



Impact of macular pigment on visual performance

Jessica Dennison, Professor Stephen Beatty, Graham O'Regan and Dr John Nolan discuss glare and review the evidence for the involvement of macular pigments in influencing visual performance and glare. Module C20151, one general CET point for optometrists and DOs

There are two types of glare: disability glare and discomfort glare. Disability glare occurs when light scatter creates a veiling luminance (see below) making an image difficult to distinguish due to the resulting decreased contrast and detail of the image. Disability glare has an impairing effect on vision because it makes it difficult to establish an accurate image. An example of this type of glare is oncoming car headlights at night when driving. Discomfort glare, on the other hand, is caused by high luminance sources in the visual field that can be distracting or uncomfortable. An example of this type of glare is looking at a snow-covered field on a sunny day.^{1,2}

What is light scatter?

Light scatter occurs in the atmosphere, but also within the eye. When light waves come in contact with particles suspended in the atmosphere or in the eye, they are reflected and diffracted by the particle. In the atmosphere, scatter is created by a variety of particles,

including oxygen and nitrogen, haze aerosols, fog, mist, clouds, among others. Within the eye, about 70 per cent of scatter is created by the lens, about 30 per cent by the cornea, and a small fraction is due to light passing through the aqueous and vitreous. Light scatter can adversely affect the distance and amount of detail one can see. It has been found that short wavelength (SW) blue light scatters more than other wavelengths (Figure 1), resulting in a blue haze.³ Scattered light that reaches the retina, termed forward scatter or stray light, causes veiling luminance. Veiling luminance is a screen of bluish light that is superimposed on the retinal image. This excess of bluish light decreases the contrast of the image, resulting in poor contrast sensitivity.

What is contrast sensitivity?

Contrast sensitivity (CS) is the visual ability to discriminate between an object and its background and is crucial for detecting objects, judging distances, and distinguishing details.³ CS declines with age and can also decrease as a result of cataracts (due to the increased

clouding of the crystalline lens which causes increased scatter), diabetic maculopathy, and early age-related macular degeneration (AMD). Poor CS affects visual performance (VP), and results in vision-related difficulties, including:

- Trouble for drivers seeing traffic lights or cars at night
- Trouble for pilots when landing planes
- Trouble with outdoor sports such as golf or tennis
- Not being able to see spots on clothes, counters, or dishes
- Missing facial gestures
- Needing a great deal of light to read
- Experiencing tired eyes while watching television.⁴

What is photostress?

Photostress occurs when the retina is suddenly exposed to bright light after being in a darker environment.¹ For example, when stepping outside on a sunny day after being in a dark room one might react with a momentary blepharospasm (squinting). The intense incoming light bleaches the

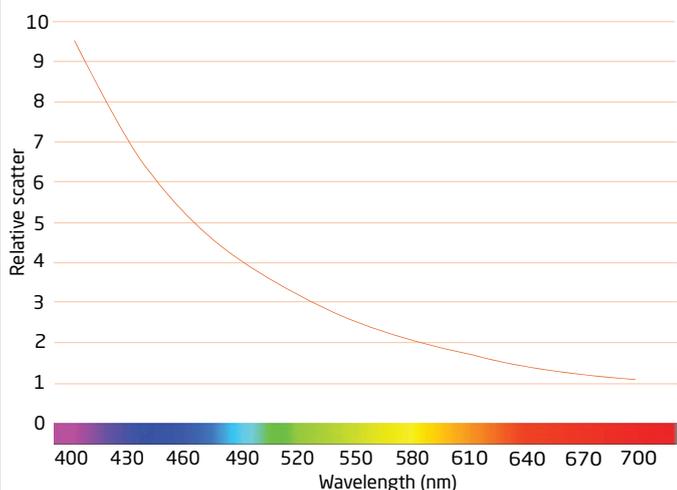


Figure 1 The amount of scatter relative to wavelength of visible light. The shorter the wavelength, the greater the amount of scatter

