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Macular Re-pigmentation Enhances Driving Vision in Elderly Adult Males with Macular Degeneration

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Background: The risk of injury or fatality (driver, passenger or pedestrian) associated with motor vehicle accidents has been determined to increase with age, as a result of age-related declines in vision, motor and cognitive functioning. Elderly drivers with age related macular degeneration are particularly vulnerable to sensory visual impairment when driving at night, as they suffer declines in both Contrast sensitivity (CS) and Glare recovery (GR).

Objective: This study evaluates the relationship between carotenoid supplementation, CS and GR and the relationship between driving ability and retinal macular pigmentation.

Methods: Self-described driving performance is the basis of this report, with data derived from the Zeaxanthin and Vision Function (ZVF) Study (FDA IND #78,973), a 1 year, n=60, 4 visit, prospective randomized controlled clinical trial (RCT) of predominantly elderly male veterans (74.9 SD 10 y) with mild / moderate Age related Macular Degeneration (AMD). The twenty five question - National Eye Institute Visual Functioning Questionnaire (VFQ-25) v. January 2000, Rand Corporation® includes 3 questions assessing driving performance and were completed at baseline and 1 year after nutritional supplementation with approximately equal daily doses of the retinal macular carotenoids: lutein (9 mg) or zeaxanthin (8 mg). Replicate measures of foveal 1 degree estimated retinal macular pigment optical density were evaluated with the QuantifEye® (ZeaVision, Chesterfield, MO) heterochromatic flicker photometer.

Results: VFQ25 self-described driving ability was notably associated with baseline pre-supplementation macular pigmentation. Linear regression modeling suggests that self-described ability to safely drive a car was strongly associated with final macular re-pigmentation post supplementation ($P=0.02$). Moreover, the greatest effect was found with zeaxanthin (ns but $P = 0.057$ for trend) even though lutein had greater effects than zeaxanthin with respect to CS and GR, suggesting that unique zeaxanthin post-receptorial processes may be at play.

Discussion: Carotenoid supplementation and subsequent macular repigmentation improved the self-described driving ability of patients with macular degeneration. Older male drivers with AMD should be encouraged to have their foveal macular MP measured at yearly eye examinations. If low macular pigment is found, these patients should attempt macular re-pigmentation via diet and/or supplementation to improve the sensory aspect of driving.

Keywords: Driving vision; Age related macular degeneration; Macular pigment; Carotenoids

Introduction

As of 2009, there were almost 39 million drivers aged 65 and older in the United States [1]. While driving enables an aging population to remain active and autonomous, motor vehicle accident is one of the leading causes of death for the elderly [2]. The risk of injury or fatality associated with motor vehicle accidents has been determined to increase with age as a result of age-related decline in vision [3,4], motor and cognitive functioning [5,6]. Elderly drivers with Age related Macular Degeneration (AMD), a leading cause of vision loss in patients of European ancestry in the Western world, are particularly vulnerable to sensory visual impairment when driving at night, as they suffer declines in both CS [7,8], and GR [9,10].

It is clear that the pathogenesis of AMD is amenable to environmental nutritional modification [11-14]. The yellow pigment of the human fovea is largely composed of the dietary carotenoids, specifically lutein and zeaxanthin, collectively termed Macular Pigment (MP). They are selectively accumulated in the retina at a concentration between 1000x and 10,000x greater than that in the blood serum [15]. Dietary carotenoids have been determined to protect the human lens

against cataract through their antioxidant function and play a crucial pre-photoreceptor protective role through absorption of short-wavelength light (400-500nm) [16]. More recently, MP has been found to be intimately involved in pre-receptorial receptor (rods / cones) and post-receptor-neural-cognitive function [17].

MP naturally declines with age and increasingly so in patients with AMD [18]. Denser MP improves dark and light sensitivity, which is especially useful for drivers driving in and out of tunnels. Accordingly, an increase in MP has been associated with an increase in CS [19].

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Enhanced MP translates to lessened glare disability and better GR as well [20]. The clinical importance of MP in retinal health and disease is summarized in a recent consensus paper [21]. In the present paper, we examine the role of MP in elderly (primarily male) drivers, with retinal degeneration.

