USAARL Report No. 2019-07

Macular Pigment Density and Vision Related Quality of Life: Demographics

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United States Army Aeromedical Research Laboratory

Warfighter Performance Group

June 2019

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
03-06-2019	Final	

4. TITLE AND SUBTITLE

Macular Pigment Density and Vision Related Quality of Life: Demographics

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

St. Onge, Paul M.; Temme, Leonard; O'Brien, Kevin; Goosey, Raquel; Hayes, Amanda

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL 2019-07

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

10. SPONSOR/MONITOR'S ACRONYM(S)

USAARL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

USAARL 2019-07

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

Oak Ridge Institute for Science and Education

14. ABSTRACT

Macular pigment (MP) is a distinctive yellow region in the human retina that protects the photoreceptors from blue light. A robust literature shows that vision and visual performance my benefit from increased levels of MP thereby increasing the optical density to blue light. The literature also reports huge individual differences in MPOD, explained at least in part by dietary preferences since the MP is comprised of carotenoids derived from nutrition. Thus, many people with low MPOD can improve their vision by increasing their MPOD with the increased consumption of dietary carotenoids, for example by eating more leafy greens or taking dietary supplements. The purpose of the present study is to assess the distribution statistics of MPOD in samples of military and civilian volunteers in the local area around Fort Rucker, AL to determine whether there is room for improvement in the MPOD as compared to values reported in the literature. The MPOD was measured in samples of 32 military pilots, 60 non-pilot military, and 59 civilians, along with demographic, dietary, and eyehealth questionnaires.

15. SUBJECT TERMS

retina, macular pigment optical density, MPOD, military personnel, aviators, pilots, nutrition, demographics, vision vision performance, eye health.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine St. Onge, PhD
UNCLAS	UNCLAS	UNCLAS	SAR	37	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

14. Abstract (continued)
The most important finding is that the MPOD does not differ statistically between military pilots (MPOD mean, standard deviation = 0.455, 0.144), military non-pilots (0.485, 0.235), and civilians (0.427, 0.173). Moreover, these means tend to be below the means the literature reports for samples drawn from the general population. These results strongly support the possibility that diet can increase the average MPOD in the sampled populations with concomitant improvements likely in vision and visual performance.

Acknowledgements

The authors would like to express their sincere gratitude to the following people for their contributions to this project:

- Thanks to the research volunteers, Mel for recruiting, Jill and Steph for administrative details, Tom Harding for overall project support, and Jessica for editing, Vicky for routing…

This research was supported in part by an appointment to the Postgraduate Research Program at the U.S. Army Aeromedical Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army Medical Research and Materiel Command.

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Introduction

Macular pigment (MP) is a distinctive yellow region in the human retina that filters blue light. Wald (1945) showed that the MP is composed of xanthophyll carotenoids that were identified as lutein (L) and zeaxanthin (Z) (Krinsky, Landrum, & Bone, 2003). The carotenoids are not synthesized in the body but are obtained from diet (Kvansakul, et al., 2006). Of the 35 or so carotenoids present in the serum, ocular tissue aggregates only L and Z. These typically accumulate with sufficient concentration in the inner layers of the foveal retina to form a normal, optically dense, macroscopic retinal landmark, the macula lutea (Snodderly, Auran, & Delori, 1984; Snodderly, Brown, Delori, & Auran, 1984). Although the spectral characteristics of the MP are a constant, set by the chemical structure of L and Z, the MP optical density (MPOD) depends on the amount of the MP accumulated in the macula. An MPOD, measured in log units, valued between 0.0 and 0.21 is considered low, between 0.22 and 0.49 is moderate, and 0.50 and above is high. At 460 nm, the wavelength of the MP's maximum spectral absorption (see Figure 1), the MPOD range between individuals extends from a low of about 0.0 MPOD, which permits essentially 100% of incidental light to reach the photoreceptors, to a high of about 1.5 MPOD, which permits about 3.0% of the light to reach the photoreceptors. In a sample of 280 mid-western Americans, average MPOD was 0.211 (*SD* = 0.130) (Ciulla, et al., 2001). College students are well represented in the MP literature and typically have peak averages around 0.5 MPOD with ranges between 0.0 and 1.0; for example, Hammond, Fletcher, and Elliot (2013) reported a peak average of 0.54 (*SD*=0.03) MPOD and a range of 0.0 to 1.04 MPOD for a sample of healthy American college-aged students. Similar values, report peak averages between 0.49 and 0.51 MPOD, for healthy Irish subjects (Nolan, et al., 2011).

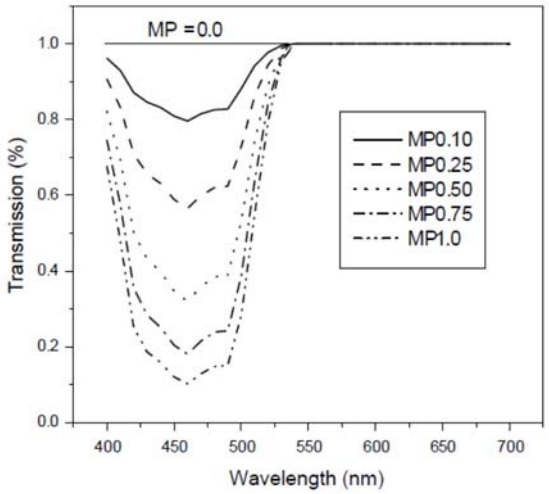

Figure 1. The percent transmission of the MP as a function of the wavelength of light through the visible spectrum. The parameter variable is MPOD (from Wooten & Hammond, 2002)

Factors Impacting Macular Pigment Optical Density

The human body obtains MP carotenoids L and Z from dietary sources alone. Leafy,

green vegetables such as kale, spinach, and mustard greens are key sources (Figure 2). Since the human body absorbed MP rather than synthesizing it, the absolute amount of MP varies between people based on a number of factors (Ciulla et al., 2001; Hammond & Caruso-Avery, 2000; Nebeling, Forman, Graubard, & Snyder, 1997). Given that food availability, preferences, and selection among individuals varies drastically, it is not surprising that the MP levels are substantially different between people. For example, individuals who regularly consume mustard greens and collard greens on average consume twice as much lutein (about 3 mg/day) as those who do not (1-2 mg/day) (Marse-Perlman, et al., 2001; Whitehead, Mares, & Danis, 2006). Additionally, food preparation impacts the available L and Z. For example, L is better absorbed when consumed with fat than with carbohydrates and proteins alone (Whitehead et al., 2006).

