THE AGING EYE AND CONTACT LENSES - A REVIEW OF VISUAL PERFORMANCE

Russell L. Woods*

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Abstract - Most contact lens practitioners are dealing with an increasing number of otherwise healthy older (presbyopic) patients. Examination of the literature indicates a persistent theme of age-related change which generally becomes significant after the fourth decade. This review, the second of two parts, documents reported age-related changes in visual acuity, contrast sensitivity, stereovision, hyperacuity, colour vision, and visual fields. The effects of these various changes on the fitting and wear of contact lenses by older patients are discussed.

KEY WORDS: Age, aging, review, visual performance, colour vision, visual acuity, contrast sensitivity, hyperacuity, stereopsis, visual fields.

Introduction

As discussed in Part 1, contact lens fitting is likely to alter slowly, since population demographics in all the western nations indicate a trend towards an aging population. Ocular changes acknowledged to occur with age that may influence contact lens wear include decreased pupil diameter \(^{4,5}\), decreased corneal sensitivity \(^{13,14}\), decreased corneal fragility \(^{15}\), changes to the palpebral aperture \(^{4,5,8}\), decreased lacrimal secretion \(^{9,10}\), reduced tear stability \(^{11,12}\), reduced corneal sensitivity \(^{13,14}\), increased corneal fragility \(^{15}\), changes to the ocular media \(^{16-18}\), and the effects of the increased intake of systemic drugs \(^{19,20}\). These aspects have been discussed in the first part of this review. \(^1\) In this, the second part, age-related changes in visual acuity \(^{21}\) (and the effects of luminance level \(^{22}\)), contrast sensitivity \(^{23-25}\), stereovision \(^{26,27}\), glare sensitivity \(^{28,29}\), colour vision \(^{30-33}\), and visual field \(^{34}\) are discussed. All of these factors are of importance when fitting the aging eye. With increased age, physiological considerations alter and visual performance is generally reduced. Particular care must then be taken with contact lens modalities which compromise aspects of visual performance, for example bifocal and monovision contact lenses.

Interest in bifocal contact lenses is increasing in industry, the optical professions, and amongst the public as they become aware of the option through the general and optical media. Contact lens companies are developing and publicising hydrophilic versions of the rigid bifocal contact lenses used by a limited number of experienced practitioners for many years and, recently, diffractive bifocal contact lenses have become available. \(^{35,36}\) Most contact lens practitioners are wary of fitting bifocal contact lenses because of a general perception of poor success rates and prolonged chair time. Some of these difficulties may be due to a lack of understanding of the differences between younger and older patients, which this article attempts to address.

Further development of bifocal contact lenses, the marketing capabilities of the large companies, and an increased acceptance of contact lenses as a potential modality may lead to an increase in the number of presbyopes fitted with contact lenses. Despite this enormous potential market, recent contact lens surveys \(^{37-39}\) indicate that only 1% of contact lens patients are fitted with bifocal lenses (consider this against the ‘bread-and-butter’ presbyopic spectacle provision in an average practice). Slightly more patients are fitted with the alternative presbyopic contact lens option (monovision), the most successful system \(^{37}\), but considered by many practitioners to be unsatisfactory because of its deleterious effects upon binocular vision. \(^{40-43}\)

The proportions of contact lens patients who are presbyopic and of presbyopes who wear contact lenses are uncertain, but generally assumed to be small. Despite this, as mentioned above, practitioners are likely to encounter an increasing number of presbyopic contact lens patients. With this in mind, some of the special visual problems which may influence contact lens fitting and wear are reviewed herein.

Visual Acuity

Visual acuity (VA) at birth is approximately 6/250, improving to 6/6 within the first year and reaching a peak in the third decade, after which there is a gradual decline. \(^{21,44}\) There is some variability in the published data, much of which can be explained through differences in experimental techniques and subject selection criteria. Figure 1 contains results from a number of published studies reviewed by Pitts. \(^{21}\) The reduction in high contrast VA is found to be most pronounced after the fifth decade.

