy diffraction pattern with a bright central core surrounded by progressively fainter bright rings. However, this PSF can be modified by altering the pupil function (ie, varying the amplitude and phase transmittance across the pupil area). For example, if a central circular obstruction is placed in the pupil, the diameter of the central disc of the PSF diminishes, and resolution improves, albeit with some loss of light. Depth of focus (DOF) can also be enhanced by manipulating the amplitude and phase of the light across the pupil. As yet, this has been exploited very little in presbyopic corrections, although small-aperture corneal inlays are a very crude example.

aspheric surface: Although this term nominally includes any surface that is not spherical, in correcting lenses, it is normally restricted to surfaces that are rotationally symmetric about an optical axis, the surface being perpendicular to the axis at the point where it crosses the axis. These surfaces are often, but not necessarily, conicoidal (ie, they are formed by rotating a conic section [ellipse, parabola, circle, hyperbola]) about the axis. In contact and intraocular lenses (IOLs), a major effect of changing the asphericity is to alter the spherical aberration, a phenomenon that can be used to produce a simultaneous-image (or simultaneous-vision) multifocal lens. An aspheric lens may have one or more aspheric surfaces.

Badal system: This is an optical system for presenting a target, such as a test chart, to the eye at varying dioptric distance (vergence) but at constant angular subtense. Essentially, it consists of a fixed positive lens, which is usually positioned so that its second focal point is at the entrance pupil of the eye, the target being anterior to this lens. Moving the target along the lens axis changes the effective vergence of the target, the effective vergence being linearly related to the axial position of the target.

birefringence: Whereas most commonly used optical materials are isotropic, so that the velocity of light within the medium is independent of the direction and state of polarization (ie, the medium has a unique refractive index), this is not true of optically anisotropic materials. *Uniaxial* birefringent materials, often crystals or polymers that have been stretched, have a single optic axis (ie, a direction in which light of all linear polarizations travels with the same velocity). However, in the direction perpendicular to the optic axis, light that is plane polarized with its electric vector parallel to the optic axis has one velocity (the *ordinary beam*) while that which is polarized perpendicular to the optic axis has a different velocity (the *extraordinary beam*). Thus, the material possesses 2 refractive indices *(double refraction).*

capsulorrhexis: A technique (sometimes called continuous curvilinear capsulorrhexis, or CCC) used to create an aperture with a smooth circular boundary in the lens capsule during cataract surgery prior to IOL insertion. It is generally used on the anterior capsule, but in children it may also be used on the posterior surface to avoid the problems of posterior capsule opacification (PCO).

cataract: A clouding or opacity that develops in the crystalline lens of the eye or in its envelope (capsule), varying in degree from slight to complete opacity and obstructing the passage of light.

closed- and open-loop systems: In control systems with feedback loops (see page 302), a signal related to the difference between the input and the output is normally fed back to be added or subtracted from the input. However, it may be possible to "open" or disconnect the loop, in which case feedback no longer occurs and the output ceases to influence the input. In accommodation studies, the accommodation system can be made open-loop by observing the stimulus through a pinhole. The DOF is then so large that changes in the accommodation of the eye have no effect on the clarity of the image and the final accommodation response is not influenced by the dioptric difference between the stimulus and response.

coma: An optical aberration making the image of a point (the point-spread function [PSF]) appears like a small, blurred comet or exclamation mark (mainly a third-order aberration in Zernike aberration theory).

contrast: Although other definitions of contrast exist, in the context of test charts, it usually refers

to luminance contrast. In the case of a grating test, where the maximum and minimum luminances are L_{max} and L_{min}, the ***contrast***, or ***modulation*** M, is:

$M = [(L_{max} - L_{min})/(L_{max} + L_{min})]$ known as Michelson contrast.

For isolated single letters or other symbols of luminance (L_s) seen against a background of luminance (L_b), the contrast can be expressed as:

$C = (L_s - L_b)/L_b$ known as Weber contrast.