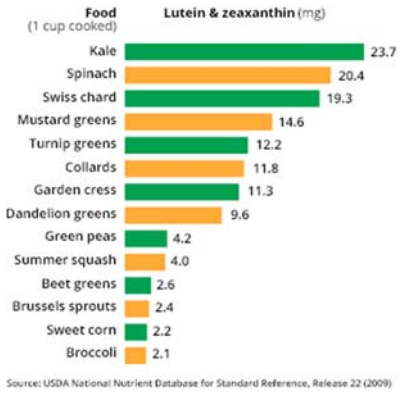

Figure 2. The available carotenoids lutein and zeaxanthin in 1 cup of cooked vegetables.

In addition to diet, MPOD is influenced by the efficiency with which individuals absorb, transport, and deposit carotenoids throughout the body (Whitehead et al., 2006). A few early studies (Broekmans, et al., 2002; Hammond, et al., 1996) reported gender differences; but when the analyses included percent body fat composition, the gender differences disappeared and total body fat was found to be inversely related to MPOD (Broekmans et al., 2002; Ciulla et al., 2001; Wooten & Hammond, 2002). Iris color seems correlated to MPOD; those with dark irises tend to have greater MPOD than those with blue or gray irises (Hammond, Fuld, & Snodderly, 1996). Cigarette smoking is associated with reduced MPOD (Hammond, Wooten, & Snodderly, 1996). On the other hand, the relation between age and MPOD is more complicated. Berendschot and van Norren (2005) found evidence that the spatial distribution of MPOD within the eye varies with age. However, the relation between age and MPOD appears in some studies (Hammond & Caruso-Avery, 2000) but not others (Iannaccone, et al., 2007), suggesting that the effect of age on MPOD is likely either weak or that age is related to other variables that might influence MP, such as body composition. It is also possible that age-related changes in the retinal distribution of MP introduce measurement artifacts by altering peripheral measurement points usually assumed to have negligible levels of MP.

Individual differences in MPOD are directly attributable to nutrition, percent body fat,

iris color, smoking status, and maybe age, but apparently not gender. Soldier nutrition and regular physical activity (Moran, et al., 2017; Munch, Linneberg, & Larsen, 2013; Rock, et al., 2002) coupled with MEDCOM's efforts to curb tobacco use could result in MPOD levels higher than the general population.

Macular Pigment Importance in Vision

Unlike photoreceptor pigments, the MP is a passive filter that does not produce neural responses to light; consequently, the MP historically seemed of secondary importance for vision, possibly more of a nuisance than an opportunity for research. However, over the past 15 years, a number of ways the MP might be important for human vision have been theorized and supported by empirical evidence. The possible MP influences on vision include: (a) chromatic aberration, (b) atmospheric visibility, (c) vision function, (d) protective hypotheses, and (e) retinal health (Krinsky et al., 2003; Wooten & Hammond, 2002).

Chromatic Aberration.

The basis for this idea is the observation that the MP absorbs light in the short wavelength (SW) region of the visible spectrum, from about 400 nm to 530 nm. This spectral range is important since, under normal viewing conditions, the eye is subject to substantial chromatic aberrations, mostly in the SW end of the spectrum. Chromatic aberration occurs because the eye has different refractive indices for the different wavelengths of white light, making it impossible to focus all the visible wavelengths to a single point on the retina. The chromatic aberration of the human eye is such that when correctly focused for distance vision, the eye is essentially 1.2 diopters nearsighted for 460-nm light. Consequently, the focused image is not really crisp but smeared with chromatic fringes, resulting from the longitudinal and lateral chromatic aberrations (Autrusseau, Thibos, & Shevell, 2011; Cheney, Thibos, & Bradley, 2015; Thibos, Bradley, Still, Zhang, & Howarth, 1990). The MP could reduce such chromatic aberrations by filtering out the SW portion of the white light spectrum, essentially enhancing vision by preventing such poorly focused light from reaching the photoreceptors in the first place. This function of the MP, originally proposed by Schultz in his original 1866 description of the macula lutea, suggests important but yet-to-be-answered questions about visual processes and functions; such as, for example, the relative contribution of SW cones to such visual functions as acuity, contrast sensitivity, and object identification and recognition (Landrum, Bone, Neuringer, & Cao, 2013).

Atmospheric Visibility.

The role of MP affecting visibility through the atmosphere is described well by Wooten and Hammond (2002) and is closely related to the chromatic aberration function described above. However, while the chromatic aberration function emphasizes the impact of visual physiological optics (i.e., optics within the eye), the visibility hypothesis emphasizes vision through the atmosphere. For this situation, visibility is defined as the "…clearness with which objects in the atmosphere stand out from their surroundings," a definition adopted from

Middleton (1952). The fundamental point is that the way light is scattered through the atmosphere is dependent on the wavelength of the light and the size of the atmospheric particles scattering the light. Accordingly, for particles whose size is about a tenth of the wavelength of light (λ), Rayleigh scatter applies, as described by the equation:

$$\beta_{sc} = {}^{c}/_{\lambda^4}$$

in which β_{sc} is the amount of scatter, c is a constant, and λ is the wavelength. Thus, theoretically, under relevant conditions, which include the visible spectrum and particles of the appropriate size, scatter is inversely proportional to the fourth power of wavelength. In practice, the exponent of λ is typically in the range of 1.5 (Wooten & Hammond, 2002). Nonetheless, since β_{sc} remains inversely proportional to λ, the more short wavelength light, the more atmospheric light scatter. Hence, the atmospheric light scatter between an eye and target can reduce the apparent contrast of the target at the eye; the greater the eye-target distance, the greater the reduction in apparent contrast. Therefore, by selectively decreasing the amount of short wavelength light, the amount of atmospheric scatter can be decreased, thereby enhancing the apparent contrast between the target and the background, which in turn enhances target visibility.

