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Effect of Mediterranean diet and blue light exposition on macular pigment optical density values in a Spanish childhood population

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ABSTRACT

Background: Macular pigment in retina is formed by lutein and zeaxanthin. These carotenoids must be ingested. Fruit, vegetables, and eggs are rich in lutein and zeaxanthin. In adults, there are many factors that increase macular pigment values, although not enough studies have been performed in children.
Objective: The main aim of this study was to analyze macular pigment in children considering healthy habits and exposure to LEDs screens.
Methods: A cross-sectional, observational study was conducted, recruiting 27 children aged 7–13 years. Healthy habits, demographic data and exposure to LEDs were analyzed using a questionnaire. To study adherence to the Mediterranean diet, the validated KIDMED questionnaire was used. Macular pigment optical density was measured using Heterochromatic Flicker Photometry, and weight and height were also recorded and expressed by body mass index.
Results: The mean MPOD value was 0.45 ± 0.14. BMI percentile was studied in the children, with most of them presenting normal weight (55.55 %). Regarding the KIDMED questionnaire, ingesting a fruit or fruit juice every day increases macular pigment optical density (0.47 ± 0.13 vs 0.24 ± 0.07, $p = 0.034$). No correlation was found for the KIDMED questionnaire score, BMI or age with MPOD value.
Conclusion: Lutein and zeaxanthin intake, as well as healthy habits, increase MPOD value. However, no relation was found for several of the factors evaluated with MPOD value.

1. Introduction Background

Macular pigment (MP) is a structure located in front of the fovea, in the retina. It is formed by lutein (L) and zeaxanthin (Z), which are two xanthophyll carotenoids that must be ingested through vegetables, fruit, or eggs [1].

In the human body, L and Z are found mostly in the eyes, kidneys, adipose tissue and the brain, presenting antioxidant and anti-inflammatory properties [2,3].

Many risk factors must be studied with MPOD values in order to understand the role that MP plays in the human body. Consequently, the presence of L and Z in the brain seems to have a positive effect on cognitive function and neurocognitive diseases such as Alzheimer's and Parkinson's [2,3]. In addition, MP absorbs short wavelength light (blue light spectrum, present in most flat screen devices), whose retinal oxidative damage leads to age-related macular degeneration (AMD) [2]. Lower MPOD values may increase the

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risk of AMD [2,4]. Therefore, higher intake of fruits and vegetables or a dietary pattern such as the Mediterranean Diet, rich in L and Z, could help to protect against AMD.

Furthermore, it is well known that carotenoids are stored by adipose tissue [5]. Therefore, people with high body fat percentage or high body mass index (BMI) may have lower MPOD values due to adipose tissue absorbance. It has been reported that a BMI above 29 % and/or 27 % body fat has an inverse relationship with MPOD [6,7]. Nevertheless, normal or lower BMI and body fat seems to have no correlation with MPOD [8].

A proportion of the spectral emission of LEDs is light at wavelengths of 435–440 nm, which are included in the "blue light hazard" [9]. Several studies conducted in mice and cell cultures exposed to LED illumination describe a negative effect of blue light due to a decrease in mitochondrial function, leading to the appearance of reactive oxygen species, with cellular apoptosis and oxidative damage in retinal ganglion cells and photoreceptor cells [10]. Electronic devices with visual displays are illuminated by LEDs. The exposure to an increasing number of electronic devices for longer periods of time is a matter of growing public concern [11].

L and Z are accumulated preferentially in the retina, indicating that carotenoids may play a role in visual function, especially when glare disability, photo-stress recovery, contrast sensitivity and best corrected visual acuity are analyzed [12]. However, other optometric measures, such as refractive status, remain unclear.

MP can be studied through objective measurements or using subjective techniques, mainly heterochromatic flicker photometry (HFP), with varying macular pigment optical density (MPOD) values in density units (du), ranging from 0 to 1 [13,14].