* BOptom (Hons) MBCO.
Whilst there has been much interest in contrast with age, after the third decade, for all contrast levels measured note that, for all age groups tested, with luminances those patients less likely to succeed with the lenses. When fitting contact lenses which reduce VA (e.g., bifocals) a test under low luminance may determine fringes. 46

Increased target luminance greatly improves the VA of older subjects, but not to that of younger subjects. 21,47 Hence the need for improved lighting for fine or detailed tasks. The age-related loss in VA has been partially simulated with the use of filters, but not completely. 48 It has been suggested that the sensitivity of VA tests can be improved when performed under low luminance conditions. 49,50 The VA of older subjects will reduce significantly more than the VA of younger subjects when luminance is reduced, but a preliminary study 51 did not find any increased significance when determining the effect of changes in pupil size of concentric bifocal lenses. When fitting contact lenses which reduce VA (e.g., bifocals) a test under low luminance may determine those patients less likely to succeed with the lenses. 46

**Pupil size**

Theoretical evaluation of the human ocular modulation transfer function (MTF) 69 indicates that the optimal pupil diameter is between 2–3mm, and that higher spatial frequency targets are only severely attenuated for pupil size below 2mm. For pupil sizes above 2mm, VA increases with increasing luminance 69 from 0.03 to 1000cd/m² and the optimal pupil diameter reduces 69 from approximately 4mm at 10cd/m² to 2.5mm at 1000 cd/m². Campbell and Gregory 60 concluded that ‘the human pupil light reflex subserves the useful role of adjusting the aperture of the eye so as to optimise visual acuity over a wide range of luminance.’ Woodhouse 62 repeated this work with targets of high (97%) to low (11%) contrast and confirmed that ‘this rule applies over a wide range of contrast levels.’ Neither report considered the known changes in pupil size 4–4 and VA with age. Woodhouse and Campbell 61 argue that pupil size variation serves principally to aid dark adaptation by reducing retinal illumination prior to reductions in external illumination, pupil size being adjusted to maintain the level of retinal illumination within a preferred range. Some tinted contact lenses will artificially reduce light sensitivity and worsen dark adaptation 62, which is already reduced with increasing age. 44

An average (light adapted) pupil of approximately 3mm is found at about 70 years of age, and one of
Pupil size influences visual performance with most bifocal lenses. The choice of optimal size for a concentric design bifocal contact lens is pupil size dependent and is complicated by on-eye decentration. Calculations which incorporate the Stiles-Crawford effect, optical performance measures, and high and low contrast VA indicate that the optimal (equal distance and near) pupil coverage by the segment is about 40%. Visual performance and optimal segment size will vary with the natural luminance-related changes in pupil size. Aspheric or multifocal lenses (e.g., PS45, CALS, PA1) are also pupil size dependent, such that the effective addition will be governed by the patient’s pupil size. The relatively small (3.5mm) diameter of the diffractive zone of Echelon soft bifocal contact lenses could reduce near VA for some patients with larger pupils and under low luminance conditions.

Visual performance with alternating-vision bifocal contact lenses, when fitted well, can be excellent, but is influenced by aspects of the fitting parameters and will also vary with pupil size. With increased pupil size a larger section of the near segment will intrude upon the pupil zone during distance viewing. Also, for near viewing with a larger pupil, more lens movement will be necessary to obtain full coverage of the pupil by the near segment. Hodd and Charman and Walsh have demonstrated diagrammatically the image form of certain alternating-vision and simultaneous-vision bifocals.

Summary
With increasing age VA reduces. This reduction is greater for low contrast targets and under low luminance conditions. Neural effects have been suggested to explain these changes, which cannot be fully explained by a reduction in retinal illuminance.

Contrast Sensitivity
Spatial Contrast Sensitivity
A common complaint amongst the elderly is that, though the VA is good, they experience difficulties of reduced illumination and contrast in real life situations. An explanation can be found in the age-related changes in contrast sensitivity (the ability to see faint stripes of varying width). Contrast sensitivity (CS) declines with age for intermediate and high spatial frequencies (i.e., above 3–5cpd) but is retained or only slightly reduced for low spatial frequencies (e.g., Figure 3a). This is found over a wide range of test luminances, from 2cd/m² (McGrath and Morrison) to 300cd/m² (Ross et al). Peak CS shifts to a lower spatial frequency with increasing age, as shown in Figure 3a. Supra-threshold CS may not

Figure 2. A compilation of light-adapted pupil diameters, as measured in eight unrelated studies. No attempt has been made to compensate for the illuminance of the eye, which varied from study to study. Luminance levels quoted varied from 6-103cd/m².