Using these relationships, and with reasonable assumptions about the known contrast sensitivities of the eye, the distances and sizes of targets, and their spectral composition, Wooten and Hammond (2002) estimated the relationship between MPOD and the relative distance at which a target can be detected. Based on their calculations, an increase in the MPOD from 0 to 0.5 can produce an 18.6% increase in the distance at which an arbitrarily large target can be detected. They conclude that "…reasonable assumptions of values for atmospheric conditions, observer sensitivity, and target parameters clearly lead to the conclusion that physiologically realistic values of MP could significantly increase visual range" (Wooten & Hammond, 2002). These conclusions completely corroborate earlier work by Marsh, Cushman, and Temme (1991) who calculated the effects spectral filters had on the visibility of arbitrarily large targets viewed through the atmosphere. These investigators predicted the effectiveness of spectral filtering to enhance the contrast of targets, thereby extending target detection distances. The difference between the work of the two groups is that Wooten and Hammond (2002) modeled the effect of the MP as the spectral filter inside the eye, whereas Marsh et al. (1991) modeled the effect of spectral filters outside the eye. The MP, as an internal natural filter, provides a number of advantages over externally worn filters. Macular pigment improves contrast sensitivity by reducing only the wavelengths that scatter the most within the eye and that contribute to glare in the regions of the retina most responsible for resolving fine detail. MP functions completely independently of head or eye orientation because of its fixed position immediately anterior to the fovea, and remains with the individual continuously, allowing the neurologic components of the visual system to re-normalize and thus retain maximum visual detail as well as spectral adaptation to preserve apparent color.

Vision Function.

A third function of the MP is based on the visual consequence of its spectral filter characteristics. A key to understanding the visual effects of the MP is to consider it in the context of evolution; thus the MP must have provided some ecologically important visual advantages. As Gordon Walls conjectured in his classic 1942 textbook, *The Vertebrate Eye and Its Adaptive Radiation*, "[b]y cutting out the different amounts of blue in different but alike-looking green mixtures, the greens can be made to look unlike; and almost any other contrasts can be sacrificed by the animal if only those between green, so numerous in nature, can be enhanced (Walls, 1942)."

Several psychophysical studies have demonstrated that the increased MPOD is associated with enhanced vision (Loughman, et al., 2010; Renzi & Hammond, 2010; Stringham & Hammond, 2008; Wooten & Hammond, 2002). Stringham et al. (2015) found that subjects with increased MPOD had significantly improved contrast sensitivity at mesopic, low ambient, star light levels, and this finding was weighted with regards to acuity demands of the task. Higher acuity visual targets were more difficult to detect for those with low MPOD. Operationally, this is important to night and night vision goggle (NVG) operations where the light output of the NVG is typically within the mesopic to low photopic luminance range. The authors' findings are highly relevant in terms of degraded visual environment (DVE) conditions that include low contrast and often low luminance.

The MPOD is also effective at mitigating the effects of glare, which can be defined as a difficulty seeing in the presence of a bright light, such as direct or reflected sunlight, artificial light, or the headlights of an oncoming car at night (Kalich, et al., 2009). Glare can cause discomfort and even interfere sufficiently with vision to cause a disability. The literature now provides clear evidence that MPOD is inversely proportional to the severity of disability glare; specifically, the greater the MPOD, the less the impact of disability glare (Hammond et al., 2013; Hammond, Fletcher, Roos, Wittwer, & Schalch, 2014; Stringham & Hammond, 2008). MPOD improves recovery from photostress, which is typically measured as the time required for (usually cone) vision to recover following exposure to a brief, bright flash of light. MPOD is inversely proportional to the length of time required for vision to return following the bright flash (Hammond et al., 2013; Stringham & Hammond, 2008). The photostress recovery test should be distinguished from true dark adaptation, which traces the return of visual sensitivity over time usually to include both cone and rod detection thresholds. As with glare and photostress recovery, so too with dark adaptation, the greater the MPOD, the sooner the rods recover sensitivity during dark adaptation (Patryas, Parry, Carden, Aslam, & Murray, 2014). These studies demonstrate that the effects of MP on vision go much beyond the reduction of chromatic aberration.

Several studies of relatively young healthy/normal subjects suggest that MP may play a key role in visual health through a complex interplay among optical, neurological, and physiological mechanisms of the vision system. These observations include positive

relationships between MPOD and 1) critical flicker fusion frequency (Hammond & Wooten, 2005), 2) crystalline lens transparency, cataract formation (Hammond, Wooten, & Snodderly, 1997), 3) concentration of carotenoids in the primary visual cortex (Craft, Haitema, & Garnett, 2004), and 4) pattern electroretinograms, P50 amplitudes, and better dark adapted cone sensitivities (Carboni, Forma, Mutolo, Jennings, & Iannaccone, 2010). Additionally, MPOD positively correlates with processing speed and cognitive performance in healthy elderly subjects as well as with older adults with mild cognitive impairment (Feeney, et al., 2013; Johnson, et al., 2008; Renzi, Dengler, Puente, Miller, & Hammond, 2014). Another study reported statistically significant improvements in visual processing speed in young healthy subjects considered to be at peak cognitive efficiency who had improved MPOD following supplementation (Bovier, Renzi, & Hammond, 2014).

Protective Role.