Methods

The Zeaxanthin and Vision Function Study was a 1 year, n = 60, 4 visit, prospective randomized controlled clinical trial of patients (74.9 SD 10 y) with mild / moderate AMD (FDA IND #78,973). 22 Patients were randomly assigned to one of 2 dietary supplement carotenoid pigment intervention groups: 8mg zeaxanthin (n=25) & 8 mg zeaxanthin + 9 mg lutein (n=25) or to a 9 mg lutein (faux – placebo – control group, n=10). The National Eye Institute Visual Functioning Questionnaire score (NEI VFQ-25) is a validated instrument employed to assess the patient's vision-related quality of life and was used as an additional secondary outcome measure in ZVF [22]. The 25 question version 2000, self-administered format, January 2000, Rand Corporation® was utilized, specifically the 3 questions that address driving performance (Appendix 1) [23].

Statistics

Baseline within treatment group differences was assessed with one-way ANOVA assessing the equal variance assumption using Bartlett's test. Post-Hoc differences were assessed using Scheffe's test. Within group differences were assessed using a two-sample t test with equal variances. Multivariate linear regression models were built with candidate variables selected ($P < 0.05$). All calculations were made using STATA 10.1 (College Station, TX, USA) software.

Macular Pigment (MP)

Replicate measures of foveal 1 degree estimated MP were evaluated with the Quantify® MPS 9000 macular pigment screener, a modified Heterochromic Flicker Photometer (HFP). Estimated foveal MP (without an eccentric reference) was chosen for the ZVF study population because a substantial number of elderly subjects had concurrent cataracts (more so than in our first RCT study of lutein, called LAST), introducing additional variability, in addition to fatigue and uncertainty. Central only foveal readings have been found to be statistically representative of the degree of macular pigmentation of the retina [22].

Contrast Sensitivity (CS)

The area under the curve of the resulting CS function at 5 spatial frequencies was measured with The Vision Function Analyzer® (Stereo Optical, Chicago, IL) with best refraction. The CS function is a measure of how an eye sees large objects (low spatial frequencies @ 1.5 and 3 cycles / degree) as well as small objects such as Snellen letters (higher spatial frequencies i.e. 18 cycles / degree) – x axis, at differing contrasts – y axis [24].

Glare Recovery (GR)

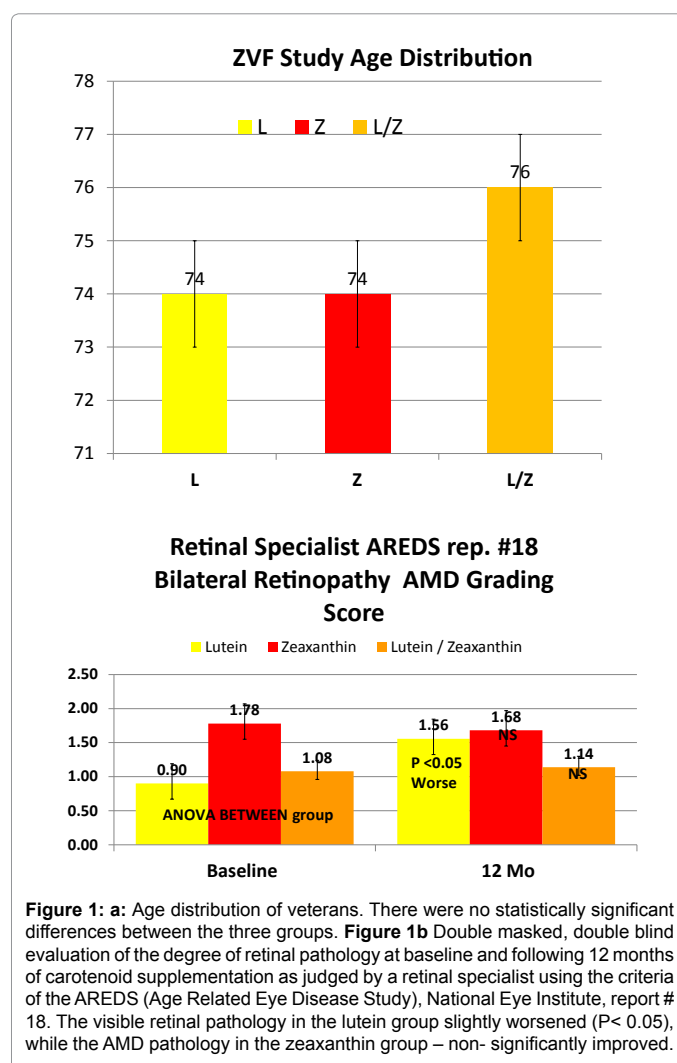
Glare photo-stress recovery (in seconds) following 30 seconds of continuous retinal bleach, was assessed using 2 line supra-threshold low contrast randomly presented Landolt Cs using the KOWA AS14B Night Vision Tester (KOWA Optimed, Tokyo, Japan).