Figure 3. The contrast sensitivity of 16 old (72 ± 4.3 years) and 16 young (21.5 ± 2.7 years) subjects measured with (a) a monitor-based computer system and (b) a modified Rodenstock retinometer. The latter technique theoretically bypasses the effects of the optical media and assesses the function of the retinal and neural systems. The former assesses the complete visual system with a conventional technique. The older group displays significantly lower contrast sensitivity, with both tests implying that most of the loss is retinal and neural, with optical factors having only a slight effect at the highest spatial frequency (18.5cpd) (redrawn from Elliott).
show an age-related reduction\cite{25,28}, though this requires further examination. This does imply that threshold and supra-threshold perception may be processed differently.\cite{28}

Interferometric techniques, which theoretically are not affected by the optical quality of the eye, demonstrate age-related reductions in sensitivity.\cite{25,79} Subjects were poorly selected in the Morrison and McGrath study\cite{79}, as some in the older group had evidence of ocular abnormalities. Elliott\cite{25}, who made a more careful subject selection, found an age-related difference as shown in Figure 3b. Elliott concluded that optical factors only have an influence on CS at higher spatial frequencies (>11 cpd) and that the demonstrated reduction must primarily be of retinal or neural origin. This conclusion is not absolute as there is some doubt that interferometric techniques are entirely free of the effects of the ocular media.

**Luminance**

With reducing retinal illuminance, CS reduces and the peak sensitivity shifts to a lower spatial frequency.\cite{84} This simulates the age-related reduction in the ability to detect contrast, which has been demonstrated across a large range of luminances. Blackwell and Blackwell\cite{87} demonstrated a reduction with age in the minimal discernible contrast of a small (4') luminous disc on a background with a variable luminance of 0.003–1710 cd/m². The age-related reduction in contrast detection was greater at lower levels of luminance (Figure 4). Similar reductions were found for Landolt C acuity, which could be predicted by the Blackwell and Blackwell contrast multiplier.\cite{50} Sloan et al.\cite{85}, measuring at three luminance levels, noted that CS decreased with reduced luminance, and the difference (younger—older group) was most pronounced at the lowest luminance level (0.1 cd/m²).

This cannot be explained entirely by the age-related reduction in retinal illuminance.\cite{25}

**Pupil Size**

At higher luminance levels a reduction in pupil size has the effect of improving CS, and shifting the peak sensitivity to a slightly higher spatial frequency.\cite{86} The reverse occurs with increasing age, as sensitivity decreases despite reduced pupil size. Smaller pupils are optimal at the luminance levels used in many studies and hence senile miosis is not sufficient to counter other changes in the visual system. At lower luminance levels, Kay and Morrison\cite{87} found only a minimal effect of pupil diameter upon CS. Optical defocus resulted in a large reduction in CS for spatial frequencies higher than the peak sensitivity, and a smaller reduction for spatial frequencies below the peak. The reduction with defocus resembles the results with low contrast VA charts\cite{88} and the age-related reduction in sensitivity. Similarly, Sloane et al.\cite{85} noted that the smaller senile pupil actually improved CS despite the reduction in retinal illuminance.

variations in CS with pupil size will be similar to those previously noted for VA. Woods et al.\cite{51} found that the optimal segment cover of a concentric bifocal lens varied with the spatial frequency of the task, with optimal coverage for lower spatial frequency tasks being >50% and <50% for higher spatial frequency tasks. The significance of this result requires further investigation.

**Peak Sensitivity and Edge Detection**

Cunningham et al.\cite{96} demonstrated a positive correlation between edge detection (typically a target composed of two halves of different luminances with a sharp straight border) and pedestrian mobility of low vision subjects. Edge detection correlates with peak spatial frequency sensitivity\cite{60,91}, which shifts toward lower spatial frequencies with age.\cite{25,80,81} This correlation would be expected if the visual system processes an image in parallel channels, effectively performing a Fourier analysis of the image\cite{92,85}, and would agree with the theoretical proposal of Marr and Hildreth\cite{84}, which emphasises the importance of intensity changes at borders.

Edge detection (using the Melbourne Edge Test (MET)) has been demonstrated by Verbakken and Johnson\cite{16} to remain relatively constant until the fifth decade, after which there is a gradual decline in sensitivity. Conversely, Grey and Yap\cite{96} could not demonstrate an age-related change. A change would be expected to be consistent with alterations in peak spatial frequency CS with age. An age-related decrease in detection of the large (approximately 1 cpd at 1m) letters of the Pelli–Robson contrast threshold chart has been demonstrated.\cite{97,98} This reduction was greater at a reduced luminance level.\cite{98}

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**Figure 4.** The relationship between contrast detection, age, and luminance level as determined for 156 subjects. The contrast multiplier is the increase in contrast required for each age group to equal the performance of the youngest age group. Hence, with decreasing luminance the level of contrast required for equal performance increases with increasing age (redrawn from Blackwell and Blackwell\cite{14}).
Temporal Contrast Sensitivity