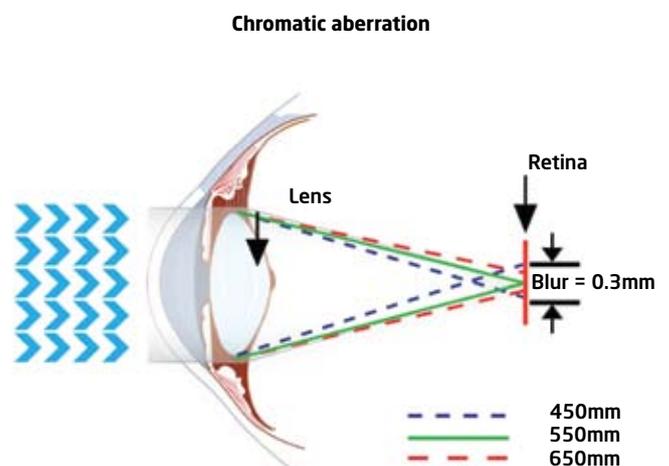
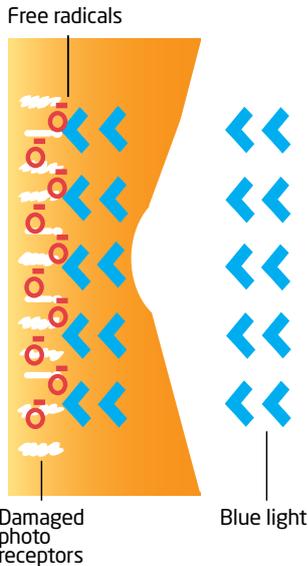


Figure 2 Chromatic aberration is caused by the bending of short wavelength light, focusing this light in front of the retina

Macula without macular pigment



Macula with macular pigment

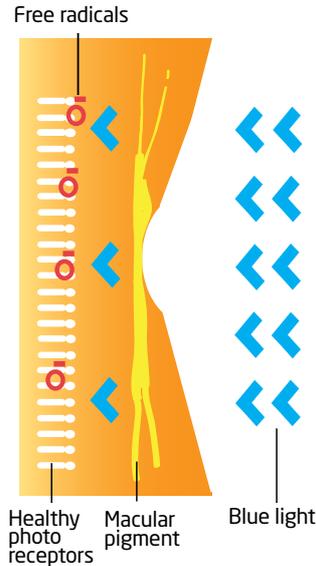


Figure 3 Without macular pigment, short-wavelength blue light reaches the photoreceptors, exacerbating oxidative stress, and causing negative effects on visual performance. Short-wavelength blue light is absorbed by the macular pigment, which is located pre-receptorally, protecting the photoreceptors and enhancing visual performance

photoreceptors, temporarily 'blinding' the observer. Photostress recovery time (PRT) is the time it takes to distinguish a target after exposure to the bright light. The shorter the PRT, the quicker objects can become detectable. In general, PRT increases as we age.⁵ The time it takes one to recover from photostress is important for VP with obvious implications for driving at night.

What is chromatic aberration?

Chromatic aberration (CA) is caused by defocused SW blue light. When light enters the eye, different wavelengths are bent to different degrees, with SWs being bent more than longer wavelengths (Figure 2). The bending of SW light causes the incoming light to be defocused. For example, incoming blue light at 460nm is defocused by up to 1.2 dioptres more than green light at 550nm.⁶ CA appears at the edge of an image as a bluish blur.⁷ Reducing CA would increase CS by diminishing the blur resulting from the defocused blue light, thus improving vision. It has been reported that when chromatic and monochromatic aberrations are reduced, CS and corrected distance visual acuity (CDVA) improve.⁸

What is macular pigment?

Macular pigment (MP), a yellow pigment at the back of the eye, is composed of the carotenoids lutein (L), zeaxanthin (Z), and meso-zeaxanthin (MZ).^{9,10} L and Z are of dietary origination;¹¹ whereas there is no satisfactory study to date investigating the presence of MZ in foods, although there is one published study by Maoka

et al who reported MZ to be present in certain fish and seafood (eg trout, bass, salmon, shrimp).¹² Such an investigation is currently under way in Waterford, Ireland, at the Macular Pigment Research Group. Previous research has suggested that MZ is generated uniquely from L at the retina;¹³ however, this hypothesis is now being revisited, as it was driven by a single study before the advent of recent and necessary technology to address this question. Furthermore, it is possible that MZ may, in fact, be dietary in origin, and, as mentioned above, this is currently an area of research being conducted by our group. Of interest, studies have shown that supplementation with L, Z, and MZ can increase MP.¹⁴⁻¹⁸

MP is believed to play a protective role for the retina through the carotenoids' antioxidant and blue-light filtering properties.¹⁹⁻²¹ Through these two mechanisms, MP is believed to protect the macula from cumulative (photo)-oxidative damage. L and Z have been shown *in vitro* to quench reactive oxygen intermediates (ROIs), especially singlet and peroxy radical oxygens.²¹⁻²³ MZ is also believed to be an important antioxidant.²⁴ For example, a recent publication by Li *et al* has shown that when L, Z, and MZ are together, their collective antioxidant potential is greatly enhanced.²⁵ MP also reduces light-induced oxidative stress because of its ability to absorb harmful SW energy before it reaches the photoreceptors and retinal pigment epithelium (Figure 3). Wald, in 1945, was the first to show that MP absorbs SW light (430-490nm),²⁶ and it

was later reported that the chemical structure of the macular carotenoids make them good absorbers of SW light.²³ Of interest to this report, it is MP's SW-filtering property that is believed to be most important to VP.²⁷