The MP may protect the foveal retina from the damaging effects of light in at least two ways. One way is that the spectral absorption characteristics of the MP effectively shields the vulnerable photoreceptors and other structures from SW light, which, as is well known, can be exceptionally damaging to the photoreceptors (Noell, 1980). The MP accumulates primarily in the Henle fiber layer, which is composed of the photoreceptor axons that course over the photoreceptors. Thus, light must pass through the Henle fiber layer in order to reach the photoreceptors, the pigment epithelium, and the choroid. Several researchers have noted that the presence of these carotenoids in the Henle fiber layer reduces the intensity of the SW light incident on the photoreceptors as well as the pigment epithelium and the choroid (Barker, et al., 2011; Johnson, Chung, Caldarella, & Snodderly, 2008; Nolan, Stringham, Beatty, & Snodderly, 2008). Thus, MP filters the actinic SW light, thereby reducing the probability of high energy light damaging these vulnerable tissue structures. L and Z can reduce the rate of radical generation by SW light and thereby reduce the chances of peroxyl radical-induced oxidative chain reactions, as first suggested by Kirschfeld (1982). Hence, L and Z in the fiber layer of Henle may have a passive antioxidant role since a dietary antioxidant may be defined as a food substance that significantly decreases the adverse effects of oxygen and other reactive species on normal physiological function (Anonymous, 2000). This passive role may be particularly important given the extraordinarily high partial pressure of retinal oxygen at the level of the photoreceptors, pigment epithelium, and choroid where partial pressure of oxygen is among the highest of all tissues in the body.

The second way the MP may provide protection is as a direct antioxidant. For a long time the carotenoids, including L and Z, have been described as natural antioxidants (Krinsky et al., 2003). *In vitro* studies have shown L and Z to be potent lipid antioxidants and as such can be expected to reduce oxidative insult over time (Stringham & Hammond, 2008). Since rod outer segments contain between 10 and 25 percent of the total retinal carotenoids, which, with the uniquely high oxygen metabolism of the rods, would be expected, if in fact, L and Z do serve a protective function as retinal antioxidants (Patryas et al., 2014; Rapp, Maple, & Choi, 2000).

Retinal Health.

A fifth function of the MP derives from evidence indicating the importance of the MP for the health of the retina, especially the fovea. This raises two points. One point addresses the incidence of retinal disease while the other concerns lessening the consequences of disease and associated symptoms. Aside from photoreceptor light damage, age-related macular degeneration (AMD) is one specific retinal pathology that has received a substantial attention in MP literature (Lima, Rosen, & Farah, 2016). In developed countries, AMD is the leading cause of irreversible blindness among individuals 65 years of age or older (Jager, Mieler, & Miller, 2008). The incidence of AMD is projected to double in the 40 years from 2010 to 2050; thus AMD is a crucial public health issue (Rein, et al., 2009). As described above, L and Z are thought to protect the macular region from photo-oxidative injury by scavenging reactive oxygen species and filtering SW light. Epidemiological studies strongly suggest that diets with high levels of L and Z are associated with decreased AMD risk and reduced visual impairment. Thus the MP seems to help preserve the health of the fovea (Snodderly, 1995).

The second point concerns lessening the consequence of AMD. Several studies have suggested that visual function of AMD patients can be improved by increasing L and Z dietary supplements. A recent meta-analysis has critically reviewed this literature and concluded that the contrast sensitivity and visual acuity of AMD patients were positively associated with MPOD, which was systematically manipulated in rigorous randomized controlled trials using L and Z supplements and placebo (Liu, Wang, & Zhang, 2015).

MP Summary

In addition to the benefits of the MP for AMD, four separate theoretical functions of the MP are listed and described above. In general, the current literature contains substantial evidence supporting each of these functions. Much of this work has been published since 2002, following the seminal paper by Wooten and Hammond. In that paper, the authors point out that, even though the MP has been studied since it was first described in 1866, the literature remained equivocal, inconsistent, and contradictory; it did not provide a clear picture of MP's importance for vision and visual performance. Wooten and Hammond had two important insights about this situation. First, the MPOD was rarely measured directly in the published studies that were trying to assess the visual importance of the MP. In other words, the important dependent variable that was the intended object of these studies was rarely measured directly. Second, the inconsistencies in the literature are not surprising since the important variable was not meaningfully measured. Following the Wooten and Hammond (2002) paper, the literature now shows clear relationships among the MP, its optical density, human vision, and visual performance.

Purpose of the Present Study

Given the importance of the MP for optimal vision, visual performance, and continued ocular health, it is important to know whether the incidence and distribution statistics of MPOD

in samples of civilian volunteers reported in the literature apply to samples of Army personnel. This information is necessary before the findings from one group can be generalized to the other. The purpose of the present research is to assess the comparability of the two groups of volunteers.

Methods

Participants

Participants were recruited with informational flyers posted in and around the Fort Rucker, AL area and through peer-to-peer word of mouth. Participants were either active-duty military or civilian volunteers of at least 19 years of age and with binocular vision.

A total of 151 volunteers participated, 86 active duty military and 65 civilians. Of the 86 military, 26 were pilots and 60 were not. Of the 65 civilians, 6 were pilots and 59 were not. The 6 civilian pilot participants were former Army Pilots currently working as pilots for the Army either as contractors or Department of the Army Civilians. Since the civilian pilots were all Army trained and continued to work for the Army, they were grouped in the military pilot category.

Procedures

When an individual prospective participant arrived at the U.S. Army Aeromedical Research Laboratory, a staff member escorted the individual to the Macular Pigment Laboratory for orientation to the study and the informed consent process. If the individual decided to participate in the study, they completed a demographic questionnaire and a self-reported subjective assessment of functional vision. Following these questionnaires, MPOD measurements were made as described below. This sequence of events took about a half hour to complete but was part of a longer data collection effort reported elsewhere.