Foveal flicker sensitivity decreases after the fourth decade and this decrease is greatest for higher temporal frequencies (10–45Hz). Differences in retinal illuminance do not or only partly explain the loss in sensitivity with increasing age. Temporal sensitivity also varies with spatial frequency, with an age-related loss noted for median but not for very low spatial frequency gratings. Peak temporal sensitivity shifts to a lower temporal frequency with increasing age.$^81,103$ A reduction in motion enhancement (sensitivity improvement to a moving low spatial frequency grating) for older subjects$^{68}$ may be partly explained by the reduction in sensitivity to peripheral objects with reduced pupil size.$^{104}$

Summary

There is a reduction in peak and higher spatial frequency sensitivity and a reduction in higher temporal frequency sensitivity with age. As with VA, the age-related reduction in CS, which remains at higher levels of illumination, cannot be accounted for by senile miosis, changes to the ocular media transparency, and reduced retinal illuminance.$^{104,125}$ There may be a neural basis to much of the loss of CS with age.

Contact lens wear is reported both to reduce and enhance VA and CS. The variability of these findings may be due to manufacturing effects, as the more recent studies show that CS with a contact lens is little different from that without a contact lens. Tinted contact lenses may slightly reduce CS.$^{115,116}$

Bifocal contact lenses of various designs result in a decrease in CS and VA$^{61,64,67,69,117–121}$, due to the inherent optical compromise of all existing bifocal designs. Typical CS functions for a single subject with a concentric design and with a diffractive bifocal contact lens are shown in Figures 5a and 5b, respectively, and compared to a single vision lens (unpublished data). The age-related decrease in CS is an additional factor often neglected when fitting contact lenses with less than optimal optical performance. The contact lens designer, manufacturer, and fitter may need to exercise care when offering contact lenses to older patients, due to the possible summation of the contact lens induced effects upon age-affected visual performance. It has been suggested by Freeman and Stone$^{108}$ that 'patients in the lower quartile of "normal" contrast sensitivity may be contraindicated for all simultaneous vision lenses.' A clinical measure of CS is recommended prior to fitting, as those older patients with reduced CS are likely to be unduly affected by the poor optical performance of simultaneous-vision bifocal contact lenses.

Stereopsis

The human stereoscopic threshold is generally between 2–5 seconds of arc.$^{122}$ This varies with exposure duration, implying that the neural processes require about 100msec to operate optimally.$^4$ There are no conclusive studies of the relationship between stereoacuity and age. Stereoscopic acuity appears to develop during the first decade, though there are difficulties in applying steroacuity tests (or any test) to young children.$^{123}$

Emmes$^{124}$ found a reduced mean near stereoacuity (Wirt polaroid vectogram) for presbyopic (over 40 years old) compared to pre-presbyopic subjects. The most comprehensive examination is that of Jani$^{125}$, who examined the percentage of failures of (screened) volunteers at an optometric screening with the Diastereo test. Jani reported a slight decrease in the number of failures after the first decade, a relatively constant number (about 5%) up to the fifth decade, after which there was a marked increase in the number of failures. This is shown in Figure 6. Bell et al.$^{126}$, using the Verhoeff stereopter, found a decrease in stereoacuity after 40 years of age in healthy subjects. Conversely, for subjects aged 8–46 years, Hofstetter and Bertsch$^{127}$, using the Diastereo test, failed to demonstrate a relationship with age. This is probably due to the restricted age range and the strict selection criteria.

Hoffman et al.$^{127}$ found a reduced distance stereoacuity, with a Howard–Dohlmann apparatus, for older subjects (mean age 64 years) compared to younger
subjects (mean age 33 years). In a study of distance (Howard-Dohlmann) and near stereoview (Titmus and Randot polaroid vectograms), Woods demonstrated a significant correlation between age and distance stereoview, but not near stereoview, for subjects over 40 years old (Figure 7). The failure to demonstrate an age-related reduction in near stereoview may have been due to a 'ceiling effect' inherent in the vectogram tests used, whereby the stereoview for many subjects was actually better than the minimum stereoview measurable. Greene and Madden found an age difference in near stereoview (Randot polaroid vectogram) between two groups (mean ages 20 and 68 years), which was no longer significant if four older subjects with no measurable stereoview were removed from the analysis (the use of non-parametric statistics would have been appropriate).

Variation in the reported results is probably due to differences in experimental design, subject selection, and the test procedures. Jani shows a similar curve to that found in other visual and ocular functions. Considering the decrease in VA and CS with age, and the effects of defocus upon stereoview, it is not surprising that stereoview would decrease with age in a similar manner. Current studies are unable to demonstrate that the decrease in stereoview with age is any greater than that predicted from the concurrent decrease in CS and VA. There may be two factors affecting the decrease in stereosensitivity with age. The first may be related to the decrease in VA and CS, and the second to an increase in the number of older persons with little or no stereoperception. This then implies losses at both lower and higher levels of the neural pathways.