Most studies about MP have been carried out in adult population, showing many factors that could or could not improve MPOD values. However, very few studies have been conducted in children, possibly due to the fact that children are less cooperative than adults and they might not understand correctly the task required. On the other hand, the difficulties to obtain ethical approval should be considered. Nevertheless, few studies have been performed to elucidate the relationship between MPOD values and other factors in children [1] focusing on cognitive function and visual function.

The main aim of this work was to analyze MPOD values with some factors such as visual function, L and Z intake, BMI, and LEDs illuminated flat screens exposure in children.

2. Materials and method

2.1. Subjects and protocol

This cross-sectional observational study was conducted in the Optometry Clinic (Faculty of Pharmacy – University of Seville, Spain). The present study recruited 27 children aged 7–13 years; the participants were siblings of Optics and Optometry Degree students. Informed consent was given by the participants' parents prior to participation, and the experimental hypothesis was explained. To reduce the variability, the inclusion criteria were: (a) Caucasian healthy children, and (b) children or preadolescents (6–15 years old). The exclusion criteria were: (a) evidence of AMD, evaluated with an Amsler grid, (b) ocular disease including lens opacity (cataract), corneal scar explored with a slit lamp or any retinal or maculopathy disease, and (c) history of systemic disease (diabetes, hypertension or similar). The study protocol was approved by the local Ethics Committee of the University of Seville and the experimental procedures adhered to the Declaration of Helsinki.

The participants were also asked about their healthy habits and the time they spent using electronic devices such as tablets, mobile phones, computers and television. Subsequently, display lighting was analyzed according to the devices' data sheets. Healthy habits and exposure to LEDs questionnaire are shown in the Supplement Material.

An ocular examination was conducted by an expert optometrist, exploring with a slit lamp, and the refraction status for each participant was measured with an ETDRS chart and subjective refraction.

2.2. Macular pigment optical density evaluation

MPOD was measured using Heterochromatic Flicker Photometry (HFP) with a macular densitometer MPS II (Macular Pigment Screener II) (Elektron Technology UK Ltd., Cambridge, UK. A central test stimulus is found, changing between two wavelengths: blue at 640 nm absorbed by macular carotenoids and green at 540 nm not absorbed. In this task, a flicker disk is shown, and the observer must press a button when stimulus flicker begins for a several blue-green ratios [13].

In the current study, only central MPOD measure was carried out to stay attention in children on due to a challenge that it involves. Moreover, L and Z are accumulated in central region of macula lutea. So that, we support ourselves to get only central measures. Finally, those participants that do not understand the task or failed were discarded.

2.3. Adherence to the Mediterranean diet: KIDMED QUESTIONNAIRE

The KIDMED questionnaire, developed by Serra-Majem et al. [15], was used to evaluate the dietary habits in the participants, who completed 16 validated questions from the KIDMED questionnaire compounded by items concerning fruits and vegetables consumed, dairy product consumed, and no intake of fast food or pastries. All questions are related to the intake or no intake of L and Z. Each question has different scores depending on the answer, scoring between +1 and −1. The score obtained was interpreted as: >8 (optimal adherence to the Mediterranean Diet); 4–7 (adherence to the Mediterranean Diet should be improved); and ≤3 (adherence to the Mediterranean Diet must be improved).

2.4. BMI measurement

To evaluate the participants' body composition, height and weight were also recorded to calculate the body mass index (BMI). BMI was calculated as kilograms (weight) divided by square meters (height). The participants were divided into four groups depending on the BMI scores. The World Health Organization (WHO) criteria were selected to classify the subjects, which are compared with percentiles, and the cut-off value determines the nutritional status considering gender and age. For children aged 5–19 years, underweight is defined below the 3rd percentile, normal weight between the 3rd and 85th percentile, overweight between the 85th and 97th percentile, and obesity above the 97th percentile.

