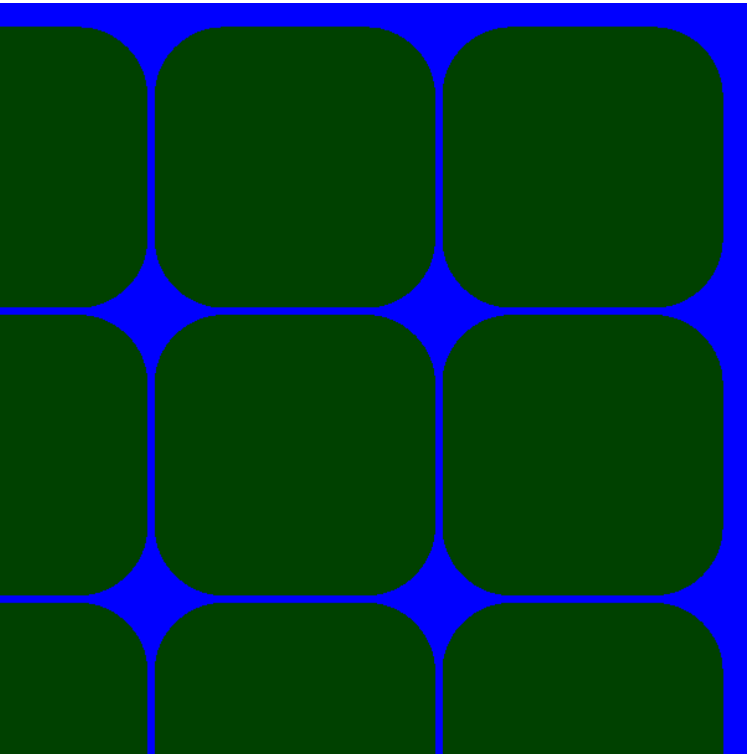
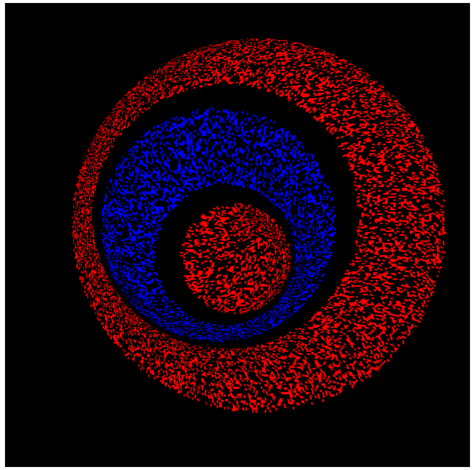
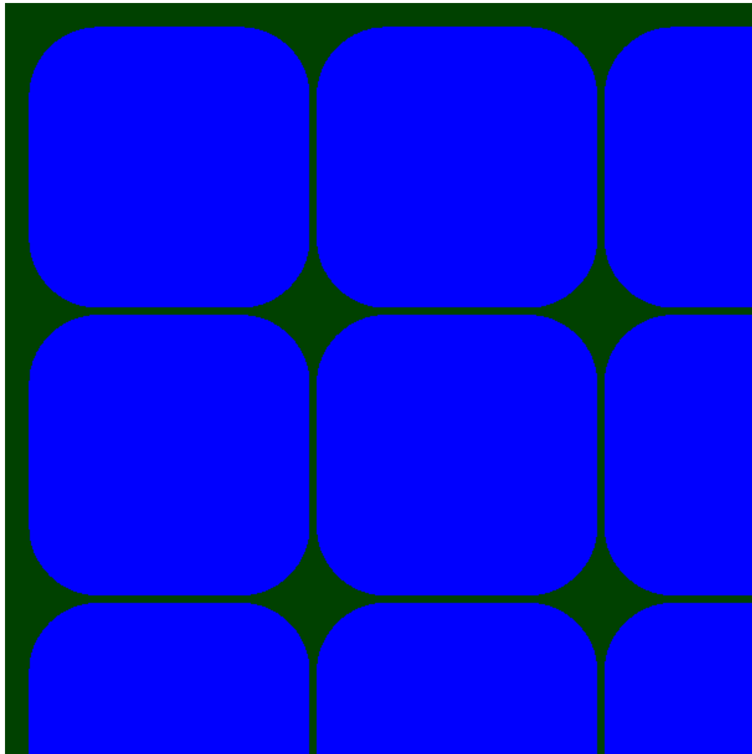
システム視覚科学研究センター10周年シンポジウム
2025年2月28日（金）16:05-16:45
立命館大学びわこくさつキャンパス・エポック立命21