Approximately 700 carotenoids have been identified in nature, 40 of which have been recognised in human serum.²⁸ However, L, Z, and MZ are the only three carotenoids that are found in the retina. Concentration of these carotenoids in the *macula lutea* is approximately 100 times greater than in the peripheral retina, consistent with the rationale that these carotenoids play an important role in central vision.²⁹

Distribution analysis of MP shows that Z and MZ are the most concentrated carotenoids at the fovea, with MZ concentration peaking centrally, whereas the concentration of L is greater in the parafovea.³⁰⁻³² Typical MP profiles peak at the centre of the fovea and then decrease exponentially to undetectable levels around 7° eccentricity.³³ However, atypical MP spatial profiles that include a central dip or a secondary peak have also been reported.^{30,34,35} Kirby *et al* showed that an atypical central dip in MP spatial profiles is found more often among older subjects and cigarette smokers, two undisputed risk factors for AMD.³⁶ Nolan *et al* demonstrated that supplementation with all three carotenoids, as opposed to a formulation lacking MZ, can uniquely correct the low epicentral MP and normalise its spatial profile in subjects with an atypical central dip at baseline.³⁷



TABLE 1

Cross-sectional studies of MPOD and VP

Principal author	Journal	Year	n	Measurements	Outcome
Hammond BR ⁵⁵	<i>IOVS</i>	1998	27	PIS, MPOD	PIS positively related to MPOD
Hammond BR ⁵⁶	<i>Ophth Physiol Opt</i>	2005	134	CFF, MPOD	CFF positively related to MPOD
Stringham JM ⁴⁵	<i>Optom Vis Sci</i>	2007	36	PRT, Glare, MPOD	Reduced glare and PRT related to higher MPOD
Loughman J ⁴⁰	<i>Vis Res</i>	2010	142	BCVA, CS, MPOD	BCVA and CS positively related to MPOD
Renzi LM ⁵⁰	<i>Exp Eye Res</i>	2010	78	CS, MPOD	CS positively related to MPOD
Renzi LM ⁴⁹	<i>Ophthal Physiol Opt</i>	2010	424	CFF, TCSF, MPOD	TCSF and CFF positively related to MPOD
Stringham JM ⁴⁶	<i>IOVS</i>	2011	26	DG, PRT, VD, MPOD	Fast PRT, lower DG, and decrease VD related to higher MPOD

Abbreviations: MPOD= Macular pigment optical density, PIS= Photopic increment sensitivity, CFF=Critical flicker fusion, PRT=Photostress recovery time, BCVA= Best-corrected visual acuity, CS= Contrast sensitivity, TCSF= Temporal CS function, DG= Disability glare, VD= Visual discomfort
 An individual's CS is often measured using the contrast sensitivity function (CSF), which defines the lowest level of contrast at which an individual can distinguish between an image and its background. CS can also be measured as a function of time using the temporal contrast sensitivity function (TCSF). The critical flicker fusion (CFF) threshold is the point at which an intermittent light stimulus appears to be continuous, but is only one measurement of temporal vision. CFF measures temporal sensitivity at a single luminance, while the TCSF differs in rate of stimuli presentation as well as luminance.⁴⁹

How does MP contribute to visual performance?

The fovea is the central and specialised part of the macula, responsible for fine detail vision.³⁸ Due to MP's pre-receptor location at the fovea, light must pass through it before getting to the photoreceptors, thereby selectively filtering the SW light that is responsible for veiling luminance and CA (Figure 4).

Wooten and Hammond's visibility hypothesis shows, theoretically, that high MP is associated with better vision by absorbing SW energy caused by atmospheric light scatter, increasing contrast between a target and the background, as well as within the target. Wooten's calculations show that minor decreases in background luminance, which can be achieved through SW absorption by MP, result in greater detection of targets at further distances.³ They later showed empirically that increased filtration by MP improves contrast thresholds.³⁹

Numerous studies have shown that MP is correlated with VP parameters including PRT, glare disability, visual acuity, and CS (Table 1), in a way that enhances VP. Furthermore, augmentation of MP by supplementation with the macular carotenoids (L, Z and MZ) has also been observed to have positive effects on VP (Table 2).

