Achieving visual excellence through optimization of macular pigment

Enrichment of MP can enhance visual performance

By Sakina Kashani, Dr John M. Nolan and Professor Stephen Beatty

Vision, or the sensation of sight, refers to the perception of the physicality of one's surroundings through the complexities of the visual system, which includes the eye, optic pathway, and cerebral cortices. To 'see' includes the ability to: distinguish objects from contrasting backgrounds; recognize and identify people or objects; appreciate colour, depth and movement.

The field of ophthalmology is concerned with the detection and treatment of eye disease, and alleviation or amelioration of the pathology's impact on vision. However, there is a fundamental and unmet need to recognize the considerable and underappreciated variability in visual performance and experience in healthy patients with no evidence of eye disease. In this context, visual performance, reflected in the subject's visual experience, can be assessed with a variety of techniques, and should not be restricted to standard and typical visual acuity (VA) testing.

Measures of visual performance

Visual acuity

VA is a useful tool for testing the resolving power of the eye. It involves the presentation of a target that has a substantially different luminance to its background. The subject's task is to read the line of the smallest letters visible to him/her. However, VA's limitations rest primarily on the fact that testing is performed under conditions of 100% contrast, and therefore does not reflect the subject's function in relation to vision because so many other parameters of the visual experience are not being tested.

Contrast Sensitivity

Contrast sensitivity (CS) refers to the ability of the visual system to distinguish an object from its background.[1] High contrast involves the presentation of two visual stimuli of substantially different luminance, whereas low contrast involves the presentation of two visual stimuli of comparable luminance. CS testing determines the lowest level of contrast required to detect the target against its background.

CS is adversely affected by increasing age, cataracts, diabetic maculopathy and age-related macular degeneration (AMD), even in cases where measures of VA are unaffected. Measures of CS have been shown to better represent the impact of eye disease on a subject's visual function than do measures of VA.[2] This is unsurprising, given that the real world visual experience is not confined to a high contrast environment.

Importantly, and especially in the context of this review, CS is adversely affected by chromatic aberration (CA) to a greater extent than is VA.[3]

Glare

Glare refers to a reduction in visual performance or a sense of discomfort because of a relatively bright light source within the field of view.[4] Clinically, there are two types of glare, and these can be classed as glare discomfort and glare disability. Glare discomfort refers to an unpleasant sensation one experiences when subjected to illumination that is too bright, for example, full beam headlights from an approaching vehicle when driving. Glare disability,

In short...

The macula is a specialized part of the retina, which facilitates central vision, best colour discrimination, and provides sharpest visual acuity and contrast sensitivity. Three hydroxycarotenoids accumulate at the macula, collectively being known as the macular pigment (MP). The vision-optimizing effect of the MP is now based on a solid and growing body of evidence. In this article, the authors discuss the MP and its enrichment to enhance visual performance.

however, refers to a reduction in one's ability to perceive visual information (without necessarily causing discomfort) because of a relatively bright light source in the field of vision.[5] CS is adversely affected by glare disability, and this deleterious impact on CS is attributable to veiling luminance (which in turn is caused by light scattering), ultimately adversely impacting the visibility of objects in one's field of view.