Image degradation produces a greater reduction in stereoview when monocular than when binocular. Anisometropia induced with lenses produces a deterioration in stereoview with even very small changes. This is also apparent when the images are spatially filtered.

Monocular aphakes wearing a contact lens often have poor stereoview and difficulty maintaining binocular vision, probably due to residual magnification effects. Monovision (artificial anisometropia) is the most common contact lens modality for presbyopic contact lens patients, despite having been criticised for its effect upon stereoview and binocular vision. Most successful monovision patients appear to suppress the out-of-focus eye. This is apparently easier when the anisometropic difference, and hence the blur, is greater, and suppression improves with experience of monovision, leading to patient reports of improved vision despite no 'measurable' change with conventional clinical tests. Woods reported that there was no difference in stereoview prior to fitting between successful and unsuccessful monovision subjects. Monovision causes a greater reduction in stereoview than bifocal contact lenses. Successful bifocal contact lens wearers appear to have slightly better stereoview than those who prove unsuccessful and it has been suggested that stereoview is a useful predictor of success with certain bifocal contact lenses.

The reduction in stereoview caused by bifocal lenses and monovision may have an effect on certain tasks that a patient may undertake. These may be work or pastime related. Driving has been suggested as an area in which the wearer must be careful. As there are many monocular and non-stereoscopic drivers, and most depth perception information comes from non-stereoscopic cues, there is no reason why a bifocal wearing or monovision patient cannot drive.
It is advisable that, upon initial fitting, the patient be made aware of the potential reduction in stereovisual acuity, and be asked to at least make the first trip in a motor vehicle as a passenger and to take particular care when parking. The effect of reduced stereovisual perception upon driving ability remains untested in law. 139

Hyperacuity
Due to concurrent optical changes, it is difficult to determine whether neural processes are involved in the age-related changes in visual function. A number of recent articles have investigated certain hyperacuity tasks140 that are relatively independent of visual optics141-143 in an attempt to answer this question. The very resistance of certain hyperacuity tasks to optical degradation implies the involvement of neural mechanisms that are different from those subserving VA, high spatial frequency CS, and stereovisual acuity.

Oscillatory movement displacement thresholds (detection of movement of vertical bars) increase with increasing age. 144,145 Odom et al. 146 investigated vernier acuity (precision with which an observer can locate one line relative to another) and vernier bias (repeatability of the observer’s alignment). They demonstrated no change in vernier thresholds, and an increased vernier bias with age. They suggest that changes in vernier bias may be due to distortion of the retinal substrate. This may relate to the phase differences noted by Walsh and Charman. 147,148 The change in vernier bias was step-like between the fourth and fifth decades, unlike a (progressive) neural degeneration, and Odom et al. conclude that this may relate to the onset of presbyopia (though they do not say why this should be so).

The resistance to optical degradation of hyperacuity tasks suggests that the reduction in image quality inherent with simultaneous-vision bifocal contact lenses and with monovision would have no additional effect upon the ability of older patients to perform hyperacuity tasks. Needless to say, if the object is sufficiently blurred then the task will not be performed adequately.

Visual Performance: A Neural Origin?
Evidence for a neural basis for the age changes, rather than the effect being due to deterioration of the optical media and reduced pupil size that induces attenuation of light transmission, comes from a variety of sources. Owsley et al. 78 demonstrated that the loss of intermediate and high spatial frequencies was comparable for similarly aged subjects with normal, clear crystalline lenses and those with intraocular lens implants, and both were worse than young adults (this makes the implicit assumption that the modulation transfer function, for higher spatial frequencies, of the intraocular lens is better than that of the aged human crystalline lens, and this has not been tested, as the authors note, though in a different context). The age-related increase in pre-retinal ocular absorption and scatter is principally within the crystalline lens, which undergoes the greatest age-related changes in transparency. 16 The effect of glare, whilst age-related, is not related to spatial frequency, implying that the age-related changes in CS are not related to changes in the optical media. 25,150 The reduction in performance cannot be entirely simulated with filters79, which produce the estimated reduction in transmission. 48,150 Changes in light transmission of the ocular media and senile miosis are therefore not sufficient to explain the reduction in CS and VA with age.