The magnitude of this expression is often used, particularly for letter charts, and both measures of contrast are often expressed as a percentage, by multiplying the above expressions by 100%.

For 0% and 100% contrast, the Weber and Michelson scales agree but in-between they differ. For the range of clinically important threshold values Weber = 2x Michelson. Unfortunately, many charts quote contrast values without specifying the scale used.

Many manufacturers use Michelson contrast for letter charts, where Weber would be more appropriate. Contrast is independent of light level for both retroilluminated and externally illuminated charts.

contrast sensitivity: The reciprocal of the contrast threshold when the latter is expressed in decimal terms and has a maximum value of 1.00.

contrast sensitivity function: A function showing sensitivity to the contrast of a grating test object is plotted as a function of spatial frequency (cycles per degree [cpd]). This is measured by increasing contrast at a particular spatial frequency until the observer's threshold is reached. Measurements are repeated for a range of spatial frequencies. The inverse of the threshold contrast is the sensitivity. The contrast sensitivity function depends upon both optical and neural factors.

contrast threshold: The lowest contrast at which a given test object can be recognized under specified conditions.

convergence: The turning inward of the primary lines of sight toward each other.

convergence accommodation-to-convergence ratio (CA/C): Due to the neural links between the control of convergence and accommodation that help to achieve clear, single vision for near objects, stimulating a change in convergence (C prism diopters) results in a change in accommodation (convergence accommodation, CA diopters). Both response and stimulus CA/C ratios can be measured, depending on whether the convergence response or its stimulus is used as C.

cycloplegia: The pharmacologically induced paralysis of the ciliary muscle of the eye, resulting in a loss of accommodation. It is usually accompanied by dilation of the pupil.

defocus curve: A plot of visual acuity or some other measure of visual performance against the vergence (dioptric distance) of the test chart. The latter is usually altered by placing trial lenses in front of the eye or by using a Badal stimulus system.

depth-of-focus (DOF): The vergence range of focusing errors that does not result in objectionable deterioration in retinal image quality. This objectionable deterioration can be determined according to different subjective and objective measures.

diffractive lens: A lens with surface relief (usually a series of concentric ridges with heights of the order of the wavelength of light), such that the secondary diffracted wavelets interfere constructively at 2 or more focal points. In this way, it is possible to obtain simultaneous-image (vision) bifocal lenses whose properties are essentially independent of pupil diameter, although their diffraction efficiency varies somewhat across the spectrum.

dysphotopsia: The experience of phenomena, such as halos around lights at night or a darkening of parts of the visual field, particularly on the temporal side after IOL implantation (negative photopsia).

emmetropia: The refractive state of the eye where an object at infinity is in sharp focus on the retina with the crystalline lens in a neutral or relaxed state.

emmetropization: The hypothetical mechanism that coordinates the growth of the components of the eye to achieve a refractive state close to emmetropia in a higher proportion of eyes than would occur if the combination of component values was random. It is thought to involve both genetic and environmental factors.

error signal: In the context of accommodation, this relates to the difference between the stimulus and the corresponding response (ie, the lags and

leads of the typical steady-state accommodation response/stimulus curve).

ETDRS format: Used for letter or symbol charts that follow the design of the charts used for the Early Treatment Diabetic Retinopathy Study. They are characterized by a logarithmic progression of letter sizes and have 5 equally spaced letters on each line. When used with the Latin alphabet, Sloan letters (nonserif C, D, H, K, N, O, R, S, V, and Z, based on a 5 X 5 grid) are preferred.

even-error cue: In cases where the response of a system (eg, accommodation) does not equal the stimulus, such a cue indicates the magnitude of the error but not its sign (eg, it indicates that the retinal image is out-of-focus but not whether accommodation must be increased or decreased to bring it into focus).

feedback systems: In many man-made and natural control systems, the initial output (eg, the accommodation response) does not match the input (eg, the accommodation stimulus), so that there is an error (output–input). As the name implies, in a feedback system, part of this error signal is fed back into the input, thereby modifying both the input and output. If it is added, we have a positive feedback system and, if subtracted, a negative feedback system. The accommodation system is thought to approximate to a negative feedback system. The "feedback loop" may have both gain and a phase lag.

