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Age-Related Changes, Optical Factors, and Neural Processes

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Seeing begins with information contained in the light reflected from objects in the environment (Sekuler & Blake, 1994). The visual system's subsequent capture, transduction, and analysis of this light-borne information depend on a variety of optical factors and neural processes, all of which are subject to change with age.

Changes in the Eye

The eye makes two different but equally important contributions to vision: optical and neural. In the first contribution, various surfaces and structures admit light into the eye and focus it on the retina's specialized photosensitive elements (rods and cones). In the second contribution. a complex, organized network of neurons processes signals generated by photoreceptor transduction of light, extracting biologically significant information that is transmitted via the optic nerve to the brain.

Over the course of the human life span, no component of the eye is immune to change. During the latter portion of the life span, the most common and consequential optical changes are senile miosis, presbyopia, and cataract. The amount of light entering the eye depends on the area of the pupillary opening, which tends to shrink with age (senile miosis). Although there is considerable variation among individuals, as a rule the average 75- or 80-year-old dark adapted eye admits only one half as much light as its teenage counterpart. Under light-adapted conditions, the age-dependent gap is somewhat smaller and less significant as a limiting factor in visual function.

Presbyopia refers to a loss of the eye's ability to focus ("accommodate") at different distances. An individual is said to be presbyopic when accommodation no longer provides clear vision at the, customary reading distance. On average, this state is achieved at about age 45 years, when the accommodative reserve has been depleted to 3 diopters from10 or more in childhood. Presbyopia's impact varies with the light level, the effort, and the demands of the visual task. The most likely causes include diminished elasticity of several related tissues, including the lens, lens capsule, and extralenticular fibers (Gilmartin. 1995).

The crystalline lens of a normal young eye is exceedingly transparent, which is highly beneficial for vision, Over time this transparency decreases, particularly for short-wavelength light. For example, at 420 nanometers ("blue".) an 80-year-old lens absorbs about 10 times more incident light than a 20-year-old lens does. Light absorbed is light not transmitted and. is therefore unavailable for vision. Age also brings increased lenticular scattering or opacification, which constitutes a cataract. The visual impact of any cataract depends on the position of the opacity in the lens; harm is greatest whet the transparency of the lens's posterior surface is compromised.

Retinal Changes

Receptor topography in retinas from healthy donor eyes suggests that the spatial density of perifoveal rod photoreceptors decreases by 30% from the second to the ninth decade. In the same eyes, the population of cone photoreceptors is essentially unchanged with age. Because visual acuity depends on the cones, stability of the cone population suggests that some postreceptoral processes must play a role in visual acuity's well documented decline with age. One candidate is the decreasing number of cells in the retina's ganglion cell layer.

Perceptual Consequences

Age-related changes in ocular structures tell only part of' the story of aging and visual function. Connections between vision and aging have real and important consequences both for individuals and for society. Along with other senses, vision makes a central contribution to a wide variety of cognitive abilities, including reasoning and memory. Surveys reveal that older observers have particular difficulties with visual tasks involving rapid processing, high light sensitivity, dynamic vision, near vision, and visual search, Many of these difficulties go undetected on standard clinical examinations.

Pattern Vision

Starting at about 50 years of age, visual acuity diminishes year by year. (Acuity is indexed by the ability to resolve fine detail.) At low spatial frequencies, contrast sensitivity does not vary with age. However, at intermediate and high spatial frequencies (e.g., greater than 4 cycles per degree of visual angle), contrast sensitivity declines steadily with age, beginning as early as 30 years.

Optical factors (e.g., intraocular light scatter, reduced retinal illumination) contribute to the age-related decline in contrast sensitivity. Changes in photoreceptor properties play a role as well; although the number of cone photoreceptors remains fairly constant throughout life, degradation in the regularity and spacing of the receptor mosaic and morphological changes reduce the area of each receptor's effective aperture. Other factors include neural changes (decreased efficiency and reduced selectivity in low-level visual mechanisms). Age-related limitations on attention are also important.

Linking Low- and High-LeveI Vision

To enable us to perceive objects, the visual system must encode information not only about the size and contrast of visual elements, but also about the elements' positions relative to one another. This positional information is referred to as "spatial phase." The ability to encode spatial phase information decreases with age (Sekuler, Bennett, & Placenza, 1995). Because spatial phase contributes to the perception of shape or form, older observers' deficits in processing spatial phase information probably impair both perception and recognition of objects. Unfortunately, no research has addressed this important issue. In fact, aside from older observers' self-reports, almost nothing is known about how object perception changes with age,

Despite this obvious gap in knowledge, there has been some success in linking performance on lower and higher level tasks. For example, visual acuity accounts for a large proportion of age-related variance on many measures of cognitive functioning, including working memory, associative learning, and concept identification (Salthouse, 1996). Of course, this association does not guarantee that declining visual acuity causes declining cognitive functioning; some third common factor could mediate the association.

