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The relationship between macular pigment and visual performance ☆

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ABSTRACT

This study was designed to assess whether macular pigment optical density (MPOD) is associated with visual performance. One hundred and forty-two young healthy subjects were recruited. Macular pigment optical density and visual performance were assessed by psychophysical tests including best corrected visual acuity (BCVA), mesopic and photopic contrast sensitivity, glare sensitivity, photostress recovery time (PRT). Measures of central visual function, including BCVA and contrast sensitivity, were positively associated with MPOD ($p < 0.05$, for all). Photostress recovery and glare sensitivity were unrelated to MPOD ($p > 0.05$). A longitudinal, placebo-controlled and randomized supplementation trial will be required to ascertain whether augmentation of MPOD can influence visual performance.

1. Introduction

The macula is a specialized part of the retina and is responsible for high spatial resolution and color vision (Hirsch & Curcio, 1989). The carotenoids lutein (L), zeaxanthin (Z) and *meso*-zeaxanthin (*meso*-Z) accumulate at the macula where they are collectively referred to as macular pigment (MP). (Bone, Landrum, Hime, Cains, & Zamor, 1993) L and Z are of dietary origin, whereas *meso*-Z is not normally found in a conventional diet, and is generated at the retina following L isomerization (Bone et al., 1993; Neuringer, Sandstrom, Johnson, & Snodderly, 2004).

Age-related macular degeneration (AMD) is a disease of the macula and results in the loss of central and color vision. AMD is the most common cause of blindness in the elderly population in the developed world (Congdon et al., 2004). It is now understood that oxidative stress (Beatty, Koh, Henson, & Boulton, 2000; Winkler, Boulton, Gottsch, & Sternberg, 1999), exacerbated in part by cumulative short-wavelength visible light exposure (Algvere, Marshall, & Seregard, 2006; Fletcher et al., 2008), is important in the aetiopathogenesis of AMD. MP is a short-wavelength (blue) light filter (Bone, Landrum, & Cains, 1992) and a powerful antioxidant (Khachik, Bernstein, & Garland, 1997), and is therefore believed to protect against AMD. This hypothesis, referred to as the "protective" hypothesis of MP, has been studied and reported on extensively (Loane, Kelliher, Beatty, & Nolan, 2008).

Beyond its "protective" hypothesis, MP's optical and anatomic properties have prompted the "optical" hypotheses of this pigment. The "optical" hypotheses of MP were originally discussed by Reading and Weale (1974) and later by Nussbaum, Pruett, & Delori (1981) and include MP's putative ability to enhance visual performance and/or comfort by attenuation of the effects of chromatic aberration and light scatter, via its light-filtering properties (Walls & Judd, 1933).

Several studies have evaluated, and reported on, the role of MP in various aspects of visual performance including visual acuity, contrast sensitivity, glare sensitivity, photostress recovery, critical flicker fusion frequency (CFF), and color vision, among others (Bartlett & Eperjesi, 2008; Engles, Wooten, & Hammond, 2007; Hammond & Wooten, 2005; Kvansakul et al., 2006; Rodriguez-Carmona et al., 2006; Stringham, Fuld, & Wenzel, 2004; Stringham & Hammond, 2007; Stringham & Hammond, 2008; Wooten & Hammond, 2002). However, the findings from these studies are inconsistent, which might be explained, at least in part, by methodological differences between studies.

In this manuscript, we present baseline data from the Collaborative Optical Macular Pigment ASsessment Study (COMPASS), and as such represents a cross-sectional evaluation of the relationship between MP optical density (MPOD) and visual performance and comfort across a broad and refined range of functional tests.

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2. Methods

2.1. Subjects

One hundred and forty-two healthy subjects volunteered to participate in this study, which was approved by the research ethics committees at both Waterford Institute of Technology (WIT) and Dublin Institute of Technology (DIT). Informed consent was obtained from each volunteer, and the experimental procedures adhered to the tenets of the Declaration of Helsinki.

The study was conducted at WIT and DIT vision science laboratories, located in the southeast and east of the Republic of Ireland, respectively. Self-selected recruitment of subjects (WIT: $n = 61$ and DIT: $n = 81$) was facilitated by poster and newsletter advertisement, and also by word of mouth, in the respective local communities. All subjects were aged between 18 and 41 years, in perfect general (self report) and ocular health, and with visual acuity of at least 20/30 in the study eye. A typical study visit lasted approximately four hours. Those aspects of visual performance assessed, and their sequence, are presented in Table 1.

All subjects recruited into the study could be classed as naïve observers to the tests carried out (with the exception of the visual acuity test, with which all subjects were familiar). To optimize performance, and also to minimize any potential learning effects on performance, all subjects underwent a defined period of pre-test training. This training consisted of careful explanation of the nature of each test, pictorial and/or video demonstration of the test requirements and procedure, and was followed by a defined session of pre-test practice.