gain: This expresses the relationship between the magnitude of the response to that of a stimulus. It is typically applied, for example, to accommodation stimuli, which vary periodically with time, when it is the amplitude of the response divided by that of the stimulus. The term *gain* is also used in the context of feedback systems, where it expresses the fraction of the error signal that is fed back into the input. When the steady-state accommodation response is plotted against the corresponding stimulus, the slope of the linear part of the curve (ie, change in response/change of stimulus) is sometimes referred to as the gain.

image plane metrics: Measures of the quality of the retinal image for either a point source of light (eg, point spread function) or sinusoidal gratings (optical transfer function).

incidence: The number of new cases of a specific disease or condition occurring within a given span of time, divided by the population at risk.

latency: *See* reaction time.

lens epithelial cells (LECs): The single layer of cells immediately below the anterior capsule of the crystalline lens, from which the lens fibers develop.

lens sclerosis: A term often used to describe the hardening of the lens, particularly its nucleus, which occurs with aging. It has, however, been argued that the use of the word "sclerosis" is inappropriate, as the lenticular changes in hardness are not accompanied by changes in the primary protein composition.

logMAR acuity: The MAR (minimum angle of resolution) is the angular subtense in minutes of arc of the limbs of the just recognizable chart symbol. The logMAR acuity is the logarithm to base 10 of this subtense. Thus logMAR = 0 (ie, MAR = 1.0 min arc) corresponds to 20/20 Snellen, 6/6 equivalent, or 1.0 decimal, etc.

Clinicians have long expressed functional visual acuity loss in terms of "lines lost." The logMAR notation codifies this. Each line lost on a logarithmic chart equals 0.1 logMAR. Normal visual acuity (better than 20/20, 6/6, or 1.0) is represented by negative logMAR values (a negative loss).

M-unit: A unit of letter size based on Snellen's reference standard. 1 M-unit subtends 5 min of arc at 1 meter; it is 1.454 mm. The term is most used in the United States to distinguish its metric nature from the originally foot-based 20/20 notation.

modulation transfer function (MTF): When a sinusoidal grating of any spatial frequency, *f*, and modulation M_o is imaged, the contrast or modulation, M_i, in the image is usually reduced. The modulation transfer at that spatial frequency is expressed by the fraction $T(f) = M_i/M_o$. A plot of $T(f)$ as a function of f is the modulation transfer function.

monovision: A means of correcting presbyopia, whereby 1 eye (usually the dominant eye) is corrected for distance vision and the other for near through creation of an acquired anisometropia. It uses the capacity of the brain to process the focused retinal image from one eye while suppressing the other eye's unwanted out-of-focus image, as rather than cooperative fusion into a single, coherent percept, the 2 images compete for perceptual dominance (known as binocular rivalry). Because binocular vision is impaired, stereoacuity is reduced.

odd-error cues: In cases where the response of a system (eg, accommodation) does not equal the stimulus, such a cue indicates both the magnitude and the sign of the error (eg, it indicates that the retinal image is out-of-focus) and whether an increase or a decrease of accommodation is required to bring it into focus. Odd-error cues to accommodation include spherical aberration, astigmatism, and longitudinal chromatic aberration.

optical transfer function (OTF): This is a complex function that combines the modulation and phase transfer functions. Its modulus is the MTF and its argument the PTF.

phase lag (temporal): This describes the time delay between the peaks and troughs of a temporally periodic stimulus and those of the corresponding response. It is often expressed in degrees, where 360 degrees means that the response lags by a full period behind the stimulus.

phase transfer function (PTF): The image of a grating of spatial frequency (f) may not be in the transverse position expected by Gaussian optics (ie, it may be spatially phase-shifted by a phase angle $\varphi[f]$), where a sideways shift of 1 grating cycle represents a phase shift of 360 degrees. A plot of $\varphi(f)$ as a function of f forms the spatial phase transfer function.