Macula, Maxwell’s spot, and Haidinger’s brushes

黄斑・マクスウェルのスポット・ハイディンガーのブラシ







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眼底写真
（練馬総合病院）

Macula (Macula lutea) (黄斑)

- In the retinas of diurnal primates, including humans, there is an area called the macula lutea.

- The macula is not found in mice, but is present in birds*. (*I could not confirm these. Could be confusion with the fovea.)

- The macula is located in the center of the visual field. It exists in a circular shape. The size is between 200 and 900 μm diameter around the center of the fovea[9].

→

Provis JM, Penfold PL, Cornish EE, Sandercoe TM, Madigan MC. Anatomy and development of the macula: specialisation and the vulnerability to macular degeneration. Clin Exp Optom. 2005 Sep;88(5):269-81.

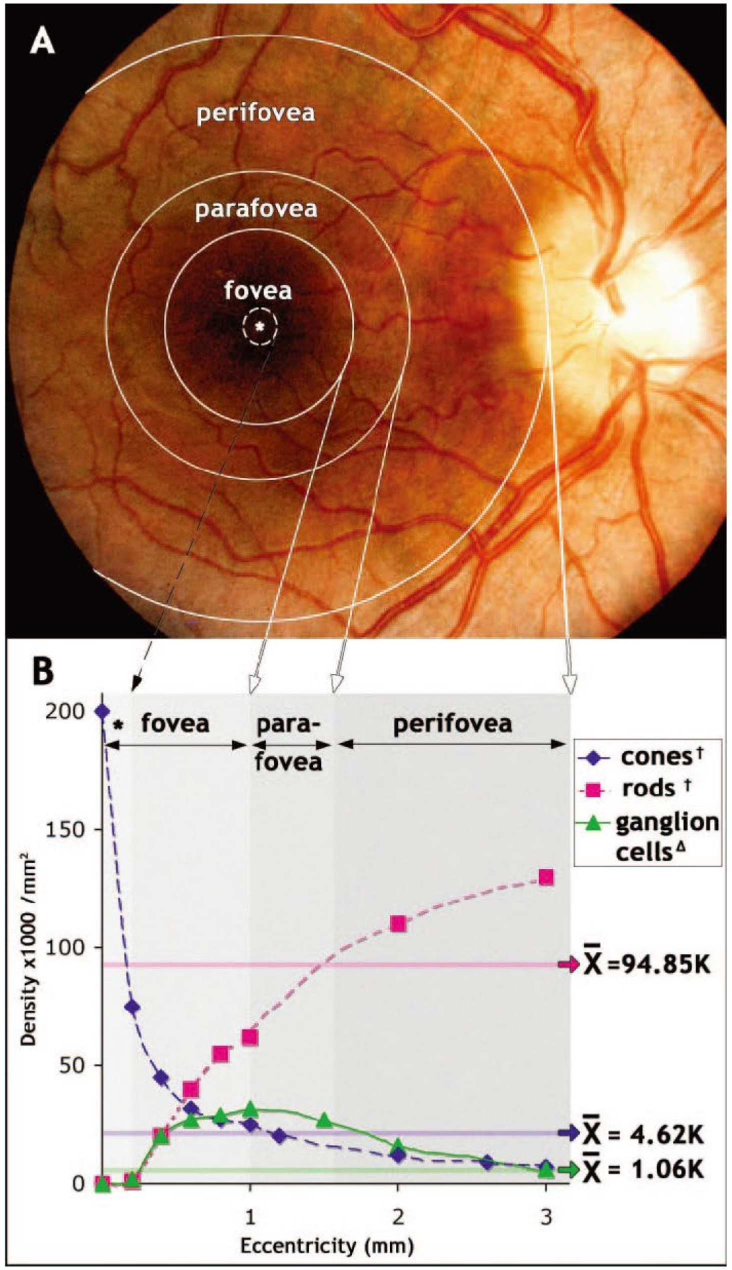


Figure 1. A: The anatomical regions of the fundus, according to Polyak;[8] B: graphs showing the densities of rods,[118] cones[118] and ganglion cells[10] in the fovea, parafovea and perifovea

Macular pigments

- The macula is yellowish because macular pigments absorb short-wavelength light (blue light).
- Lutein, zeaxanthin, and meso-zeaxanthin are known as macular pigments[2,3,5].

名称：ルテイン・ゼアキサンチン含有マリーゴールド配合食品

機能性表示食品 健康系サプリメント 軽減税率対象

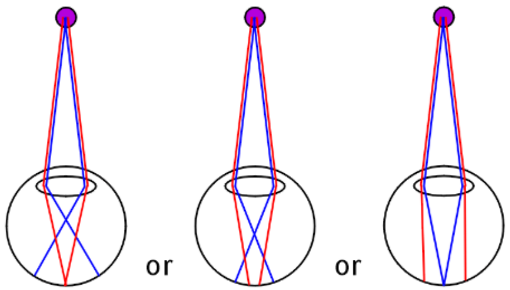
ルテイン

くっきりと見る力をサポート
黄斑部の色素量を増やす

単品容量	メーカー希望小売価格 (税抜)
30粒 30日分	1,600 円
60粒 60日分	3,000 円

https://www.kobayashi.co.jp/seihin/lutein/