2.5. Statistical analysis

The statistical analyses were performed with SPSS software version 23.0 (Inc., Chicago, IL, USA). Data normality was studied with the Shapiro-Wilk test and Kolmogorov-Smirnov test. For the comparison between population subgroups, independent sample t-tests were used for normally distributed data. Nonparametric analyses of variance by Kruskal-Wallis and Mann-Whitney *U* test were performed. Spearman's correlation coefficient (r) was used to study the correlation between variables. A p-value (p) < 0.05 was considered statically significant.

3. RESULTS

The sample consisted of 27 Caucasian children (16 boys and 11 girls) with an average age of 8.74 ± 1.46 years. No hypertension, high cholesterol levels or history of AMD were observed. The BMI study showed a mean value of 18.09 ± 3.99 kg/m2, with 55.55 % of the population presenting normal weight and 40.74 % presenting excess weight (overweight and obesity). Healthy habits were also analyzed: 41 % practiced physical exercise, mainly football, tennis, swimming, or basketball, and most children (85.18 %) slept more than 8 h/day (maximum 10 - minimum 7 h). Refractive error was considered, with 85.18 % being emmetropic. Table 1 summarizes the sample characteristics assessed. None of the participants used sunglasses.

On the other hand, 51.85 % of the sample were exposed to LEDs screens for less than 5 h/day. Table 2 shows the use of electronic devices, with television and tablets being the most used, followed by computers and mobile phones. None of the participants used laptops or e-books.

In addition, MPOD was studied to describe changes as a function of demographic characteristics and habits, obtaining a mean value of 0.45 ± 0.14 (d.u.). No differences have been found between gender and MPOD. MPOD values increased from overweight to underweight, with more than 150 min per week of physical exercise, and with less than 5 h of daily exposure to LED screens. Although the highest MPOD value (0.50 ± 0.0) was found in underweight BMI, no statically significant differences were found in MPOD based on BMI classification. Thus, no correlation was found between MPOD and BMI ($r = 0.203$; $P = 0.342$).

In relation to refractive status, emmetropic subject had higher MPOD values, with myopic children obtaining lower MPOD. However, statically significant differences were not observed ($p > 0.05$) (Table 1).

Furthermore, adherence to the Mediterranean diet was studied using KIDMED test (Table 3). According to the results, 55.55 % and

Table 1
Demographic characteristics and healthy habits.

	Factors (mean ± SD)	MPOD (mean ± SD)
Total Sample	n = 27	0.45 ± 0.14
Age (*y*)	8.74 ± 1.46	0.19-0.91
Range (min-max)	7–13	
Boys/girls	16 b/11g	
BMI (kg/m^2)	18.09 ± 3.99	0.5 ± 0.0
Range (min-max)	13.64–27.83	0.42 ± 0.09
BMI distribution (*n (%)*)	1	0.48 ± 0.21
Underweight	15	
Normal weight	11	
Weight excess (overweight + obesity)		
Exercise (150 min/week)	13	0.47 ± 0.16
YES	14	0.43 ± 0.13
NO		
Hours sleeping (>8 h/d)	23	0.43 ± 0.14
YES	2	0.60 ± 0.03
NO		
Exposure to LEDS screens (<5 h/d)	14	0.51 ± 0.08
YES	13	0.40 ± 0.21
NO		
Refractive error	23	0.46 ± 0.15
Emmetropic	1	0.35 ± 0.0
Myopic	3	0.45 ± 0.06
Hyperopia		

Table 2
Exposure to electronic devices luminated by LEDs.

	Time of exposure (hours/day) (mean ± sd)	Range (hours/day) (Min-Max)
TV	1.83 ± 1.5	0–4
Tablet	1.22 ± 0.73	1–4
Computer	1.0 ± 0.0	1–1
Mobile Phone	1.0 ± 0.0	1–1
Video Games	0.72 ± 0.88	0–3
LEDs	5.78 ± 2.36	3–12