Demographic and Functional Vision Questionnaires

The self-reported demographic information collected included gender, birth year, height, weight, eye color, military status, and, if active duty, rank, number of service years, and current military occupational specialty (MOS). The functional vision questionnaire included a self-reported use of prescription reading glasses, blurred vision up close or far away, and ratings of vision compared to one's peers. Participants also answered questions about lifestyle factors correlated with MPOD such as tobacco use and weekly servings of leafy green vegetables. The full survey is in Appendix A.

Macular Pigment Optical Density (MPOD)

The Macular Metrics II ™ densitometer (Macular Metrics II, LLC, Rehoboth, MA) was used to measure MPOD. The participant's view of the densitometer is shown in Figure 3. The densitometer is a commercially available device designed for rapid clinical assessments of MP. All MPOD reported here are from right eyes; an eye patch covered the left eye.

Figure 3. The participant's view of the MP densitometer when sitting in front of it. The black circle is the lens through which the subject would look and the white button is located immediately below the lens.

The densitometer measures the MPOD using the technique of heterochromatic flicker photometry (HFP), a standard photometric method to equate the luminance or brightness of lights with different colors. The HFP technique uses a pair of spatially superimposed flickering lights each of a different color. The relative luminance or brightness of the two lights is adjusted to minimize the apparent flicker of the alternating lights. This means that when the luminance or brightness of the two lights is equal, they do not appear to flicker at all; instead, they look like a single, steady light. The MP densitometer uses the HFP technique with a pair of lights each with a carefully selected color. One light is a blue light of about 450 nanometers (nm), which is highly absorbed by the MP. The other light is green with a wavelength of about 525 nm, which is essentially invisible to the MP; that is, the green light passes through the MP and reaches the photoreceptors without being absorbed at all.

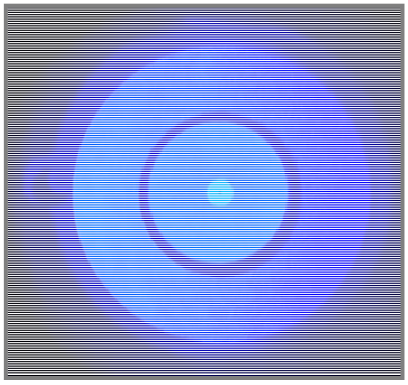

Figure 4. The participant's view of the bulls eye when looking into the lens of the MP densitometer. The small center dot is the focus point. For the central measurement point, the blue green area immediately around the focus point would flicker as the relativie luminance of the blue and green lights were slowly changed and the subject would press the button to indicate the perception of flicker.

Consider the case of an individual with a lot of MP; to equate the illuminance of the blue and green light, the individual has to use a lot more blue light to make the two lights appear

equally bright since the MP absorbs so much of the blue light. On the other hand, an individual with essentially no MP needs relatively little blue light to match the green light. This means that the MPOD determines the relative amounts of blue and green light needed to make the colors look equally bright. Consequent, the relative amounts of blue to green light needed to make the two lights look equally bright directly indicate the amount of MP in an eye, or equivalently, the MPOD. The densitometer uses this HFP principle but uses a couple of steps to bypass the between-individuals comparisons in order to increase the precision of the MPOD measurements.

Participants looked into the densitometer and focused on the central point in Figure 4. The lens of the system was focused by the individual and the subject pressed the white button when the small blue-green area around the focus point appeared to flicker. First, each individual makes the typical blue-green HFP setting at the fovea using central vision. The fovea is the part of the retina where MP is most concentrated so that this HFP measurement not only indicates the maximum amount of MP in the retina, but is also the part that underlies central vision, the most important part of what we see. For the second step, the HFP measurement is repeated in a location of the retina that is known to contain negligible amounts of MP. This is in the peripheral areas of the retina; the part that supports the peripheral visual field. By comparing these two HFP measurements made in the same eye of the same individual, the variability between people is eliminated. Thus, the difference between the matching blue-green luminance measured in the fovea relative to the matching blue-green luminance measured in the periphery is the direct measure of MPOD in the foveal area of the individual. In practice, the MPOD measurements are means of 5 or so repeated HFP measurements made at each of the two retinal locations so that each volunteer made 10 HFP settings.

Results

Descriptive demographic characteristics of the three different volunteer samples are summarized in Table 1. Since the samples were not normally distributed, statistical difference among the three samples is assessed with the Kruskal-Wallis chi-squared statistic.

Table 1. Demographic characteristics of the three volunteer samples.

	Response	Military and Civilian Pilot (*n* = 32)	Military Non-Pilot (*n* = 60)	Civilian Non-Pilot (*n* = 59)	Overall (*n* = 151)
Gender*	Male Female	29 3	46 14	13 46	88 63
Age	Mean *SD*	38.25 *12.02*	32.48 *9.92*	36.69 *13.12*	35.35 *11.87*
Height* (in)	Mean *SD*	70.75 *3.14*	68.95 *4.20*	66.34 *3.66*	68.31 *4.14*
Weight* (lbs)	Mean *SD*	198.88 *31.90*	182.00 *32.88*	165.73 *41.94*	179.28 *38.38*
Body Mass	Mean	27.80	26.81	26.34	26.84

Index	*SD*	*3.28*	*3.50*	*5.28*	*4.28*
Eye Color	Amber	0	0	0	0
	Blue	8	6	17	31
	Brown	12	45	28	85
	Gray	1	1	1	3
	Green	4	2	6	12
	Hazel	7	5	7	19
	Other	0	1	0	1
Tobacco Use	Never	19	38	42	99
	Former	8	7	9	24
	Occasional	5	7	3	15
	Frequent	0	7	4	11
	Heavy	0	1	1	2
Military Service Branch	Not Applicable	6	1	65	65
	Army	26	58	NA	85
	Air Force	0	0	NA	0
	Navy	0	0	NA	0
	Marine Corps	0	0	NA	0
	Other	0	1	NA	1
Rank	Warrant Officers	14	0	NA	14
	Enlisted	0	51	NA	51
	Commissioned Officers	12	7	NA	19
	Not Active Duty	6	0	59	65
	Other	0	2	NA	2
Years of Service	High	14.47	7.75	NA	
	Low	10.07	6.02		