The function of the macula



- The function of macular pigments is not well understood.
- According to one theory, macular pigments reduce the effects of light scatter and chromatic aberration on visual performance[1].
- According to another theory, macular pigments reduce the damaging photo-oxidative effects of blue light through its absorption[1,5].
- According to yet another theory, macular pigments protect against the adverse effects of photochemical reactions because of the antioxidant properties of the carotenoids[1,2].

The function of the macula (continued)

- Recent evidence introduces the possibility that macular pigments may protect against macular degeneration[4].
- An intake of dietary supplied nutrients rich in the carotenoids appears to be beneficial in protecting retinal tissues, but this is not proven[4].

Absorption of blue light by macula pigments

- Macular pigments attenuate short-wavelength light. The peak of absorption is at a wavelength of 460 nm[5,6,7,11], though the peak is broad between 430 nm and 490 nm[10].

- “These blue wavelengths have been shown to be more dangerous than longer wavelengths of visible light since they are more energetic and seem to be more efficient at generating reactive oxygen species from endogenous photosensitizers such as lipofuscin.”[5]

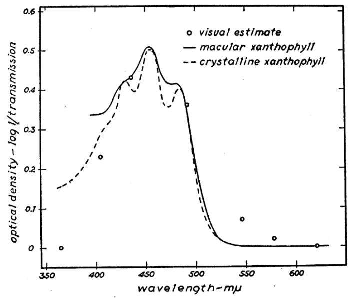
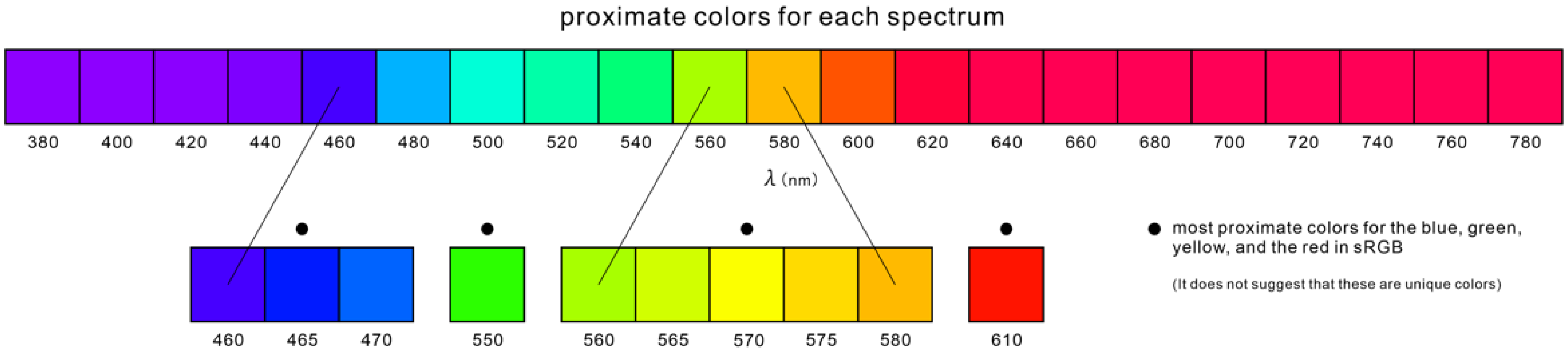