Interferometric evaluation of grating detection, which bypasses the ocular media, also indicates that the reduction in sensitivity is partly due to neural changes which occur with increasing age. 25,79 This almost certainly relates to the reported displacement and distortion of cell nuclei in the outer nuclear layer, to reduction in density of macular photoreceptors151,152, and to reduced retinal rod density.153,154 Retinal ganglion cell axons are also distorted155 and reduced in number156,157 with age. This must affect the function and resolution of the visual system. Slightly surprisingly, spatial summation areas under both photopic and scotopic viewing conditions are not reduced with age. 158 Further anatomical changes include a substantial reduction in cortical (macular projection area) cell density found with age. 159 There is obviously a large degree of redundancy in the visual system as, for example, more than half the ganglion cell axons in the optic nerve are damaged before a clinical reduction in visual field occurs. 160 Most visual functions are probably reduced with age, but the ability to detect them is limited by the resolution of the test procedure and other confounding factors (e.g., retinal illumination).

Thus, a common mechanism almost certainly underlies the age-related changes in visual function, including VA, CS, and stereovisual acuity. 81 Though reduced retinal illumination explains some of the decrease, it appears that there is probably also a neural loss with age that accounts for the reduction in VA in apparently healthy older subjects. Weale150 suggested (with some very broad assumptions) that the decrease in VA is due to neural loss at all levels of the visual system, with a suggested 0.29% loss of cells per year. More recent anatomical studies report higher rates of cell loss. 152,154,159

The optical performance of modern single-vision lenses161 will not detrimentally affect the visual performance of older patients. On the other hand, bifocal contact lenses reduce CS, VA, and stereovisual; hence a clinical measure of CS or low contrast VA is recommended prior to fitting. Stereovisual (e.g., polaroid vectograms) may be predictive of success with simultaneous-vision bifocal contact lenses. Monovision appears to have only a slight effect upon CS.
and VA while suppression is maintained. A trial wearing period is recommended to ensure that the patient can perform normal daily tasks successfully.

**Colour Vision**

Colour vision changes with increasing age due principally to changes in the crystalline lens which resemble the effects of a yellow filter. Short wavelengths are attenuated, resulting in a shift of white towards yellow and a relative darkening of blue objects. The location of the the trichromatic coefficients changes progressively with age. This is more enhanced at low luminance levels. Reported results with clinical tests are discussed in more detail.

Verriest and Pinckers, using the Farnsworth-Munsell 100 Hue test, demonstrated an improvement in colour discrimination in the first two decades, followed by reduced hue discrimination for blue-green and red with increased age. This could be partially simulated with yellow filters, giving an apparent acquired tritanomaly. Knoblauch et al. demonstrated that the age-related tritan-like defects on the Farnsworth-Munsell 100 Hue test can be partially mimicked in younger subjects by a reduction in test illuminance, and noted that this may be related to the Bezold-Brucke effect (variation in luminance alters the perception of hue).

Helve and Krause used the Panel D-15 as a screening test for elderly subjects (mean age 74 years), and reported a significant number of tritan defects, principally related to maculopathy, some of indeterminate cause, as well as several undefinable defects. Pinckers found no age relationship for pseudo-isochromatic tests (American Optical Hardy-Rand-Rittler (AOHRR), Ishihara and Tokyo Medical College (TMC)). The best performance for the Farnsworth-Munsell 100 Hue derivative tests (Panel D-15, New Colour Test (NCT) Box 6/4, and the desaturated Panel of Lanthony (D8/2)) was during the third to fourth decade, with an increased incidence of blue-green confusions with increasing age.

Lakowski and Verriest et al., with a Pickford anomaloscope, demonstrated a systematic tritan-like change with increasing age, which again could be partially simulated with yellow filters. Verriest and Pinckers, with a Nagel anomaloscope, also simulated the demonstrated age-related trend to the green end of the Rayleigh equation with a series of yellow filters. Nuclear cataract causes a shift to the red (the opposite to the normal age shift). This suggests that lenticular changes, or at least cataractous changes, are not responsible for the age-related changes in colour vision.

Ruddock demonstrated a positive correlation between age and both short and medium wavelengths, as measured with a trichromatic colorimeter. This age-related change is independent of the spectral transmission of the ocular media, and would hence demonstrate a neural element in decreased colour sensitivity with age. Ruddock felt that the observed age shift may have been a function of the experimental methods. Werner et al., in a review of colour vision, suggest that the three-cone types probably decline in sensitivity approximately equally through changes at the receptoral and post-receptoral level, but the blue-yellow opponent channel is selectively attenuated with advancing age.