Visual acuity (VA) measures the minimum angle of resolution, most typically measured with Snellen or LogMAR charts. VA has been shown to relate to MP levels in studies involving normal subjects.^{40,41} Additionally, interventional studies

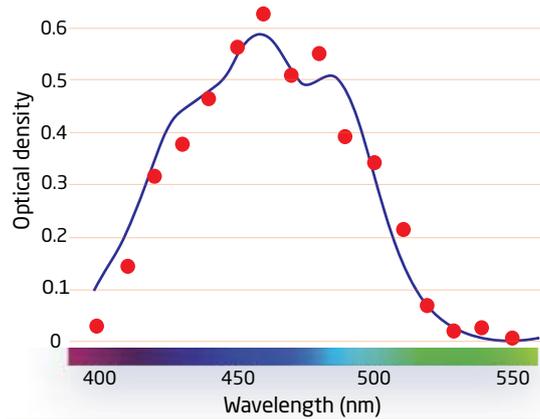


Figure 4 Spectral absorption curve of macular pigment

glare sensitivity and PRT, respectively, after supplementation with L and/or Z.^{44,47}

CS, which is a more important measure of VP than VA,⁴⁸ has been reported to correlate positively and significantly with MP.^{40,41,49,50} Furthermore, studies that have looked at MP augmentation and its effect on CS performance have reported a positive relationship between these variables.^{42,47,51-54} It is likely that these benefits are due to a decrease in CA and veiling luminance by the SW light-filtering properties of MP, as both CA and veiling luminance are caused by incoming SW light.

Research in this area is on-going, including research by our group entitled the Meso-zeaxanthin Ocular Supplementation Trials (MOST). MOST AMD is a trial that involved 67 subjects with early AMD who were supplemented with either L and Z alone, or with L, Z, and MZ. The study found that supplementation with all three of the macular carotenoids results in the greatest augmentation of MP across its spatial profile. Of interest, the supplement formulations that included MZ were associated with the greatest improvement in VP. Indeed, for subjects with early AMD, only those supplemented with a formulation containing MZ demonstrated improvements in CS at low and high spatial frequencies.

Our research group has also tested the potential of supplementing with

have shown improvements in VA for normal subjects⁴² and those with eye pathologies such as retinitis pigmentosa,⁴³ cataracts,⁴⁴ and AMD, following supplementation with the macular carotenoids.³⁴⁻³⁷

The adverse effects of glare have also been shown to be influenced by MP levels. Stringham and Hammond found, in 2007, that subjects with higher MP levels could tolerate greater amounts of glare.⁴⁵ In an interventional study, Stringham and Hammond then tested the causal relationship between MP augmentation and improvements in VP under conditions of glare. They found that an increase in MP following supplementation with L and Z significantly reduced the adverse effects of glare on VP, including PRT and glare disability.¹⁷ Stringham *et al* later determined that higher MP accounted for nearly 32 per cent of variability in disability glare thresholds.⁴⁶ Studies involving patients with cataracts and AMD have also reported improvements in



TABLE 2
Interventional studies

Principal author	Journal	Year	n	Intervention	Duration of study	Measurements	MPOD increase (density units)	Outcomes correlated with supplementation
Healthy eyes								
Kvansaku J ⁵²	<i>Ophthalm Physiol Opt</i>	2006	34	10/20mg L and/or Z/day	12 months	CS, LS, WA, MPOD	Not given	Reduced LS and CS, downward trend in WA
Wenzel AJ ⁵⁷	<i>Vis Res</i>	2006	4	30mg L + 2.7mg Z/day	12 weeks	MPOD, PLT	0.07	PLT positively related to MPOD
Stringham JM ¹⁷	<i>Optom Vis Sci</i>	2008	40	10mg L + 2mg Z/day	6 months	MPOD, GD, PRT	0.16	Reduced GD and PRT
Ma L ⁴²	<i>B J Nutrition</i>	2009	37	6 mg L/day 12mg L/day Placebo	12 weeks	Serum L, VA, CS	N/A	Increase CS and VA
Nolan JM ⁴¹	<i>Vis Res</i>	2011	121	12mg L + 1mg Z/day Placebo	12 months	MPOD, mesopic and photopic CS, GD	0.11	Increased CS, reduced GD
Eye pathologies								
Dagnelie G ⁴³	<i>Optometry</i>	2000	16 RP	40mg L/day followed by 20mg L/day	4 months	VA, CVF	N/A	Improved VA and CVF
Olmedilla B ⁴⁴	<i>Nutrition</i>	2003	17 Cataracts	15mg L/3x/week	24 months	Serum L, VA, GS	N/A	Improved VA and GS
Richer SP ⁵¹	<i>Optometry</i>	2004	90 AMD	10mg L/day 10mg L + antioxidants + vitamins + minerals/day	12 months	MPOD, VA, CS	L: 0.09 L+: 0.08	Improved VA and CS
Bahrami H ⁵³	<i>BMC Ophthalm</i>	2006	34 RP	10mg L/day followed by 30mg L/day	48 weeks	VA, CS, CVF	N/A	Improved VA and CVF
Cangemi FE ⁵⁸	<i>BMC Ophthalm</i>	2007	37 AMD	8mg L + 400mcg Z + vitamins + minerals/6x/day	6 months	BCVA	N/A	Improved VA
Richer SP ⁴⁷	<i>Optometry</i>	2011	60 AMD	8mg Z/day 8mg Z + 9mg L/day 9mg L/day	12 months	MPOD, VA, CS, Glare recovery	Z: 0.13 Z+L: 0.20 L: 0.18	Improved VA, CS, glare recovery
Sasamoto Y ⁵⁴	<i>Graefes Arch Clin Exp Ophthalm</i>	2011	43 AMD	6mg L/day	12 months	MPOD, CS	0.08	Increased CS
Weigert G ⁵⁹	<i>IOVS</i>	2011	126 AMD	20mg L/day followed by 10mg L/day	6 months	MPOD, MDLT, VA	0.08	Increased MDLT and VA