* denotes statistically significant differences as evaluated by the Kruskal-Wallis chi-squared comparisons

Kruskal-Wallis chi-squared comparisons revealed an almost statistically significant difference in age among the Pilots, Military Non-Pilots, and Civilian Non-Pilots (χ^2 =5.828, p = 0.054) such that the pilot group is older than the non-pilot military who are younger than the civilians. *T*-tests between the three groups identified a statistically significant difference in age between the military pilots and non-pilots (p = 0.024). Kruskal-Wallis chi-squared comparisons of gender showed statistically significant differences between Pilots (10% female), Military Non-Pilots (23% female), and Civilian Non-Pilots (79% female) (χ^2 = 53.63, p = 2.26e-12). Body Mass Index showed no statistically significant difference among Pilots, Military Non-Pilots, and Civilian Non-Pilots (average: χ^2 = 5.050, p = 0.080) and *t*-tests between the three groups confirmed this finding. However weight showed statistically significant differences between Military and Civilian Pilots, Military Non-Pilots, and Civilian Non-Pilots (χ^2 = 21.819, p = 0.00002). Analysis with *t*-tests showed that weight was significantly different between all three groups. Similarly, there were statistically significant differences between the height of Military

and Civilian Pilots, Military Non-Pilots, and Civilian Non-Pilots ($\chi^2 = 27.313$, $p = 0.000001$). Again, *t*-tests showed that there was a significant difference in height between all three groups. Lastly, pilots had significantly longer duration of military service than did the military non-pilots ($p = 0.001$). Differences in the other tabulated characteristic such as rank, eye color, and tobacco use were not statistically evaluated.

Table 2. MPOD Means and standard deviations (SD) for the different groups of volunteers

	n	**MPOD mean *SD***	**Kruskall-Wallis chi-squared**	***p*-value**
Total	151	0.456 *0.196*	NA	NA
Military	86	0.478 *0.212*	1.716	0.190
Civilian	65	0.427 *0.169*		
Pilot	32	0.455 *0.144*	0.226	0.634
Non-Pilot	119	0.456 *0.208*		
Military and Civilian Pilot	32	0.455 *0.144*	1.563	0.458
Military Non-Pilot	60	0.485 *0.235*		
Civilian Non-Pilot	59	0.427 *0.173*		

The summary statistics and Kruskall-Wallis chi-squared comparisons of MPOD for each of the volunteer groups are summarized in Table 2. These results show no evidence for statistically significant differences in MPOD among the groups. Similarly, Figure 5 demonstrates the non-significant differences among the groups with no meaningful relationship between BMI and MPOD.

Figure 5. BMI and MPOD scatterplot

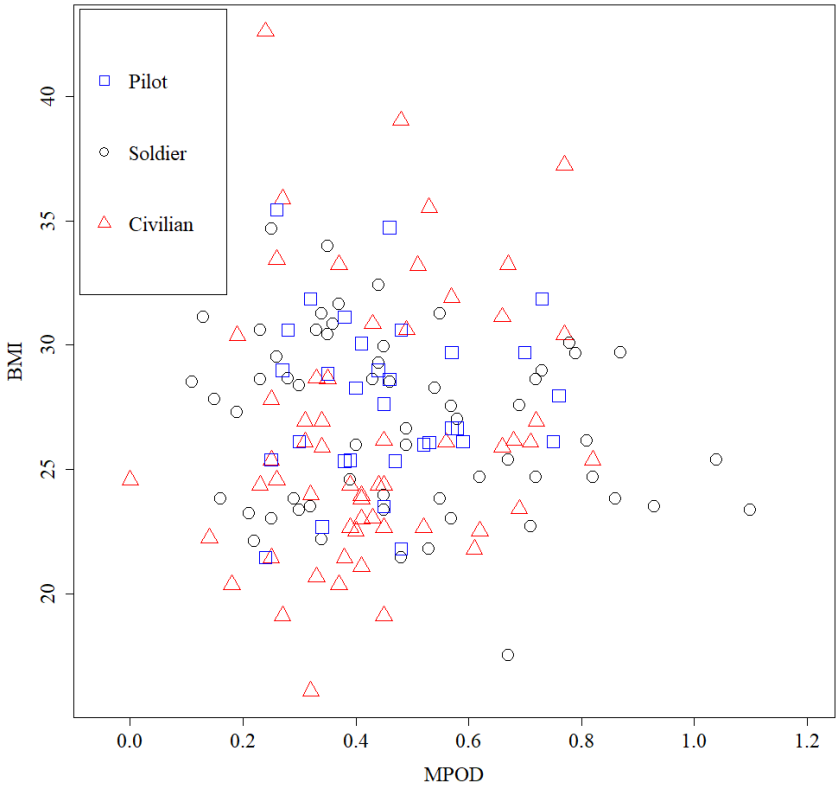

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Table 3. Functional Vision Questionnaire

Question 1. Do you currently use prescription glasses or nonprescription reading glasses ("drugstore readers") in order to see clearly and in focus at either far or near distance?

Response	Military and Civilian Pilot (*n* = 32)	Military Non-Pilot (*n* = 60)	Civilian Non-Pilot (*n* = 59)	Overall (*n* = 151)
Yes	7	26	31	69
No	24	34	28	82

Question 2. Do you experience blurred vision; either when trying to see far away or things up close?

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Yes	8	20	31	59
No	24	40	28	92

Question 3. Compared to other people of your age; would you say your overall corrected vision is

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Much worse than average	0	0	2	2
A little worse than average	0	7	4	11
About average	5	27	35	67
A little better than average	20	14	15	49
Much better than average	7	12	3	22

Question 4 How is your vision at night affected by glare of headlights from approaching vehicles?