Factors adversely influencing contrast sensitivity

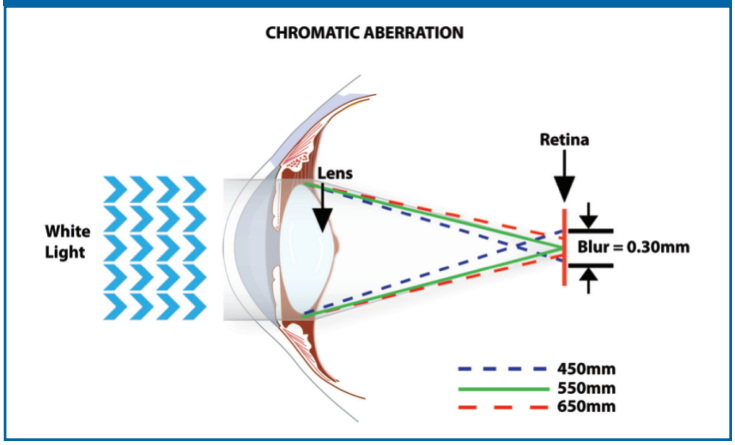
Chromatic aberration

CA refers to an inability of the eye to focus visible light of different wavelengths at a single point of convergence, because of the differing refractive indices associated with the respective wavelengths. Short (blue) and long (red) wavelengths are focused proximal and distal to green wavelengths of light, respectively, resulting in a myopic defocus of approximately 1.2 dioptres (D) for blue light (460 nm) and a hyperopic defocus of approximately 0.4 D for red light (Figure 1).[6] As a direct result of myopic defocus of blue visible light, a bluish hue/blur is apparent at the edges of perceived images, and this phenomenon is known as CA.[7] In other words, and given that the foveola does not contain blue-sensitive cones, blue visible light is deleterious (and not in any way beneficial) to the generation of a clear image in the human eye.

Light scatter

Light scattering refers to the reflection and diffraction of light waves by particles suspended in the atmosphere or in the eye. Atmospheric light scattering is generated because of visible and non-visible particles, varying in size and abundance. Oxygen, nitrogen, haze aerosols, fog, rain, clouds, and so on, generate this form of scatter, which has an adverse effect on a subject's visual discrimination and visual range.

Figure 1: Chromatic aberration is caused by the bending of short wavelength light, focusing this light in front of the retina.



The most obvious manifestation of light (Rayleigh) scattering is seen when we perceive the sky as blue, due to the reflection, or absorption and re-radiation of light incident upon a multitude of aforementioned particles. Rayleigh scattering is wavelength-dependent, being greater for short (blue) wavelengths of light, and consequently, the light scattered down to the observer on earth is predominantly at the blue end of the spectrum.

Light scattering within the eye is primarily attributable to the crystalline lens, and secondarily to the cornea, with a small amount being scattered by particles within the aqueous and vitreous humour. When light from a source close to the optic axis is scattered, either by particles external to the eye or by particles within the ocular media, it is dispersed across the macula, and this phenomenon is known as a 'veiling luminance'. Veiling luminance is, therefore, superimposed on the retinal image and adversely impacts upon CS and overall visual performance.

Macular pigment

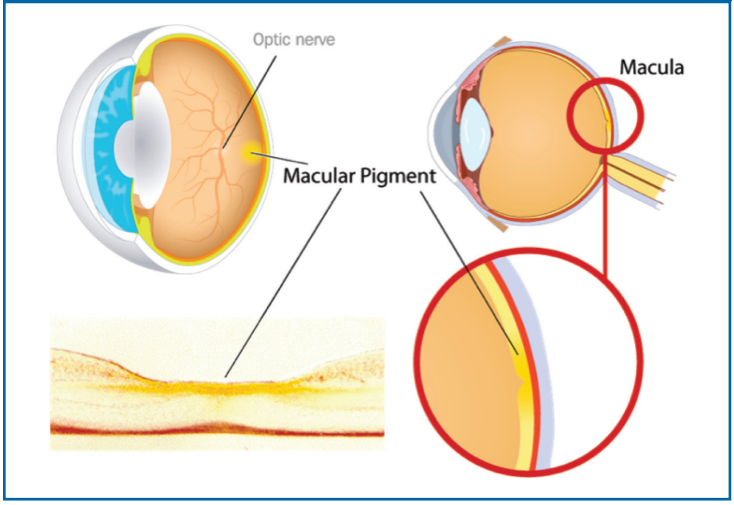
The macula is a specialized part of the retina, which facilitates central vision,[8] best colour discrimination, and provides sharpest VA and CS. Three hydroxycarotenoids, lutein (L), zeaxanthin (Z) and *meso*-zeaxanthin (MZ) accumulate at the macula (to the exclusion of approximately 40 other dietary carotenoids), where they are collectively known as macular pigment (MP) (Figure 2).[9,10] MP is at its highest concentration in the receptor axon layer and in the inner plexiform layers of the retina, and its concentration peaks at the foveola.[11,12] L is the dominant carotenoid in the peripheral macula, Z in the mid-peripheral macula, and MZ at the epicentre of the macula.