Results

ZVF (FDA IND #78, 973) did not evaluate carotenoid serum values,

only the more important biologic end-tissue response of macular pigment. Compliance was assessed independently through pill count and serial telephone query. There was 96% pill intake compliance. The age distribution and retinal specialist AMD severity grading score of the n= 60 patients is shown in (Figures 1a, b).

Measures of low contrast vision comprise greater contributions of rod-based parafoveal vision and are shown in (Figures 2a–d). Baseline (pre-supplementation) low contrast near visual acuity, important in driving, was inferior to that of high contrast letters by at least 2 to 5 visual acuity lines (data not shown), consistent with the presence of retinal degeneration in these elderly patients. Lutein supplementation proved superior to zeaxanthin with respect to multiple measures of rod-based vision. (Figure 1a) illustrates that following 12 months of supplementation, the low contrast letters were better visualized with either lutein (+ 7.2 letters, $P = 0.04$) or lutein and zeaxanthin supplementation (+ 8.8 letters, $P = 0.02$) but not significantly improved with zeaxanthin alone (+ 4.3 letters, $P = \text{ns}$). An overall increase in average CS was demonstrated, with the lutein group most effective (Figure 2b). Baseline and final AUC CS function (integrated Area-under-the-curve, CS @ 5 spatial frequencies) for lutein (% difference improvement = + 48%; $P = 0.05$) and zeaxanthin (+ 24%; ns but $P = 0.09$ for trend) but surprisingly not for equally weighted lutein and



zeaxanthin supplementation (+ 20%; ns). For blue cone parafoveal thresholds, lutein proved best (ns but $P = 0.09$ for trend) ANOVA @ 8 months and ($P = 0.05$) ANOVA @ 12 months consistent with its known anatomical distribution. (Figure 2c) GR (seconds) improvement was significant for lutein ($P = 0.02$) and particularly for the combined lutein and zeaxanthin group ($P = 0.002$) with only a trend for improvement with the zeaxanthin subgroup (ns but $P = 0.09$), paired t-Test, baseline to 12 months (Figure 2d).

A greater self-reported vision function score on the NEI VFQ-25 self-evaluation driving subscale was associated with greater MP (average eye macular pigment at 12 months post supplementation), demonstrated as increasing self-reported composite driving subscale scores associated with increased average eye macular pigment at 12 months post supplementation (Figure 3). Accordingly, MP12 had the highest correlation with driving by the end of the study, post supplementation ($p = 0.02$) as determined via linear regression model of ($n = 60$) subjects enrolled in ZVF, using the parameters MPB (average eye macular pigment baseline), MP12, VFQB (NEI VFQ25 composite driving score baseline) and VFQ12 (NEI VFQ25 composite driving score at 12 months post supplementation) (Figure 4).

Discussion

There is benefit in determining MP in the retina as it can be nutritionally modified in most seniors. Both the LAST (Lutein Antioxidant Supplementation Trial) RCT emphasizing the carotenoid

lutein, and the ZVF study, emphasizing the carotenoid zeaxanthin, demonstrate MP enhancement through supplementation, with attendant improvement in CS and photo stress GR. Both parameters are related to the sensory aspects of vision involved in twilight and night driving. Both visual parameters diminish with aging.

The importance of CS in driving has been shown [7]. Owsley et al. studied state motor vehicle crash record and found that crash involved drivers were 8 times more likely to have a severe CS reduction in the worse eye and 6 times more likely to have severe CS reduction in both eyes compared to crash-free drivers [3]. Specifically, CS is associated with decreased highway sign discrimination [7], decreased performance on braking [25], poorer driving maneuvers/skills [26], patient-reported driving difficulty [27], and slower reaction times [28]. Turano et al. have described that in glaucoma, CS was associated even with the walking speed [29].

The importance of GR in driving has been shown before, as decreased GR restricts driving [30]. Rubins et al. showed that glare sensitivity is a significant predictor of crash involvement [9], and Gray and Regan demonstrated that increase in glare is significantly associated with decrease in safety margin [10]. Detailed analysis of how high intensity discharge lamps impair driving of older adults, was evaluated by Mainster and Timberlake [31].