photodisruption: Short pulse laser interaction where low energy but high power focusing leads to plasma formation (free electron ionization of tissue) followed by expanding cavitation bubble formation. The plasma leads to microscopic tissue cutting, whereas the cavitation bubble leads to cleavage of the surrounding tissue.

point-spread function (PSF): The light distribution in the image of a point object.

posterior capsular opacification (PCO): After extracapsular cataract surgery and implantation of an IOL, some patients may develop a posterior capsular opacification (sometimes called an *after-cataract*). This is due to the proliferation and growth of residual lens epithelial cells that may migrate to the posterior capsule on the visual axis, causing optical irregularities, scattering, and a loss in retinal image quality and visual acuity.

presbyopia: Characterized by the gradual age-related loss of accommodative ability to the point where it becomes insufficient for the daily needs of near vision.

presbyLASIK: Corneal surgical techniques based on the principles of LASIK to create a multifocal corneal surface aimed to reduce near-vision spectacle dependency in presbyopic patients.

prevalence: The number of people with a disease or condition in a given population at a specific time, often expressed as a percentage of that population.

pseudoaccommodation (apparent accommodation): In true accommodation, there is an active change in the power of the eye as a result of accommodative effort, as the result of either change in the power of the natural crystalline lens or in the effective power of an intraocular lens (pseudophakic accommodation). Pseudoaccommodation refers to the situation, occurring either naturally or after implantation of a monofocal IOL, where patients achieve good distance and near vision without any true change in ocular power (ie, where passive DOF is unusually extended). This may occur as a result of small pupil diameters or ocular aberrations, particularly myopic astigmatism or corneal multifocality.

pseudophakic accommodation: An active change in the total power of the eye occurring as a result of accommodative effort after implantation of an IOL. The change in power may either be due to an axial movement of a monofocal IOL or to an active power change in an IOL consisting of 2 or more components.

Pulfrich effect: If the effective retinal illuminance in one eye is much lower than the other, the spatial trajectory of moving objects may appear distorted. This will occur, for example, when a neutral density filter is placed in front of one eye or if one eye receives a presbyopic correction that reduces the amount of light reaching its retina (eg, a pinhole inlay).

pupil plane metrics: Measures of the quality of the optics referenced to the pupillary plane. These include the root-mean-square wavefront error.

reaction time (latency): This is the time interval between the instant of stimulus change and the initiation of the corresponding response.

response time: When a stimulus is changed abruptly, this is the time interval between the start of the response and the time at which the response stabilizes to the new level.

saturation: When, for example, the accommodation response is plotted against the accommodation

stimulus, a linear relationship is obtained over most of the available ranges of accommodation. As the stimulus approaches the near point, however, the slope begins to diminish progressively, and the curve becomes nonlinear. This is the region of "soft saturation." When the stimulus corresponds to the near point, further increases in stimulus fail to elicit an increase in response (ie, the slope of the response/stimulus curve falls to 0). This is the "hard saturation" region of the plot.

simultaneous image (vision): A means of presbyopia correction (through a contact lens, IOL, or presbyLASIK) in which rays passing through the pupil to form the retinal image encounter both distance and near corrections or a smooth transition in power between distance and near corrections (multifocal). Thus, in general, any region of the retina receives 2 or more images of differing vergence. The brain ideally has to select one stimulus falling on a receptive field while suppressing an out-of-focus stimulus imaged on the same retinal field. In practice, the contrast of the desired in-focus image is reduced by the superimposed out-of-focus images(s). Although *simultaneous vision* is the term commonly used in the literature, according to ISO standards, it is now deprecated, being substituted by *simultaneous image*.