FIG. 4. The absorption spectrum of the macular pigment. The open circles are visual estimates of this, differences in log sensitivity of peripheral and foveal cones, taken from Fig. 2. The solid line is the absorption spectrum of a partially purified preparation of xanthophyll extracted from human maculas. The broken line is the spectrum of a preparation of crystalline leaf xanthophyll.

George Wald Human Vision and the Spectrum. Science 101,653-658 (1945).



Location of macula pigments in tissue

- Macular pigments are located in the cell membrane of the photoreceptor axons[1], not in glial cells.

- Macular pigments are located in Henle's fiber layer[9,11], which contains bundles of unmyelinated cone and rod photoreceptor axons that synapse in the retinal outer plexiform layer[8].

From: Revealing Henle's Fiber Layer Using Spectral Domain Optical Coherence Tomography
Invest. Ophthalmol. Vis. Sci.. 2011;52(3):1486-1492. doi:10.1167/iovs.10-5946

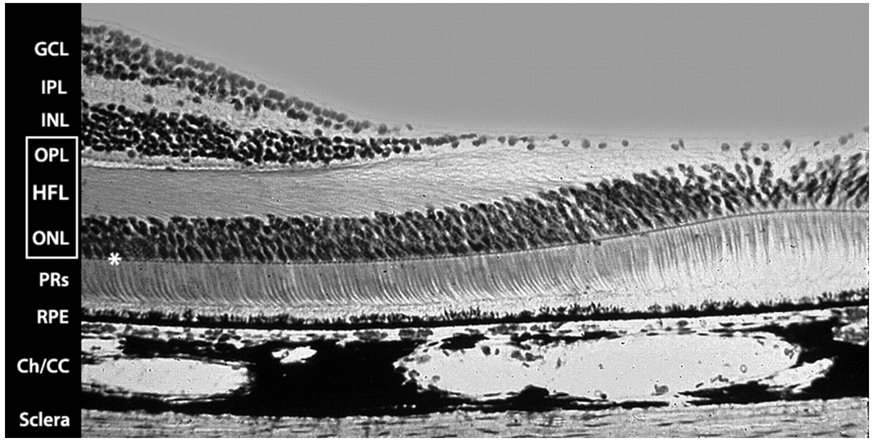
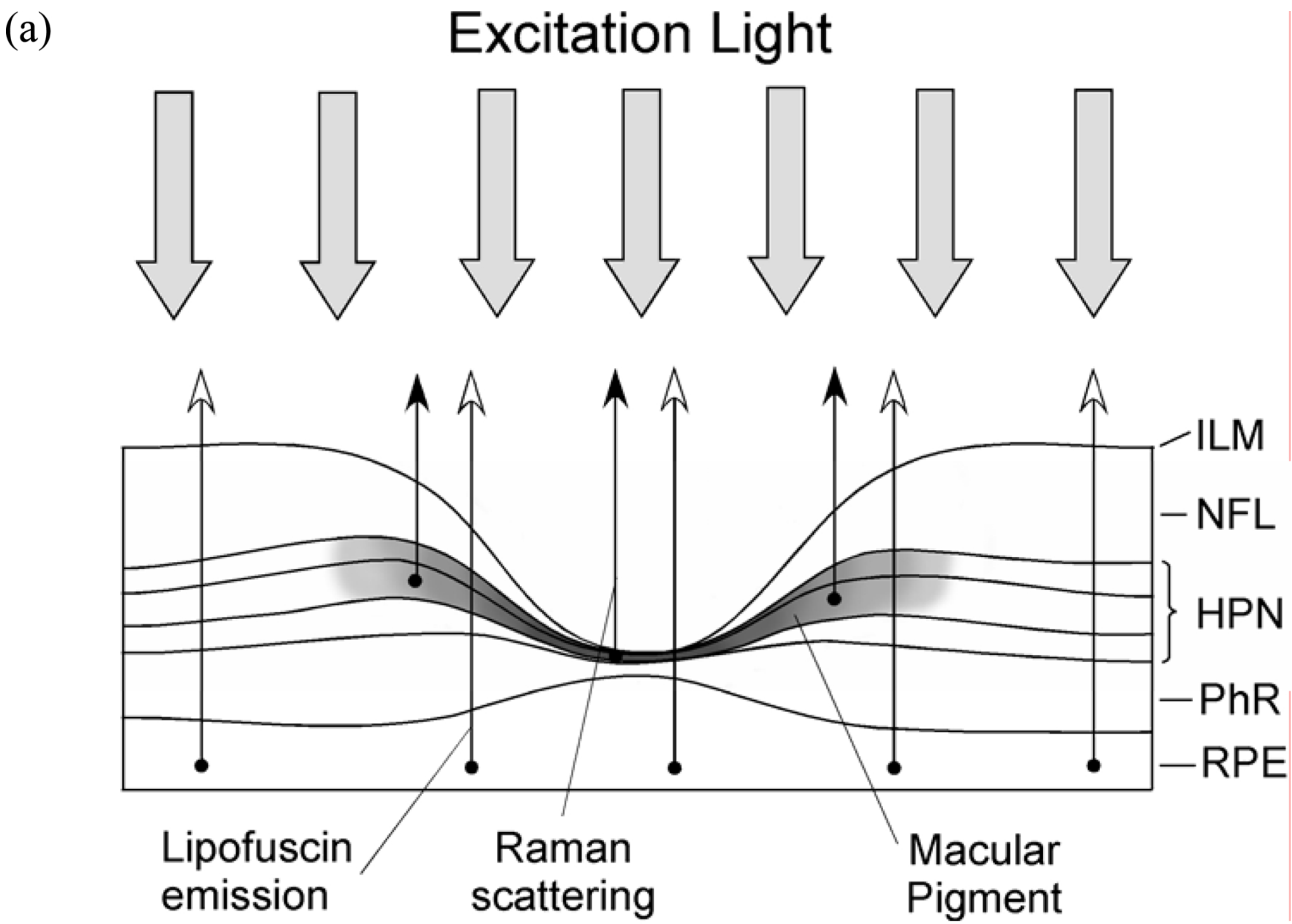


Figure Legend:

Mammalian foveal histology, courtesy of Roger C. Wagner, Professor Emeritus of Biological Sciences, University of Delaware, http://dspace.udel.edu:8080/dspace/handle/19716/1884. Photoreceptor components are indicated by the rectangle, showing the substantial contributions by the photoreceptor inner and outer segments, nuclei, and axons running in HFL. GCL, ganglion cell layer; PRs, photoreceptor IS and OS; Ch/CC, choriocapillaris and choroid. *ELM.