Most of the alterations in colour discrimination with age are attributed to age-related changes in the wavelength-dependent specular transmission. The increased short wavelength absorption of the ocular media appears to account for most of the tritanomalous shift with age. Weale argues that there is a decrease in colour discrimination which subserves other contrast discrimination abilities that are known to deteriorate with age. The differential effects of retinal diseases upon the different colour channels implies that the blue-yellow system is more fragile and may also suffer more from the aging process. Due to large individual variations in performance, with many older subjects having clear ocular media that display no alteration in colour discrimination, and the many slight, undetected ocular pathologies in the elderly, it is difficult to demonstrate what is probably a slight neural element in the alteration to colour perception with age. In addition, with increasing age there is an increased incidence of acquired colour vision defects.

Lightly tinted cosmetic contact lenses have little effect upon colour perception, but darker tints, prescribed for example to reduce photophobia, may alter colour perception. In fact, tinted contact lenses have been prescribed to aid those with defective colour vision. Some blue-tinted lenses, due to selective spectral transmission, may severely affect visual performance with monochromatic (e.g. sodium) street lighting. This effect will be compounded by the reduction in transmission of shorter wavelengths and age-related changes in colour vision. In addition, blue-tinted lenses may not be a good choice for older patients as they will be slightly more difficult to see than other colours and hence less useful as a handling tint. The distance and near images with diffractive lenses are wavelength dependent. The distance image with current diffractive lenses is more blue and the near image is more red. No effect upon colour vision has been demonstrated. In summary, contact lenses would appear to have little additional effect upon colour vision.

**Glare Sensitivity**

Glare can be divided into three types: dazzling, veiling, and scotomatic. Dazzling glare is seen when a high luminance object is near the object of regard, such as the effect of car headlights at night. Stray light falling relatively uniformly across the retina, reducing the effective contrast of the object of regard, creates veiling glare. Reflections upon a window act
as a veiling glare. Photopic stress, such as produced
by a camera flash, temporarily alters retinal sensitivity
and is known as scotomatic glare. There is an
increase in both veiling and scotomalous glare sensitivity
with age.26,29

The ability to identify a target in the presence of
veiling glare is greatest in the third decade, and
then decreases with age.28 Wolf28 noted that the two
aphakic eyes measured showed an improvement in
target detection over the mean for the age group,
but not to levels achieved in younger subjects. The
back-scatter from the crystalline lens and vitreous is
weakly correlated with age and veiling glare sensitivity.17 Allen and Vos18 demonstrated increased light
scatter in both the cornea and lens with increasing
age, and a reduction in variable contrast VA with
increasing age. They felt that back-scatter in the
anterior ocular media could not account for the de-
crease in visual performance. Back-scatter may not
be a a measure of the forward-scatter by the anterior
ocular media, which actually impairs visual perfor-
ance. Increased glare with a greater degree of
incipient cataract suggests that changes to the lens
with age cause much of the glare sensitivity increase
with age28, but there are other contributory factors.

Paulsson and Sjosstrand149 and Elliott25 demon-
strated that the sensitivity to veiling glare of older
subjects was greater than that for younger subjects
by a factor of two. Glare sensitivity was greater for
lower spatial frequencies for all ages. This correla-
tion with spatial frequency suggests that the age-related
changes in CS are not due to increased light scatter
by the optical media. Evidence is limited in this area,
but this would imply that there is not a neural
element in increased glare sensitivity.

Increased sensitivity to veiling glare with age may
be due to a variety of factors, which include increased
light scatter and absorption by the ocular media
(including the retina) and neurological impairment.
Senile miosis would be expected to reduce glare
through a reduction in oblique rays, but as all the
light must pass through the thicker, central portion
of the lens, light scatter may increase. The cornea
and vitreous alter in absorption and scatter with age
and may contribute to glare.24 Wavelength-dependent
Rayleigh scatter, particularly in the crystalline lens,
is thought to account for much of the alteration in
ocular media absorption with age178, and may be
the cause of increased glare sensitivity with age.
Carter176,177 suggests that veiling glare may be further
increased with age by the increased fluorescence of
the aging lens, though this has not been demon-
strated.

Simultaneous-vision bifocal contact lenses are
known to reduce image quality28 by effectively split-
ting the light into two separate foci. At least one of
these foci will be out of focus for any particular object
of regard, and will thus act as a type of glare source,
diffusing light across a relatively broad area of the
retina. This may then increase the sensitivity to
veiling glare of these patients. Some wearers of dif-
fractive bifocal lenses have reported glare associated
with monochromatic (e.g., sodium) lights used in many
built-up areas and on motorways, and which has lead
some wearers to avoid their use for night driving.35
Edge glare associated with multivcurve rigid contact
lenses might be expected to be a greater problem for
older wearers, but, thankfully, pupils are typically
smaller with increasing age. Under conditions of
decreased luminance, the near portion of an
alternating-vision bifocal contact lenses will cover
more of the pupil and may cause increased veiling
flare.