40.74 % of the sample showed medium and high adherence, respectively, presenting higher MPOD values than those who showed poor adherence ($p > 0.05$). None of the participants visited fast food restaurants more than once per week, and everyone consumed olive oil at home. Considering L and Z intake, 93 % of the sample ingested a piece of fruit or fruit juice every day, presenting higher MPOD values than the 7 % who did not ($p = 0.034$). The MPOD values were also higher when a second piece of fruit or vegetables were ingested, although no significant differences were observed ($p > 0.05$). In this population, the intake of fatty acids from nuts led to higher MPOD levels, although dairy or fish consumption led to lower MPOD values ($p > 0.05$). When the total KIDMED test score was analyzed, most participants showed medium adherence to the Mediterranean diet, obtaining higher MPOD value (0.46 ± 0.17) than those who had low or high adherence (0.34 ± 0.0 and 0.45 ± 0.10, respectively). However, no differences were found in the scoring classification.

No correlations were detected for age ($r = -0.039$; $P = 0.847$) or L and Z intake according to KIDMED test punctuation ($r = 0.139$; $P = 0.49$) with MPOD.

4. Discussion

The aim of this study was to elucidate whether MPOD values are related to good life habits in children. It is evidenced that the intake of vegetables and fruits contributes to higher MPOD values [1]. This was observed in the present study, as higher MPOD values

Table 3
KIDMED test to assess the Mediterranean diet adherence.

KIDMED test	Scoring	(n = 27)	MPOD (mean ± Sd)
Takes a fruit or fruit juice every day	+1	Yes 25	0.47 ± 0.13[a]
		No 2	0.24 ± 0.07[b]
Has a second fruit every day	+1	Yes 11	0.47 ± 0.17
		No 16	0.43 ± 0.12
Has fresh or cooked vegetables regularly once a day	+1	Yes 17	0.47 ± 0.10
		No 10	0.42 ± 0.19
Has fresh or cooked vegetables more than once a day	+1	Yes 6	0.46 ± 0.07
		No 21	0.45 ± 0.07
Consumes fish regularly (at least 2–3/week)	+1	Yes 17	0.43 ± 0.09
		No 10	0.49 ± 0.09
Goes >1/week to a fast-food restaurant (hamburger)	−1	No 100 %	
Likes pulses and eats them >1/week	+1	Yes 24	0.44 ± 0.15
		No 3	0.50 ± 0.08
Consumes pasta or rice almost every day (5 or more per week)	+1	Yes 12	0.47 ± 0.19
		No 15	0.43 ± 0.08
Has cereals or grains (bread, etc.) for breakfast	+1	Yes 100 %	
Consumes nuts regularly (at least 2–3/week)	+1	Yes 10	0.51 ± 0.16
		No 17	0.42 ± 0.12
Uses olive oil at home	+1	Yes 100 %	
Skips breakfast	−1	Yes 26	0.45 ± 0.14
		No 1	0.43 ± 0.0
Has a dairy product for breakfast (yoghurt, milk, …)	+1	Yes 26	0.45 ± 0.14
		No 1	0.48 ± 0.0
Has commercially baked goods or pastries for breakfast	−1	Yes 14	0.44 ± 0.17
		No 13	0.46 ± 0.11
Takes two yoghurts and/or some cheese (40 g) daily	+1	Yes 10	0.40 ± 0.08
		No 17	0.48 ± 0.16
Takes sweets and candy several times every day	−1	Yes 22	0.43 ± 0.12
		No 5	0.54 ± 0.21
KIDMED Index	Adherence to Med Diet		
Score ≤3 points	Poor	1	0.34 ± 0.0
Score 4–7 points	Medium	15	0.46 ± 0.17
Score ≥8 points	High	11	0.45 ± 0.10

For each variable, different letters (a,b) indicate significant differences ($p < 0.05$) among rows in the same column and line.

were found when the participants answered positively in the KIDMED questionnaire regarding vegetable and fruit consumption ($p < 0.05$).