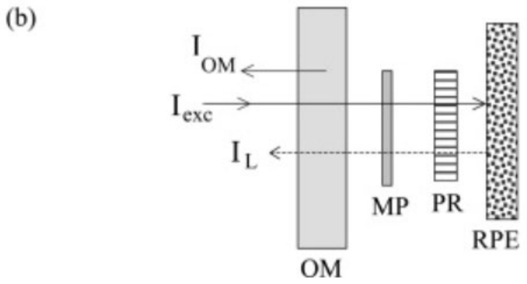
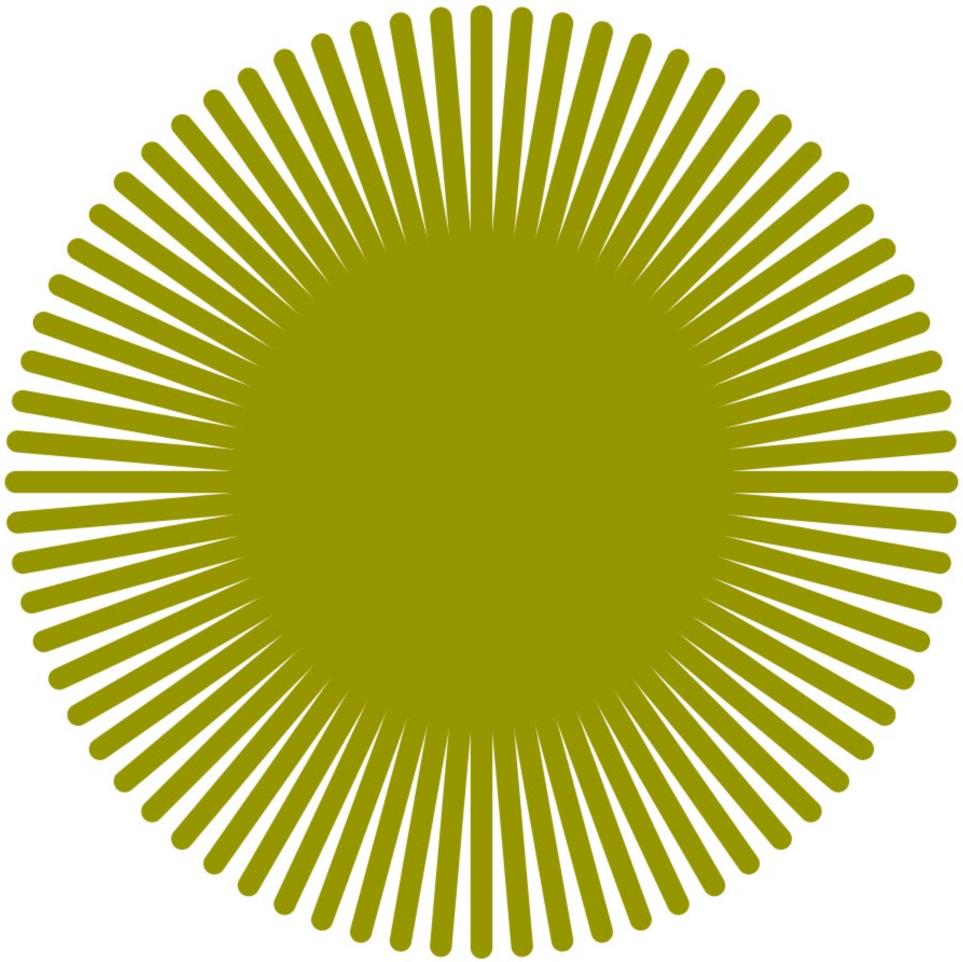


Fig. 3 (a) Schematic representation of retinal layers participating in light absorption, transmission, and scattering of excitation and emission light in the macular region. ILM, inner limiting membrane; NFL, nerve fiber layer; HPN, Henle fiber, plexiform, and nuclear layers; PhR, photoreceptor layer; RPE, retinal pigment epithelium. In Raman scattering, the scattering response originates from the MP, which is located anteriorly to the photoreceptor layer. The influence of deeper fundus layers such as the RPE is avoided. In lipofuscin spectroscopy, light emission is generated from lipofuscin in the RPE layer to generate an intrinsic "light source" for single-path absorption measurements of anteriorly located MP layers. Using an excitation beam diameter exceeding the spatial extent of MP, the MP distribution can be quantified and spatially imaged (see the text). (b) Schematics of anterior optical media and retinal layers traversed by excitation laser light, fluorescence from anterior optical media, and fluorescence from lipofuscin. I_{exc} excitation light; I_L, lipofuscin fluorescence; OM, ocular media; MP, macular pigment; PR, photoreceptors; RPE, retinal pigment epithelium; I_{OM}, fluorescence from ocular media.