2.2. Demographic, medical history, lifestyle and vision case history questionnaires

The following details were recorded for each volunteer by questionnaire: demographics; general health status; smoking habits (never, current or past); alcohol consumption (average unit weekly intake); exercise (minutes per week); body mass index (BMI, kg/m^2); blood pressure; ethnicity; marital status; education; occupation.

Vision case history included: time since last eye examination; spectacles or contact lens use; history of ocular treatment or surgery; history of occlusion therapy or visual training in childhood; family history of eye disease; current problems with vision; asthenopia associated with computer use; history of headaches.

Table 1
Parameters assessed and their sequence for a typical study visit.

Description	Time (min)
Information leaflet discussion and informed consent	10
Collection of blood for serum carotenoid analysis	10
Demographic, medical history, lifestyle and vision case history questionnaires	20
Spectacle refraction, visual acuity, and ocular dominance	25
Color vision	20
Glare sensitivity	10
Visual function questionnaire	10
Contrast sensitivity	25
Break	~30
Macular pigment optical density spatial profile	30
Dietary questionnaire	30
Short wavelength automated perimetry	15
Photostress recovery	15
Fundus and iris photography	10
Total time	260

2.3. Spectacle refraction, visual acuity, and ocular dominance

Each subject underwent precise spectacle refraction by an experienced optometrist to determine refractive error and best corrected visual acuity (BCVA) for each eye. A computer generated LogMAR test chart (Test Chart 2000 Pro; Thomson Software Solutions) was used to determine BCVA at a viewing distance of 4 m, using a Sloan ETDRS letterset. BCVA was determined as the average of three measurements, with letter and line changes facilitated by the software pseudo-randomization feature. Best corrected visual acuity was recorded using a letter-scoring visual acuity rating, with 20/20 visual acuity assigned a value of 100. Best corrected visual acuity was scored relative to this value, with each letter correctly identified assigned a nominal value of one, so that, for example, a BCVA of 20/20^{+1} equated to a score of 101, and 20/20^{-1} to 99. The study eye was selected on the basis of ocular dominance, determined using the Miles Test (Roth, Lora, & Heilman, 2002) with the dominant eye chosen as the study eye, except in cases of observed equidominance, in which case the right eye was selected. All subsequent tests were conducted with the subject's optimal subjective refraction in place.

2.4. Glare sensitivity

Glare sensitivity was assessed using a Functional Vision Analyzer (Hohberger, Laemmer, Adler, Juenemann, & Horn, 2007) (Stereo Optical Co., Inc., Chicago, IL) using the Functional Acuity Contrast Test (FACT) Hitchcock, Dick, & Krieg, 2004; Terzi, Buhren, Wesemann, & Kohnen, 2005) and a customized inbuilt glare source. The test comprised linear, vertically oriented, sine wave gratings presented at five different spatial frequencies including 1.5, 3, 6, 12 and 18 cycles per degree (cpd). Nine circular patches were presented at each spatial frequency, the contrast of each patch decreasing by 0.15 log units from the previous. Gratings were tilted −15°, 0° or +15° with respect to the vertical, to keep them within the orientation bandwidth of the visual channel. The background was tapered into a grey field in order to keep retinal illumination constant and avoid ghost imaging. Baseline contrast sensitivity was determined on the basis of the lowest contrast compatible with accurate determination of patch orientation across all five spatial frequencies for mesopic (3 cd m^{-2}) conditions, initially in the absence of a glare source. Subjects were asked to identify grating orientation, starting with the patch at highest contrast, and continuing until identification was no longer possible due to reducing contrast. Subjects were instructed not to guess, but to respond "don't know" if patch orientation could not be correctly identified.

Glare sensitivity was assessed using a radial glare source consisting of 12 white LED's arranged circumferentially in an oval pattern surrounding the grating charts (ranging from 4.5° to 6° from central fixation). Two customized intensity settings were used to determine the effect of different levels of glare on contrast sensitivity. Glare source settings were set at a medium intensity of 42 Lux and a higher intensity of 84 Lux. All correct responses were entered into the Eyeview software provided, and contrast sensitivity scores for no glare, medium and high glare conditions were determined for the respective spatial frequencies.

2.5. Contrast sensitivity function

A Dell Dimension 9200 computer and a Metropsis Visual Stimulus Generation device (VSG (ViSaGe S/N: 81020197), Cambridge Research Systems Ltd., Cambridge, U.K.) were used to generate and control the stimuli. The VSG provided 14-bit output resolution per phosphor. The stimuli were displayed on a 19″ ViewSonic professional series p227f color CRT flat screen monitor with a frame