Quality of vision: beyond the fields of ophthalmology and optics

Vision is a complex process and the perception of a visual stimulus is affected by many factors. As such, quality of vision is a multifactorial concept affected by the entire visual system which includes optical, sensory and neural processing. Thanks to recent advances in research and instrumentation in this field, good vision now goes beyond the classic 20/20 Snellen definition of visual acuity.

The first stage of the visual process is the formation of the retinal image through the optical system of the eye. The quality of the retinal image influences basic visual tasks, such as resolution and contrast detection. The optics of the human eye are truly remarkable. Our visual system possesses clear optical media that transmit light towards the photosensitive cells on the retina; along the optical path to those cells, the amount of light is graded by means of an adjustable diaphragm (the pupil) and the crystalline lens allows the image to be focused on the retina. Although the eye is a relatively simple optical instrument providing exceptional functionality, the optics of vision go beyond these well-known elements: the optical surfaces of the eye are not perfect from an optical point of view and are misaligned, so the visual system is affected by aberrations.

Higher order aberrations of the eye (beyond defocus and astigmatism) only represent approximately 10% of the total aberrations of the normal eye[1]. Nevertheless, the effect of these aberrations is crucial in diminishing retinal image quality. It is interesting to analyze not only the overall magnitude of aberrations of the eye, but also the contribution of single ocular components to those aberrations, and especially the aberration compensation occurring between the cornea and the lens. In this respect, two aberrations in particular show a significant level of compensation: spherical aberration and horizontal coma. In these two cases, the cornea has higher values than the complete eye. Although we cannot yet fully understand all the factors involved in this process, the angular misalignment between the line of sight (the line connecting the center of the entrance pupil and the fixation stimulus) and the pupillary axis (the line perpendicular to the cornea passing through the center of the entrance pupil) has been shown to be linearly dependent on the generation of coma in both the cornea and the lens. This supports the idea that the optics of the eye have an aplanatic design, a configuration where spherical aberration and coma are somewhat compensated. Because the compensation is not perfect, as in any artificial system, the eye is still affected by aberrations.

Currently, it is possible to objectively measure retinal image quality in clinics using wavefront sensing or double-pass measurements. In collaboration with LOUM (Laboratorio de Optica, Universidad de Murcia), we developed the OQAS (Optical Quality Analysis System), a new instrument based on the double-pass technique. This instrument is manufactured by Visiometrics, a spin-off from the Universitat Politècnica de Catalunya (UPC)[2]. This development was a model example of the benefits that collaboration between universities and companies can bring.

Besides aberrations, intraocular scattering may also severely degrade the retinal image quality. In eyes suffering early cataract symptoms, it can produce visual disturbances, even if visual acuity remains normal. We showed (working in collaboration with LOUM) that the double-pass technique can capture the complete optical information of the eye, including the effect of higher-order aberrations and intraocular scattering[3].

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From double-pass images it is possible to calculate an Objective Scatter Index (OSI)[4] as the ratio of the intensity at an eccentric location in the image and the central part of it. This index provides information on the relevant forward scatter affecting vision and has proven to be a valuable tool for grading cataracts. The comparison between the OSI and other parameters for the evaluation of scattering level, such as LOCS III, in general reported good percentages of agreement in eyes with nuclear, cortical and posterior subcapsular cataracts. The OSI was shown to be especially useful in daily clinical practice for detecting early cataracts, suggesting its suitability as a tool for assessing low amounts of intraocular scattering, which may remain hidden or can be difficult to differentiate using other conventional clinical classifications[5].

The optical quality of the retinal image is the result of light passing through the ocular structures. The tear film is the first medium that modifies the optical path of the light that finally reaches the retina. The impact of the tear film on the quality of the retinal image greatly depends on the homogeneity of the tear film and might be especially important in eyes with disorders, such as dry eye. In these eyes, the homogeneity of the tear film and its temporal stability may be greatly compromised by the severity of the disease. Tear film deterioration affects intraocular scatter, so by using dynamic analysis of double-pass images, and more specifically the changes in OSI between blinks, we could develop a new objective method to objectively assess the quality and stability of the tear film[6].

More in-depth understanding of visual optics, and the developments of new instrumentation and surgical procedures will allow patients to be offered a better quality of vision. In the study of the human eye, optical physics and photonics converge with ophthalmology and surgery. The collaborative work of professionals from both fields should definitely produce an exceptional potential for advancement in the near future.

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