L and Z are entirely of dietary origin, whereas MZ is derived (at least in part) from retinal L through a poorly-understood process of bioconversion, and its content in the typical diet remains under investigation. The exquisite biological selectivity for accumulation of L, Z and MZ at the macula indicates a specific and non-accidental role for the properties of these compounds in this tissue of maximum visual performance.

Properties of MP

MP's accumulation at the macula is believed to relate to that tissue's need to use the pigment for its optical and/or biochemical

Figure 2: Macular pigment is uniquely located at the macula, the central part of the retina. Image courtesy of Professor Max Snodderly and Dr John Nolan.



properties.[13–15]

The optical properties of MP include its pre-receptoral filtration of short wavelength (blue) visible light. This renders MP capable of enhancing visual performance by attenuating the effects of CA, thus improving CS and reducing the adverse effects of scattered light at the retina, thereby enhancing visual function, especially under bright light conditions.

The biochemical properties of MP that are believed to confer advantage for vision include its antioxidant capacity, and consequential contribution to neural efficiency,[16] and protection against age-related oxidatively-induced photoreceptor degradation and associated loss of function (reflected in the observed age-related decline in CS).

The vision-optimizing effect of MP is no longer a hypothesis, and is based on a solid and growing body of evidence. The most recent study by Loughman *et al.* has shown that supplementation with a formulation containing L, Z and MZ (Macushield, MacuVision Europe, Solihull, UK) results in rapid augmentation of MP and improved CS at almost all spatial frequencies under mesopic (intermediary light) and photopic (bright light) conditions, whether in the presence or absence of a glare source.[16] However, supplementation with a formulation lacking MZ (but containing L and Z) did not result in augmentation of MP, nor an enhancement in visual function.

Spatial profile of MP

Typically, the spatial profile of MP peaks at the fovea and exhibits a monotonic decline with increasing eccentricity. Sometimes, however, a central dip is seen in the spatial profile of MP and, therefore, in theory at least, such a relative lack of MP centrally is compromising. This is because the short wavelength filtering and antioxidant capacity of the pigment will be substantially lower due to a relative lack of MP at this central location.

In fact, a study published in 2003 which investigated MP optical density in subjects with and without AMD demonstrated that those suffering with AMD were more likely to exhibit a central dip in MP than those without AMD.[17] Furthermore, Kirby *et al.* have shown that, prior to disease onset, known risk factors for AMD are associated with this atypical central dip in the spatial profile.[18] This study identified the presence of a central dip in 12% of the population. As MZ is the dominant carotenoid in this location (at the epicentre of the macula), it is probable that a lack of this carotenoid represents a risk for AMD, and is also associated with sub-optimal visual performance in normal subjects with healthy maculae.

In a recent study, where subjects with such atypical and undesirable dips in the spatial profile of their MP were supplemented with differing formulations of the macular carotenoids, it was found that supplementation with all three of MP's constituent carotenoids (MZ, L and Z; Macushield) was required to augment MP across its entire spatial profile (including the epicentral peak), whereas this was not the case if supplemented with a formulation that was lacking MZ.[19]

Of interest, a mixture of L, Z and MZ, *in vitro*, in a ratio of 1:1:1, has been shown to be more efficacious in its collective antioxidant capacity (by quenching more singlet oxygen species, which cause cumulative tissue damage) than any of these individual carotenoids at the same total concentration.[20] Therefore, and in addition to the vision-optimizing evidence published by Loughman *et al.*, it appears that supplementation with a formulation containing all three macular carotenoids (L, Z and MZ; Macushield) is required to afford the greatest antioxidant defence at the macula.

Conclusion

In short, there is firm evidence that visual excellence, in normal subjects with no evidence of eye disease, is dependent upon optimum levels of MP. The enrichment of a subject's MP across its spatial profile can enhance visual performance by attenuating the effects of CA (and therefore improve CS), and

by reducing the adverse impact of light scatter on visual function, but this can only be achieved with a formulation containing all three of MP's constituent carotenoids (L, Z and MZ; Macushield).

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