Scotomatic glare sensitivity has been shown to
increase after the fourth28, fifth178, or sixth179 decade.
Reading29 found that increases in readaptation time
can be accounted for partially by the decrease in
retinal illumination with age.48 In a well-controlled
study, Elliott and Whitaker180 found that, even when
changes in retinal luminaus were taken into
account, scotomalous glare recovery time increased
throughout adulthood.

Older patients are more susceptible to glare and,
as noted, this can be influenced by certain forms of
contact lens. Contact lens practitioners should be
aware of these changes, but should be careful that
problems with glare are not simply dismissed without
an adequate check for potential causes, such as len-
ticular changes or corneal oedema. Veiling glare due
to corneal oedema might be expected to be have a
greater effect upon older patients, though they may
be less likely to report it if glare is considered normal.
Tinted contact lenses prescribed to alleviate photo-
phobia, which may be due to increased glare, could
reduce transmission to an extent which may signific-
antly effect visual function under low lumin-
ance.22,47,50,62,98 Glare may be worse in the mornings
and evenings, as corneal oedema is often greater
then, and the sun is lower in the sky.

Visual Field

Like the other psychophysical functions examined
here, age-related changes occur in the visual field.
There is a general, continuous shrinkage of the visual
field with age, traditionally described as a depression
of isopters.24 The older 'hill of vision' becomes depres-
sed and steeper due to a greater reduction in sensi-
tivity in the periphery than the centre.181 This may
result from senile miosis104, the increased absorption
of the ocular media48, the location of the upper eye-
lid5,8, neuroretinal delays and the decrease in reaction
times with age29, and may be simulated by reducing
the oxygen tension of the gas mixtures inspired by
younger subjects.192 As would then be expected, VA
reduction in the peripheral visual field is greater for
older subjects.193

In the simplest evaluation of the extent of the
visual field, Burg184, after screening 17,479 subjects
aged between 16–92 years, found that both the nasal and temporal lateral visual fields decrease in size with age after the fourth decade.

Perimetric evaluation suggest a linear age-related change. Drance et al.\textsuperscript{185} and Williams\textsuperscript{186} reported an age-related decrease in the size of measured isopters in all meridians, as measured with a Goldmann perimeter: The reduction was greater in the superior meridian, probably due to senile ptosis.\textsuperscript{15,2} The blind spot slightly increased with age, due to the general reduction in all isopters, and measurement may lead to the false impression of baring of the blind spot.\textsuperscript{185}

Modern computerised static techniques, which allow more subtle investigation and statistical analysis, indicate a gradual loss of overall sensitivity which is linearly related to age. Light sensitivity of the central visual fields measured with an Octopus perimeter decreases with age.\textsuperscript{187,188} The reduction in sensitivity was more pronounced superiorly\textsuperscript{187}, and increased with increasing eccentricity.\textsuperscript{188} Collin et al.\textsuperscript{183} (using a Humphrey Field Analyser) reported, for three age groups, an increasing mean rate of loss of sensitivity with increasing age (i.e., non-linear) and no difference between superior and inferior visual fields.

The useful field of view may be defined as the visual area from which information can be obtained with one fixation. This useful field has been demonstrated to reduce with increasing age. The loss reported by Ball et al.\textsuperscript{189} is greater than that reported using conventional visual field measures, which may be due to the mode of presentation. These tests involve the detection and localisation of targets against more complex backgrounds, which may be a better simulation of real world situations.

Contact lenses are not known to significantly alter peripheral visual fields and an image degraded by a bifocal or near vision contact lens is unlikely to alter sensitivity due to the poor image quality and poor retinal resolution in the periphery.\textsuperscript{183,190} Hypermetropic and, particularly, aphakic contact lens wearers will have a larger field of view than their spectacle-wearing counterparts.\textsuperscript{185} Monovision reduces image quality in one eye, and there have been suggestions that the choice of eye for the near vision lens must be made with care due to potential effects upon driving ability.\textsuperscript{40–42} As there is large binocular overlap of the human visual fields there are few tasks which are performed monocularly, even when driving, except the detection of another vehicle beside and slightly behind the driver's position. A motor vehicle is a very large object, and such objects with a low spatial frequency content are little affected by defocus. Collins et al.\textsuperscript{191} reported that monovision had no effect upon VA at eccentricities greater than 10°. There are certainly other reasons for caution with the fitting of monovision and bifocal contact lenses, as discussed previously.

Address for Correspondence
Russell L. Woods, Department of Optometry and Visual Science, City University, 311–321 Goswell Road, London EC1V 7DD, UK.

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