In this paper, a small but significant aspect of driving ability that can be beneficially modified in elderly male patients with AMD was

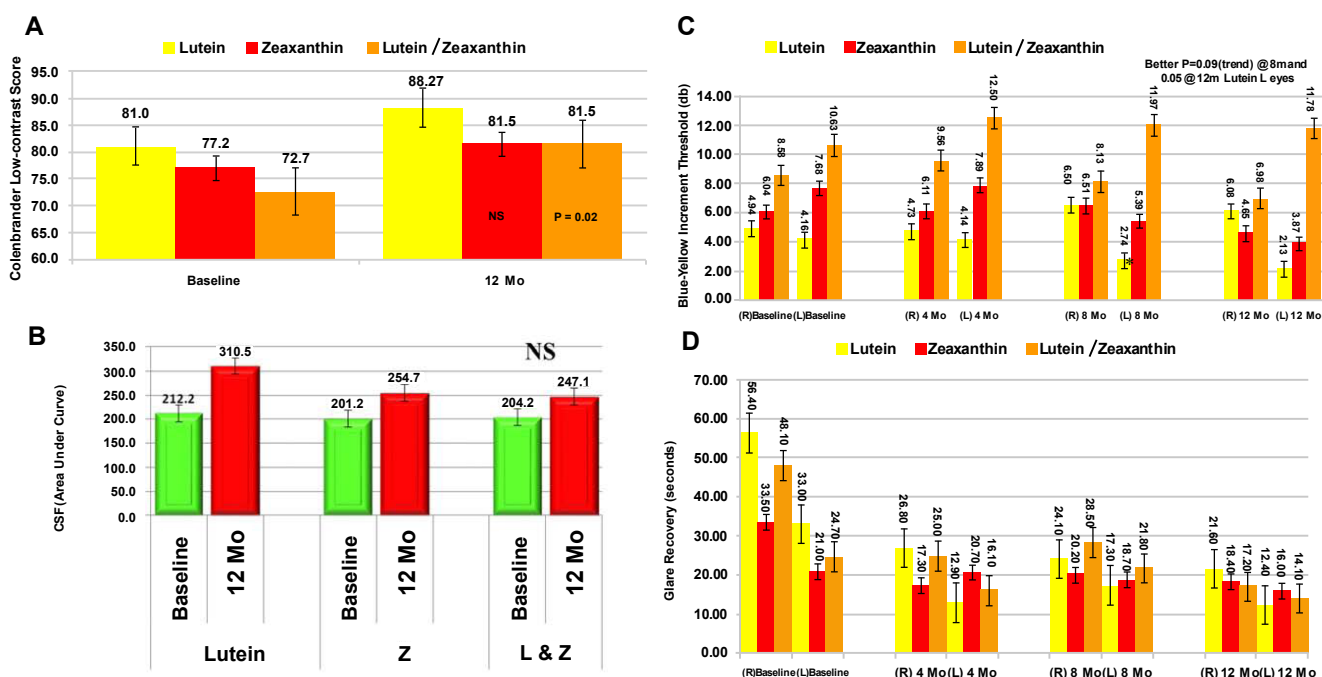


Figure 2: a, Baseline, average eye, low-contrast near visual acuity was inferior to that of high-contrast letters by at least 2 lines. By 12 months, the Colenbrander low-contrast letters were better visualized with either lutein (+7.2 letters, $P = 0.04$) or lutein plus zeaxanthin (+8.8 letters, $P = 0.02$) but non-significantly improved with zeaxanthin alone (14.3 letters, P value not significant). **2b, Baseline, average eye, and final AUC CSF (at 5 spatial frequencies)** for lutein (difference improvement, +48%; $P = 0.05$) and zeaxanthin (+24%; $P = 0.09$ for trend) but surprisingly not for and lutein plus zeaxanthin (+20%; not significant). **2c, Blue cones**, equally spaced within the parafovea provide an independent measure of parafoveal function. Of all 3 intervention groups, lutein proved best ($P = 0.09$ for trend ANOVA at 8m and $P = 0.05$ ANOVA at 12 m). **2d, GR (seconds)** improvement was significant for lutein ($P = 0.02$) and particularly the combined lutein plus zeaxanthin group ($P = 0.002$) with only a trend for improvement with the zeaxanthin subgroup ($P = 0.09$), paired t test (baseline to 12 months).

PERMISSION PENDING, Richer SP, Stiles W, Graham-Hoffman K, Levin M, Ruskin D, Wrobel J, Park DW, Thomas C, Randomized, double-blind, placebo-controlled study of zeaxanthin and visual function in patients with atrophic age-related macular degeneration: The Zeaxanthin and Visual Function Study (ZVF) FDA IND #78, 973, Optometry, 2011: 82, 667-80.