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Not affected at all	5	11	8	24
Occasionally affected by very bright headlights	24	35	33	92

Always affected- but I have no major driving difficulty	2	13	15	30
Very affected- I have great difficulty in seeing the lane markings and/or traffic signs	1	1	3	5
Severely affected to the point that I no longer drive at night	0	0	0	0

Question 5. Do you regularly wear sunglasses or "blue-blocking" glasses to improve or enhance vision or contrast (i.e., yellow or copper-tinted glasses)?

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Yes	16	14	30	60
No	16	46	29	91

Question 6. Have you ever had intraocular surgery; vision correction surgery; or any type of intraocular laser procedure performed on one or both of your eyes?

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Yes	8	11	5	24
No	24	49	54	127

Question 7. Are you currently being treated by a physician for any vision disorder or disease that cannot be corrected by wearing glasses or contact lenses alone (e.g., dry eye disease; ocular allergy; macular degeneration; diabetic retinopathy; cataract; glaucoma; retinal detachment; etc.)?

Response	Military and Civilian Pilot	Military Non-Pilot	Civilian Non-Pilot	Overall
Yes	0	0	0	0
No	32	60	59	151

The results of the 7-item self-report questionnaire concerning eyesight are summarized Table 3. These results were mostly as expected, showing substantial difference between pilots and military non-pilots and civilians. For example, in question one, 21% of the pilots reported using glasses while twice as many in the other groups did, a significant difference ($\chi^2 = 12.947$, $p = 0.002$). Similarly, question two shows 25% of the pilots reported blurred vision whereas a

larger percentage of non-pilots, either military (33%) or civilian (52%) reported blurred vision, another significant difference ($\chi^2 = 7.936$, $p = 0.019$). It should be noted that for question three, 16% of the pilots report average or better than average vision; whereas, 57% and 69% of the military and civilians, respectively, reported average or less than average vision, a significant difference ($\chi^2 = 6.069$, $p = 0.048$). A similar trend appears in question four concerning trouble with glare during night driving; 90% of the pilots reported little to no trouble with glare; whereas, the percentages were less for military (76%) and civilians (69.5%); these differences, however, were not statistically significant ($\chi^2 = 3.806$, $p = 0.149$). Question five shows that 50% of the pilots and the civilians reported regular use of sunglasses or blue blockers; but 75% of the military population in this study indicated they do NOT use tinted lenses; a difference that is of significance ($\chi^2 = 11.117$, $p = 0.004$). Question six shows that 25% of the pilots reported a history of some form of intraocular, refractive, or other laser procedure; whereas, 18% and 8.5% of the military and civilians, respectively, report a history of such procedures; but these differences are not significant ($\chi^2 = 3.806$, $p = 0.149$). Lastly, question seven shows that the volunteers were not being treated for any kind of visual disorder or ocular disease.

Table 4. Nutritional and supplementation practices

Question 1. How many servings of green leafy vegetables do you eat during an average week?

Response	Military and Civilian Pilot	Military Non-Pilot	Non- Pilot Civilian	Overall
Mean	4.91	3.78	3.94	4.07
SD	*2.14*	*2.34*	*2.18*	*2.27*

Question 2. Do you regularly (3 or more times a week) take a vitamin and mineral supplement labeled specifically for eye health; or an adult multivitamin and mineral supplement that is labeled as being complete?

Response	Military and Civilian Pilot	Military Non-Pilot	Non- Pilot Civilian	Overall
Yes	9	13	22	44
No	23	47	37	107

Self-reported nutritional and supplementation practices are summarized in Table 4. Specifically, question one shows that pilots reported consuming more leafy green vegetables more than military or civilians, a statistically significant difference ($p = 0.022$, $p = 0.046$). There was no statistically significant difference between the green vegetable consumption of military and civilians ($p = 0.690$). Lastly, no group differences emerged for regularly supplementation use specific to eye health ($\chi^2 = 3.516$, $p = 0.173$).

Discussion

Prior to the present study, the MPOD of Army personnel was unknown. The results reported here show that the MPOD of the military volunteers (mean MPOD = 0.456, *SD* = 0.196) and the civilian control volunteers (mean = 0.478; *SD* = 0.212) are not statistically different. Furthermore, the MPOD values of Army personnel while larger than mean values of 0.211 (*SD*=0.130) reported for the sample of 280 mid-western Americans, (Ciulla, et al., 2001) is less

than the more typical values of between 0.49 and 0.51 other studies have reported, as discussed in the introduction. These results therefore suggest that carotenoid supplementation could enhance the MPOD of the military as well as the civilian populations the two samples represent. The MPOD of the two samples not differing from each other may reflect the fact that the eating habits of the two groups are not that different.

The self-reported responses to Question eight suggest that the pilots consume about one serving of leafy green vegetables more per week than do the other groups. Despite this statistically significant difference, the MPOD among the groups does not differ statistically. There may be several factors influencing this finding. For example, pilots report taking fewer nutritional supplements than do the other groups. Another possibly important difference is the substantial difference in gender rations between the pilots and military versus the civilian group. However, the literature demonstrates that BMI and adiposity, and not gender, are negatively correlated with MPOD. The difference in gender ratios, although not ideal between comparison groups, may not be the important factor influencing the non-significant differences among groups in MPOD values. Moreover, the lack of a statistical difference in body mass index is more important than the distribution of gender across the groups.

While age is not a statistically significant difference among the three groups, it is significant in the comparison between pilot and non-pilot military, a comparison that excludes the civilian sample. The nearly 6-year difference in age parallels the nearly 6-year difference in the number of years in service. Since the civilian group is predominantly female, it may not be inappropriate to speculate that many of the civilian group volunteers are spouses. Thus, the average age of the spouses would be intermediate between the older sample of pilots and the younger sample of non-pilot military. Thus these results seem consistent and not surprising.