Abbreviations: MPOD = macular pigment optical density, CFF= critical flicker fusion, PRT = photostress recovery time, CS = contrast sensitivity, DG = disability glare, LS = light sensitivity, WA = wavefront aberration, VA = visual acuity, GS = glare sensitivity, MDLT = mean differential light threshold, N/A= not applicable (these studies did not measure MPOD)

all three carotenoids in young normal subjects (MOST Vision). In brief, and consistent with above, those supplemented with all three macular carotenoids (including MZ), observed a rapid and statistically significant augmentation of MP, as well as an improvement in best-corrected VA (BCVA), CS, and glare disability, whereas those supplemented with L and Z (but not MZ) did not demonstrate

significant augmentation in MP or improvements in VP.

Furthermore, in a recent publication by our group, we report that subjects with an atypical central dip in their MP spatial profiles can correct the dip only with supplementation that includes MZ. Therefore, in order to enrich MP centrally and across its spatial profile, thereby protecting the fovea from incoming SW light, and especially

the foveola which is the most visually sensitive area of the retina, the current body of scientific research shows it is important that all three macular carotenoids (L, Z and MZ) be included in any supplement designed to optimise VP and protect the central retina from oxidative injury.

In conclusion, MP is believed to play an important role in protecting the macula against age-related conditions,



most notably AMD. However, the optical properties of MP support the rationale whereby MP actually enhances VP. This VP hypothesis is now supported by a growing body of scientific evidence. We believe, and the data shows, that MP has the potential to improve VP (such as VA and CS), and reduce visual stresses (such as glare), but only if enriched with appropriate dietary modification with all three macular carotenoids, including the pigment's central component, MZ. Enrichment of MP in this way could have important implications for those involved in vision dependent specialised activities, such as pilots, vehicle drivers, and athletes. ●

References

A list of references is available from the clinical editor: william.harvey@rbi.co.uk

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MULTIPLE-CHOICE QUESTIONS - take part at opticianonline.net

1 Which of the following colours of light scatters the most?

- A Red
- B Yellow
- C Green
- D Blue

2 How much increased defocus is there for incident blue light compared with incident green light?

- A No difference
- B 0.2D
- C 1.2D
- D 2.2D

3 What wavelength of light is absorbed by macular pigment?

- A 390-430nm
- B 430-460nm
- C 460-490nm
- D 490-525nm

4 To what degree of eccentricity from the foveola is the macular pigment level undetectable?

- A 7 degrees
- B 10 degrees
- C 15 degrees
- D Evenly spread throughout the macular region

5 Which of the following effects has been found by research?

- A There is no link between macular pigment levels and glare impact
- B There is no measurable difference in impact between the three known macular pigments
- C Visual acuity is preferable to contrast sensitivity when assessing visual performance
- D Higher macular pigment levels allow greater glare tolerance

6 Which of the following statements about meso-zeaxanthin is true?

- A It is totally of dietary origin
- B It has the same properties as zeaxanthin
- C Some research has suggested it may be derived from eating fish
- D Meso-zeaxanthin is concentrated at the parafovea

Successful participation in this module counts as one credit towards the GOC CET scheme administered by Vantage and one towards the Association of Optometrists Ireland's scheme.

The deadline for responses is November 8 2012



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