Sharifzadeh M, Bernstein PS, Gellermann W. Nonmydriatic fluorescence-based quantitative imaging of human macular pigment distributions. J Opt Soc Am A Opt Image Sci Vis. 2006 Oct;23(10):2373-87



Schematic diagram of the macula

My interest

- Although the macula is located at the center of the visual field, we are rarely aware of its existence in our daily lives.
- The entoptic phenomena of the macula are known as Maxwell‘s spots and Haidinger’s brushes.
- In this talk, I will introduce stimuli that make it much easier to observe these phenomena, consider the function of the macula, and try to seek some clinical use of the phenomena.

Maxwell’s spot

- A phenomenon in which blue objects appear darker in central vision
- According to Miles (1954), Maxwell discovered this phenomenon in 1856 while looking at blue light through a prism.

Maxwell, J. C. (1856). On the unequal sensibility of the Foramen Centrale to Light of different colours. Report of the British Association.

Miles, W. R. (1954). Comparison of Functional and Structural Areas in the Human Fovea. I. Method of entoptic plotting. Journal of Neurophysiology, 17(1), 22–38. https://doi.org/10.1152/jn.1954.17.1.22

Why do Maxwell’s spot occur?

- It is believed to be caused by absorption of blue light by macular pigments (Chen, Lan, & Schaeffel, 2015; Isobe & Motokawa, 1955; Gardasevic, Lucas, & Allen, 2019).

Chen, Y., Lan, V., & Schaeffel, F. (2015). Size of the foveal blue scotoma related to the shape of the foveal pit but not to macular pigment. Vision Research, 106, 81-89. https://doi.org/10.1016/j.visres.2014.10.011

Gardasevic, M., Lucas, R. J., & Allen, A. E. (2019). Appearance of Maxwell’s spot in images rendered using a cyan primary. Vision Research, 165, 72-79. https://doi.org/10.1016/j.visres.2019.10.004

Isobe, K., & Motokawa, K. (1955). Functional structure of the retinal fovea and Maxwell’s spot. Nature, 175(4450), 306–307. https://doi.org/10.1038/175306a0

What does Maxwell's spot look like?