The results to the questionnaire concerning eyesight for the most part are not surprising, for example, the relatively small number of pilots reporting the use of a prescription or non-prescription refractive correction, experience blurred vision, reported relatively poor vision, or reporting susceptibility to oncoming headlights. In retrospect, even the relatively large percentage of pilots reporting a history of intraocular surgery is not surprising as USAARL conducted the research studies that supported the regulation change to allow for such interventions in pilots. The significant difference reported between pilot and non-pilot military use of sunglasses may warrant further analysis, possibly resulting from differences between the culture of officers, comprising mostly the pilot group, and enlisted personnel, comprising mostly the non-pilot group.

Recommendations

1. Continue the data analysis to examine the relation between MPOD and the relative visual capabilities among the different samples of volunteers.

2. Initiate an evaluation of the efficacy of carotenoid supplementation for military personnel.

3. Add to the study to match gender and age between the control and experimental groups.

4. Expand the study to compare the distribution of MPOD through MOS, and determine whether MPOD is a predictor of longitudinal MOS success.

5. Expand the study to compare different services to determine whether difference in the operational missions impost service-unique MPOD requirements.

Conclusions

There is no support for the suggestion that the MPOD of Army personnel evaluated in the present study, either pilots or non-pilots, have an MPOD greater than that expected in civilian population evaluated in the present study or the larger samples of civilians reported in the literature. This finding suggests that an increased consumption of dietary carotenoids can enhance the vision of these Warfighters.

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Appendix A. Macular Pigment Survey.

1. Gender
    a. Male
    b. Female

2. Year of Birth

3. Height
    a. < 4’9”
    b. 4’9” - 4’11”
    c. 5’0” - 2’2”
    d. 5’3” - 5’5”
    e. 5’6” - 5’8”
    f. 5’9” - 5’11”
    g. 6’0” - 6’2”
    h. 6’3” - 6’5”
    i. 6’6” - 6’8”
    j. 6’9” +

4. Weight (lbs)
    a. < 90
    b. 90 - 94
    c. 95 - 99
    d. 100 - 104
    e. 105 - 109
    f. 110 - 114
    g. 115 - 119
    h. 120 - 124
    i. 125 - 129
    j. 130 - 134
    k. 135 - 139
    l. 140 - 144
    m. 145 - 149
    n. 150 - 154
    o. 155 - 159
    p. 160 - 164
    q. 165 - 169
    r. 170 - 174
    s. 175 - 179
    t. 180 - 184
    u. 185 - 189
    v. 190 - 194
    w. 195 - 199
    x. 200 - 204
    y. 205 - 209
    z. 210 - 214

aa. 215 - 219
bb. 220 - 224
cc. 225 - 229
dd. 230 - 234
ee. 235 - 239
ff. 240 - 244
gg. 245 - 249
hh. 250 - 254
ii. 255 - 259
jj. 260 - 264
kk. 265 - 279
ll. 280 - 284
mm. 285 - 289
nn. 290 - 294
oo. 295 - 299
pp. 300 +

5. Eye Color
    a. Amber
    b. Blue
    c. Brown
    d. Gray
    e. Green
    f. Hazel
    g. Other

6. Tobacco Use
    a. Never
    b. Former
    c. Occasional
    d. Frequent
    e. Heavy

7. Duty Status
    a. Not Active Duty
    b. W01
    c. W02
    d. W03
    e. WO4
    f. WO5
    g. E1-E2
    h. E3-E4
    i. E5-E6
    j. E7-E8
    k. E9-E10
    l. 01-02
    m. 03-04
    n. 05-06

o. 07-08
p. 09-010
q. Other

8. If Active Duty, which service (including Guard and Reserve)
    a. Not Applicable
    b. Army
    c. Air Force
    d. Navy
    e. Marine Corps
    f. Other

9. Years in Military
    a. 0 - 4
    b. 5 - 9
    c. 10 - 14
    d. 15 - 19
    e. 20 - 24
    f. 25 - 29
    g. 30 - 34
    h. 35 +

10. Current MOS

11. Do you use prescription glasses or nonprescription reading glasses ("drugstore readers") in order to see clearly and in focus at either far or near distance?
    a. Yes
    b. No

12. Do you experience blurred vision, either when trying to see far away or things up close?
    a. Yes
    b. No

13. Compared to other people of your age, would you say your overall corrected vision is:
    a. Much worse than average
    b. A little worse than average
    c. About average
    d. A little better than average
    e. Much better than average

14. How is your vision at night affected by the glare of headlights from approaching vehicles?
    a. Not affected at all
    b. Occasionally affected by very bright headlights
    c. Always affected - but I have no major difficulty driving
    d. Very affected – I have great difficulty in seeing the lane markings and/or traffic signs
    e. Severely affected to the point that I no longer drive at night

15. Do you regularly wear sunglasses or “blue-blocking” glasses to improve or enhance vision or contrast (i.e. yellow or copper-tinted glasses)?
    a. Yes
    b. No

16. Have you ever had intraocular surgery, vision correction surgery, or any type of intraocular laser procedure performed on one or both of your eyes?
    a. Yes
    b. No

17. Are you currently being treated by a physician for any vision disorder or disease that cannot be corrected by wearing glasses or contact lenses alone (i.e. dry eye disease, ocular allergy, macular degeneration, diabetic retinopathy, cataract, glaucoma, retinal detachment, etc.)?
    a. Yes
    b. No

18. How many servings of leafy green vegetables do you eat during an average week?
    a. 0 to 2 servings
    b. 3 to 4 servings
    c. 5 to 6 servings
    d. 7 to 8 servings
    e. 9 or more servings

19. Do you regularly (3 or more times a week) take a vitamin and mineral supplement labeled specifically for eye health, or an adult multivitamin and mineral supplement that is labeled as being complete?
    a. Yes
    b. No

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