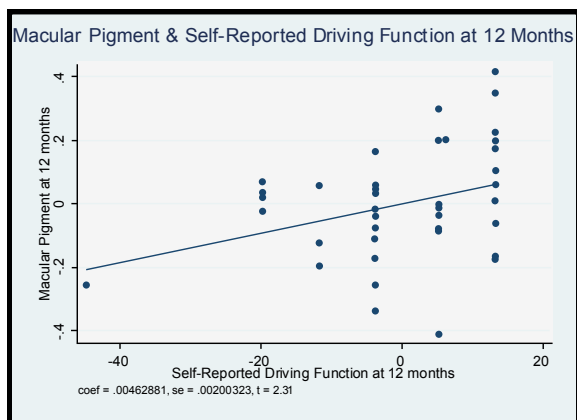


Figure 3: Macular pigment and self-reported driving function at 12 months are linearly related, post supplementation (p=0.02).

Regression (Linear Modeling n=60)

pwcorr mpb mp12 vfdribe vfdribe12 vfqb vfq12, sig

"MP12 has the highest correlation with driving at end of study, although there is a higher correlation with baseline functioning and driving..."

	mpb	mp12	vfdribe	vfdribe12	vfqb	vfq12
mpb	1.00					
mp12	0.62 0.0000	1.00				
vfdribe	0.12 NS	0.18 NS	1.00			
vfdribe12	0.26 P=0.08	0.33 P=0.02	0.68 0.0000	1.00		
vfqb	0.14 NS	-0.01 NS	0.73 0.0000	0.55 0.0001	1.00	
vfq12	0.25 0.09	0.10 0.49	0.56 0.0000	0.68 0.0000	0.90 0.0000	1.00

Figure 4: Regression and (Linear Modeling n = 60 patients) of NEI VFQ data Key: mpb = average eye macular pigment at baseline; mp12 = average eye macular pigment at 12 months; vfdribe = total NEI VFQ score at baseline; vfdribe12 = total NEI VFQ score at final visit; vfqb = NEI VFQ driving subscale composite 3 – question driving score at baseline pre- supplementation n; vfdribe12 = NEI VFQ driving subscale composite 3 – question driving score at the final visit post supplementation.

identified. Specifically, lutein supplementation, and to a lesser extent zeaxanthin supplementation, was associated with better low contrast vision and visual recovery from blinding glare. Self-described driving ability was associated with baseline pre-supplementation macular pigmentation (non- significantly). However, when subjected to linear regression modeling, the self-described ability to drive a car was associated with increased pigmentation (P=0.02) by the end of 12 months of supplementation with nutritional carotenoids. Moreover, the greatest effect was surprisingly reserved for zeaxanthin (ns but P=0.057). In the ZVF Study, zeaxanthin improved foveal visual acuity, shape discrimination and scotoma resolution and appears to beneficially impact cognitive function as well. Such post-receptorial attributes of this carotenoid might trump any differences in visual function compared with lutein.

Several groups are studying brain and / or post-receptorial visual function effects of the macular pigments. One group has shown that MP is positively related to cognition in the elderly in a battery of tests

[17]. The Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, MA, has also shown that lutein / zeaxanthin levels in centenarians' brains (upon autopsy) are related to cognitive function. Temporal CS function (TCSF) is related to MP [32]. This same group has shown that MP is related to heterochromatic luminance contrast thresholds. Both of these visual functions are post-receptorial and suggest MP assists the brain and retina function, so they work efficiently together. Future research focusing on Useful Field of View (UFOV) might also be a promising area of investigation as it involves both sensory (visual) input and cognition [33-36].

Older drivers with AMD, in particular, should be encouraged to request a foveal macular MP reading at least once during their yearly eye examination. Currently, no CPT 9 (Procedural Terminology version 9) code for MP, CR or GR testing exists, and may present a barrier to utilization. Nonetheless, two simplified and widely available commercial heterochromatic flicker photometry devices are now available: the QuantifEye® (ZeaVision, Chesterfield, MO) and the MacuScope (Marco Instrument, Jacksonville, FL). Clinicians should invest in measuring retinal pigmentation as well as CS and GR evaluation technology. A normal 1862 Snellen acuity measurement provides a false sense of security with respect to twilight and night driving even in elderly patients maintaining "20/20" high contrast visual acuity. Relatively low doses of dietary over the counter carotenoids were used in the ZVF study. No evidence of toxicity and no adverse events related to this intervention were found by the ZVF Data Safety Monitoring Protocol. Both dietary carotenoids (lutein and zeaxanthin) and macular re-pigmentation should be considered in elderly male patients having night driving difficulty.

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