To examine the link between low- and high-level functions, Spinks, Gilmore, and Thomas (1996) constructed a digital filter that simulated the vision experienced by the average healthy 80-year-old person.

Then young participants looked through this filter while they performed several tests of intelligence and cognitive function. The filter's degradation of vision, including reduced contrast sensitivity, caused substantial drops in young participants' performance. Remarkably, young participants with artificially degraded vision performed as though they were 50 to 55 years old.

In addition, contrast sensitivity is a good predictor of visual complaints, particularly complaints of difficulty seeing at night, and is a major limiting factor in reading (Legge, Kiltz, & Tjan, 1997). Contrast sensitivity also shows promise as a predictor of age-associated diminished perception of faces, road signs, and objects.

Binocular Vision

Neural interactions between signals originating in the two eyes can significantly enhance visual function. Such an enhancement constitutes an emergent property, which originates in the visual cortex of the brain, where inputs from the two eyes are combined. The best-known product of binocular integration is stereopsis, an important source of depth information. Stereopsis arises from the fact that objects at different depths are imaged on different parts of the two eyes (binocular disparity). With age, individuals require ever-larger disparities in order to perceive depth from this particular cue (Bell, Wolf, & Bernholtz, 1974).

In addition to making stereopsis possible, the combination of signals from the two eyes produces binocular summation, which improves performance on a wide range of visual tasks. Binocular summation is measured by the ratio of binocular sensitivity to sensitivity measured with the better single eve. Although binocular summation ratios tend to decline with age, especially with targets of higher spatial frequency, not all binocular tasks show equivalent age-related changes. For example, appreciable age-related elevation of binocular depth thresholds can coexist with other measures of binocular function that show no change with age (Speranza, Moraglia, & Schneider, 1995). These differences between the impacts of age on various tasks probably reflect differences in the underlying neural computational requirements of the tasks.

Perception of Dynamic Displays

Arguably, the most prominent functional decline with age is in the visual system's ability to detect temporal change. Age-related reduction in temporal resolution shows up in the altered temporal extent of visual masking, increased duration of visual afterimages, and reduced critical flicker fusion (the fastest rate at which an observer is able to perceive flicker). Little is known about age-related changes in the principal responses to a moving object: judgments of speed or direction. On the basis of limited data, it appears that speed discrimination is unimpaired by age, but that discrimination of direction is impaired. One of the most common stimuli used in studying motion perception is the random dot cinematogram, in which neither form nor motion is apparent in a single frame but emerges across frames. With stimuli that contain a wide range of different, spatially intermingled direction vectors, observers must integrate direction information across space and time to perceive global flow in the cinematogram's mean direction. When they were asked to judge the direction or flow in such cinematograms, older observers made much larger errors than younger observers; the age difference was exacerbated by short stimulus duration (Dengis, Sekuler, Bennett, & Sekuler, 1998). In addition, confirming earlier results, cinematograms' motion signals were less detectable by older observers. This age effect was especially pronounced in the oldest observers.

Color Vision

Advancing age brings diminished ability to discriminate subtle differences of hue in the blue-green range, a deficit that is particularly noticeable under conditions of reduced illumination. Changed color vision probably reflects changes in the density of the ocular media and changes in sensitivity to all three types of cone photoreceptors. Despite the cone pathways' diminished-sensitivity, the relative responses of the three different types of cone photoreceptors remain constant. Because perception of color depends on the relative responses within different types of cones, color vision remains stable across t6e life span, particularly when stimuli are well above threshold levels. For example, older and younger observers have similar color naming functions, loci of achromatic points, and loci of unique hues for yellow and blue, Thus, the visual system somehow continuously recalibrates the strength of color signals, maintaining color constancy throughout the lifespan (Werner & Schefrin, 1993).

Visual Attention: Useful Field of View

Many older people report difficulty in finding objects in visually cluttered scenes. These anecdotal reports are confirmed by empirical studies measuring the useful field of view, a laboratory analog to a cluttered environment (Ball & Sekuler, 1986). The useful field of view is that region of the visual field to which an observer can attend at any one time. There is virtually no relation between the size of an observer's useful field of view and the size of the observer's visual fields measured by clinical perimetry. However, the size of the useful field of view seems to be a particularly important measure because it correlates strongly with drivers' accident rates. The cause of the age-related decline In the useful field of view seems to be older observers' decreasing ability to process task-relevant information.

Visual Memory

Vision in complex environments requires observers not only to detect and discriminate stimuli presented simultaneously, but also to integrate information appropriately over space and time. One index of this ability is short-term memory for visual attributes, such as spatial frequency, that resist semantic encoding. Although older observers typically perform poorly on tasks that involve verbal memory, this age-related loss seems to spare memory for visual attributes. Nevertheless, brain-imaging (positron emission tomography) studies reveal that different neural systems are responsible for spatial frequency memory in younger and older observers (McIntosh et al., 1997). Those differences may reflect compensatory neural reorganization within the aging brain.

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