Several studies have analyzed L and Z intake in children, exploring correlation values with MPOD. Most of them evaluated L and Z intake with a dietary record of 3 days [16–18]. However, only Barnett et al. [16] found a positive correlation between dietary records and MPOD values. In contrast, Liu et al. [17] and Liu et al. [18] compared L and Z intake with MPOD values, finding no correlation, which is in line with our results. In the present study, no correlation was found between MPOD and KIDMED score. Although we agree with both studies, we assessed dietary habits with a validated questionnaire that represents adherence to the Mediterranean diet, which is rich in several carotenoids [19], such as L and Z, suggesting that higher scores could be related to high MPOD values in the retina. Even so, we believe that using a validated test could be more precise than filling a three-day food record to determine the L and Z intake, due to errors in completing the record or subject recall bias.

To our knowledge, MPOD has not been correlated with BMI percentile either. Some studies have analyzed the relationship between BMI and body fat percentage in adults. Hammond et al. [6] found a significant inverse relationship in the obese subjects with BMI >29kg/m2 and more than 27 % body fat. Moreover, Nolan et al. [7] showed an inverse relationship between body fat percentage and MPOD values, which was not significant in females. However, in children, the evidence remains unclear. In the present study, no correlation was found with BMI, and significant differences were not found in MPOD values as a function of BMI classification. Aversely as noticed in adults, children whose BMI percentile was >85th showed higher MPOD values than those with normal or lower BMI, although significant differences were not obtained. Equivalent results have been obtained in previous studies that found no correlation between BMI and MPOD [16–18,20]. Therefore, in children, there seems to be no relation for weight or height with having higher or lower MPOD, in contrast with the results obtained in adult populations. This could be due to differences between children and adults in the absorption of L and Z in the blood or other tissues, or differences in pathways of L and Z and their accumulation in the retina. Adipose tissue competes with other tissues such as the retina for the uptake of carotenoids [6], which could interfere with lower MPOD values. The lower adipose concentration and lower oxidative stress in children may be responsible for these differences. Therefore, further studies in children are required to clarify this hypothesis.

Exposure to LEDs light must be considered in children, due to its potential damaging effects and the extended use of devices nowadays. Blue light emitted by electronic devices is filtered by L and Z [1,21]. Thus, good dietary intake rich in carotenoids and brief periods of exposure to blue light might be a protective factor against retinal damage. In the present study, fourteen participants reported that they spend less than 5 h with LEDs screen exposure compared to the rest of the participants. Although significant differences were not found, children who had lower LEDs exposure showed higher MPOD values than those who spend more than 5 h. This could be due to the fact that using digital devices with large blue-light exposure may produce oxidative stress and damage in the retina. This is the first study to consider this factor, and thus further studies are required to analyze this fact.

The present study has several limitations that must be pointed out. Firstly, the sample was limited to 27 children. Future studies will be carried out by us to contrast these results and accept or reject this pilot hypothesis. Secondly, the homogeneity of our sample is evident. Future studies should increase the heterogeneity of the sample, for instance, with a broader age range, which will help to confirm the present findings and compare them with those of other studies.

5. Conclusions

The intake of fruit and vegetables, in addition to other healthy habits, such as practicing sports, increases MPOD values (being statically significant with the intake of fruit), which are not influenced by BMI or time of exposure to LEDs illuminated devices in children. Further studies are required to support our results.

Data availability statement

Data will be made available on request (mgarcia118@us.es).

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics Declarations

The authors confirm that we have reviewed the guidelines for Ethics in Publishing as well as Heliyon's Ethics and Editorial Policies.

The study protocol was approved by the ethics committee: "Comité de Ética de la Investigación de la Universidad de Sevilla, Spain, (1290-N-22) following the tenets of the Declaration of Helsinki. All participants were informed about the study purposes, methods and data analysis and an informed consent was signed.

-Consent for publication

All participants have confirmed consent for publication.

CRediT authorship contribution statement

García-Romera Marta-C: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Torres-Parejo Úrsula:** Writing – review & editing, Formal analysis, Data curation. **Ponce-García Victor:** Writing – review & editing, Writing – original draft, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e23361.

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