spatial frequency: Any grating-like object contains bars that repeat themselves regularly. The distance perpendicular to the length of the bars between similar points on adjacent bars is the spatial period of the grating. The reciprocal of the period is the spatial frequency of the grating. In visual work, the period is usually measured in degrees; the spatial frequency is then expressed in cycles/degree. A 20 cpd grating, therefore, has bars separated by 1/20 degree = 3 minutes of arc. Occasionally, however, as when talking about the image on the retina in relation to the dimensions of the retinal receptors, the spatial period may be expressed as a distance (eg, mm) when the spatial frequency is cycles/mm. The most common gratings are those in which the luminance or illuminance profile of the bars has a sinusoidal or square-wave form. Using Fourier series, it can be shown that a periodic grating of any form (triangular, square, etc) can be represented as the sum of a fundamental sinusoidal grating and its appropriate harmonics. Using Fourier transforms, it can also be shown that any object can be represented in terms of the sum of an infinite set of sinusoidal gratings of all possible orientations and spatial frequencies, added together with appropriate modulations and phases.

spherical aberration: An optical fault in which the power of an optical system varies as a function of an even power of the radius in the pupil or a combination of such powers. Correspondingly, the wavefront error varies as an even power (fourth or above), or combination of such powers, of the radius in the pupil. In the normal eye, Zernike spherical aberration depends mainly on the fourth power of the radius in the pupil (ie, it is a fourth-order wavefront aberration).

Stiles-Crawford effect: The effect whereby a light pencil entering the outer part of the pupil and striking the retina obliquely produces a weaker visual sensation than it does if entering near the center of the pupil and striking the retina perpendicularly.

Strehl intensity ratio (SIR): The maximum height of the point-spread function for an optical system relative to the height for a diffracted-limited system with the same pupil size. An optical system is considered to be well-corrected if SIR ≥0.8.

synechia: An eye condition in which the iris adheres to either the cornea (anterior synechia) or the lens (posterior synechia).

temporal impulse response function: The theoretical response to a flash of infinitely short duration plotted as a function of time. For a linear system, this function can be used to predict the response to any time-varying stimulus. The Fourier transform of the temporal impulse response function is the temporal contrast sensitivity function (sensitivity plotted as a function of temporal frequency of sinusoidal stimuli).

vergence: (1) The dioptric convergence or divergence of light travelling to or from an object or image, expressed as (refractive index of space)/(distance of object or image in meters). In air, it is simply the reciprocal of the object or image distance in meters. (2) Disjunctive movements of the eyes, particularly as in convergence and divergence.

visual quality metrics: These are modifications of image plane metrics in which account is taken of neural processing and subjective perception. They include the Visual Strehl ratio, which is a

modification of the Strehl intensity ratio and takes account of the neural sensitivity of the eye to a range of spatial frequencies.

wavefront aberration: A perfect optical system producing a real point image can either be thought of as producing rays that all converge to the image point or as a series of spherical converging wavefronts that are all centered at that point. The wavefronts are thus everywhere perpendicular to the rays. In real systems, rays rarely converge to a point, and the wavefronts are not spherical. If we consider the pupil of the system of the eye, we can compare the actual wavefront in the pupil with its ideal spherical counterpart. At each point in the pupil, the distance between the 2 surfaces is the wavefront aberration. This is conventionally taken as being positive if the real wavefront is in advance of the spherical reference wavefront and negative if it lags behind. If the image point is at infinity, the ideal wavefront has infinite radius of curvature (ie, it is flat).

Zernike aberrations: The wavefront aberration across the pupil can be broken down into a set of components, each corresponding to a particular type of wavefront distortion. These were first described by Fritz Zernike (1934) in terms of a set of circular polynomials, which can be expressed using either polar or Cartesian coordinates in the pupil. The magnitude of each component (ie, the coefficient of the polynomial) will vary with the faults of the particular optical system (eg, the individual eye). The second-order polynomials describe ocular wavefront aberrations, which can be corrected by an appropriate spherocylindrical correction. Higher-order aberrations (third-, fourth-, etc) are, therefore, those remaining after spherical and astigmatic errors have been corrected. Usually, the magnitude of the ocular aberrations reduces rapidly as their order increases, the most important usually being third-order coma and fourth-order spherical aberration. The aberration coefficients generally increase with the pupil diameter and are usually expressed in microns.