Neural Adaptation to Aberrations

The brain must adjust to a surgically altered visual system.

BY PABLO ARTAL, PhD

In healthy individuals, the visual system provides clear images of viewed objects despite optical aberrations that blur the retinal image.[1,2] Every eye is affected by specific aberrations that produce a particular light pattern on the retina of an object point: the point spread function. If the brain adjusts for a given eye's aberrations, the individual's vision should be clearest when looking through his usual aberrations rather than through unfamiliar optics. If this theory is correct, it has important implications for ophthalmology, especially with regard to procedures that modify the eye's optical properties such as refractive and cataract surgeries.

BACKGROUND

Neural adaptation and plasticity play a major role in many important visual tasks, and clinicians have capitalized on these properties for centuries. Many patients' complaints about unwanted visual phenomena disappear without any apparent reason except the passage of time. Common circumstances in which the visual system adjusts include the mechanisms of blur adaptation[3] and the adaptation to color or to distortions in the visual field. Similarly, a popular treatment for presbyopia is progressive addition lenses. Initially, most subjects notice the evident distortions in the retinal image caused by the lenses' optical surfaces.[4] After several days, these problems tend to disappear, and many patients are satisfied with this corrective modality.

RESEARCH

Several years ago, my colleagues and I sought to determine whether the visual system actually adapted to the eye's optical aberrations. We employed adaptive optics in our controlled, collaborative experiment with David Williams, PhD, at the University of Rochester in New York.[5] In addition to high-resolution retinal imaging, adaptive optics for vision can produce controlled patterns of aberration in the eye of a subject.

In our experiment, we conducted subjective blur matching with normal and rotated aberrations. The adaptive optics system consisted of a real-time wavefront sensor to measure the eye's aberrations and a deformable mirror to modify the aberrations. A visual channel presented a stimulus to the subject. With this instrument, we were able to rotate the aberrations (and the point spread functions) of the subject by maintaining their magnitude (Figure 1). We asked subjects to view a binary noise stimulus through the system, either with their natural aberrations or with a rotated version of their aberrations. They viewed the stimulus alternately for 500 milliseconds with both the normal and the rotated point spread function. The subjects' task was to

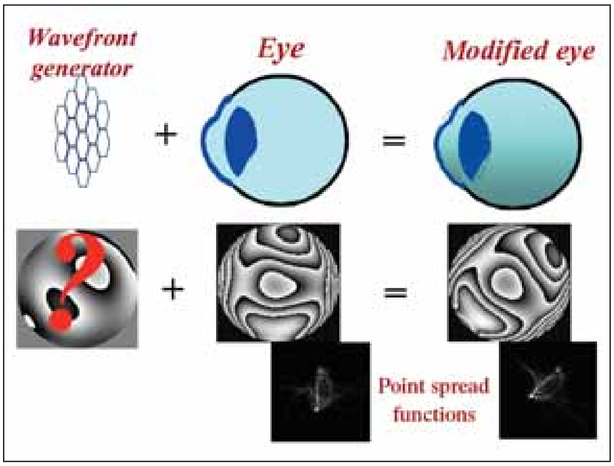

Figure 1. Aberrations and the point spread function are rotated using adaptive optics.

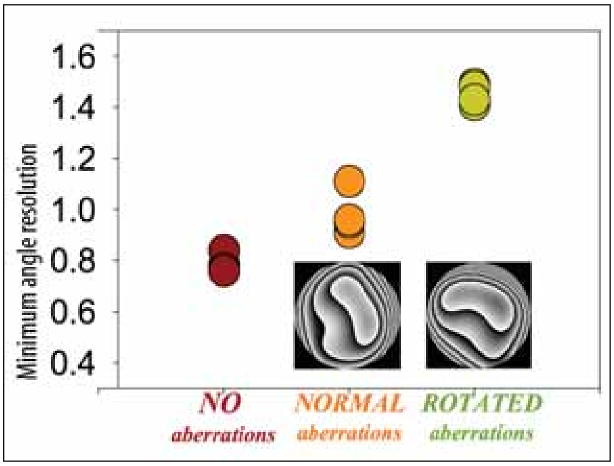

Figure 2. The visual acuity (expressed in minutes of arc) of the author's right eye is measured for corrected (brown), normal (orange), and rotated aberrations (green).

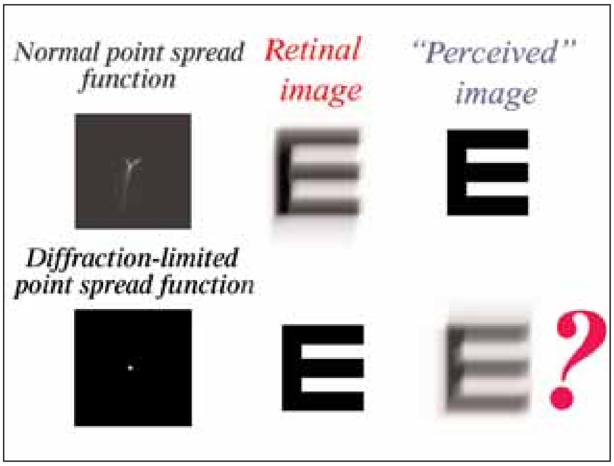

Figure 3. This cartoonish schematic diagram shows the possible effect of neural adaptation on the retinal images before and after their ideal correction.

adjust the magnitude of the aberrations to match the subjective blur of the stimulus to that seen when the wave aberration was in its normal orientation.

In all subjects, the wavefront error of the rotated wave aberration required to match the blur with the normal wave aberration was less than in the normally oriented aberration case. This finding indicates that the subjective blur for the stimulus increased significantly when the point spread function was rotated.

We also measured visual acuity for different aberration profiles. Figure 2 shows, as an example, one subject's visual acuity expressed as a minimum angle of resolution in minutes of arc without any aberration, with the normal aberrations, and with the rotated aberrations. The subject's performance was lowest with the rotated version of the aberrations.

CONCLUSION

It is important to note the role of time in neural adaptation. Moreover, although it is obvious that the visual system cannot deal with a very large amount of aberrations, it is also relevant to understand the amount of aberrations that is required to induce the adaptation.

In the area of wavefront-guided, customized refractive surgery, neural adaptation to aberrations will reduce the immediate benefit to the patient of attempts to surgically produce diffraction-limited eyes. The reason is that the brain has adapted to a particular pattern of aberrations. After surgery, the neural compensation will still be acting for the previous pattern. Figure 3 simulates the possible effect. If the brain restores the degraded image, it will also initially degrade a perfect retinal image. Again, the importance of this action in practical terms depends on the time required to reverse the previous adaptation and to allow the visual system to adapt to the newly induced aberrations.

With IOLs, ophthalmologists are currently deeply interested in mixing and matching lenses in patients' eyes to increase their overall depth of focus. The role of neural adaptation in this approach is probably very important but related to binocular vision. The scenario is complex, involving both monocular aberrations and binocular interactions. More experiments are required, for example, to provide a better understanding of binocular performance as a function of individual or binocular aberrations. The use of adaptive optics extended to binocular applications can answer many questions. This exciting area of research should ultimately help clinicians provide patients with a superior quality of vision. ■

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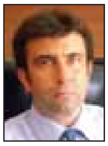

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