Concentric disks or a single disk

Isobe & Motokawa, 1955

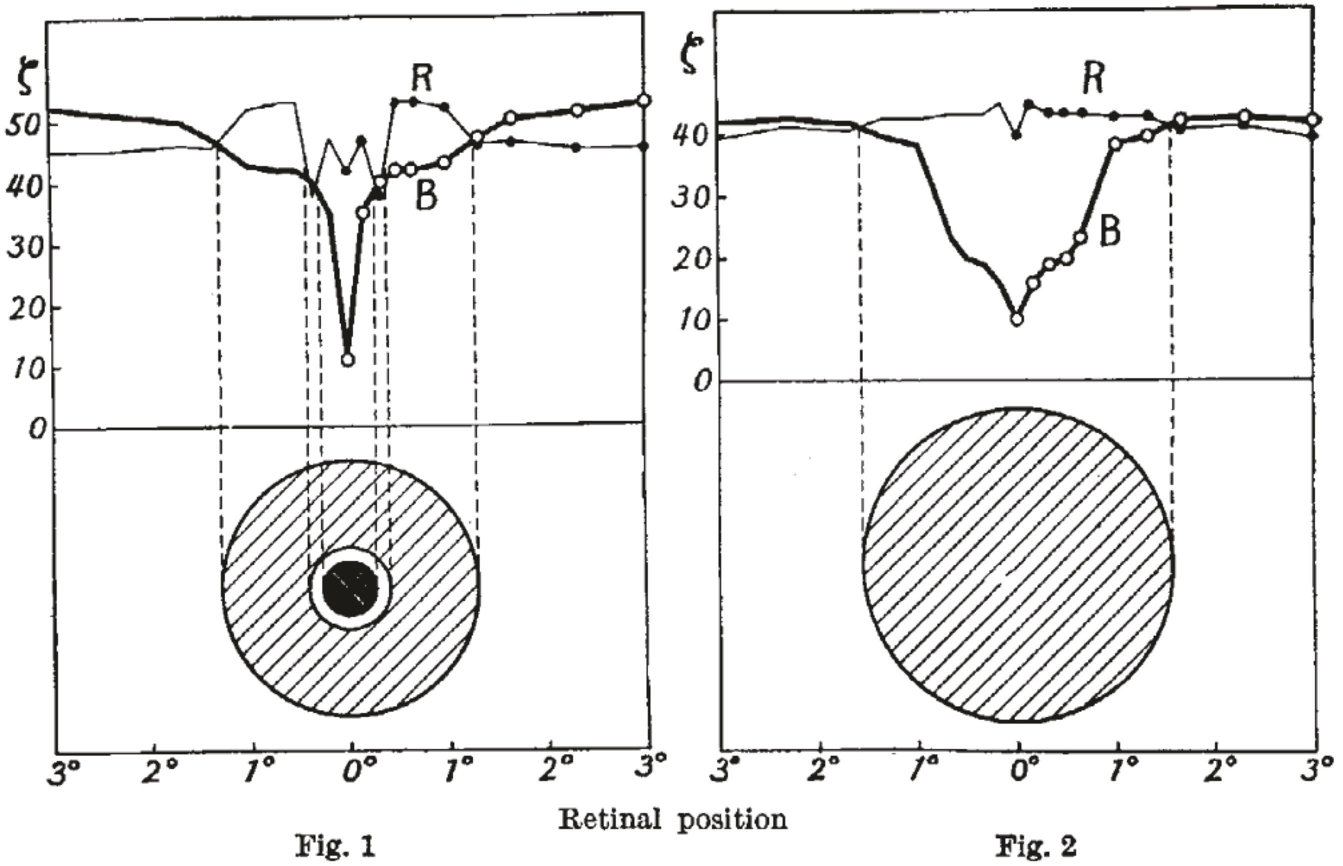


Fig. 1. Spatial distribution of red (*R*) and blue (*B*) processes in fovea (above), and Maxwell's spot (below). Exploring spot of light was 2′ in visual angle during measurement of retinal processes. The more reddish-looking areas of Maxwell's spot are shaded with oblique lines

Fig. 2. Another case of normal Maxwell's spot and corresponding distribution of retinal processes

TABLE 1

Type	I	II	III	IV	V	VI	Investigator
Number of subjects	26	7	5	11	6	2	Walls
	33	12	1	12	8	2	Isobe

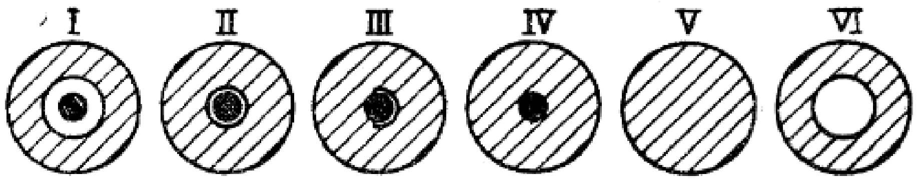


FIG. 1. Classification of normal Maxwell's spot.

Type I: halo, clearing, central spot.
Type II: halo, narrow clearing, central spot.
Type III: halo, cut up clearing, central spot.
Type IV: halo, no clearing, central spot.
Type V: homogeneous disc.
Type VI: halo, clearing, no central spot.

The commonest one (type I) looks like an archery target, consisting of symmetrical circular form made up of 3 concentric zones designated as a spot, a clearing and a halo from the centre to the outside. The colour usually reported for the central spot and the halo are reddish, while that of the clearing is a bright unsaturated lavender, identical with the background field. The three average subtenses of the spot, the clearing and the halo, measured by Miles and Walls, and also in the present experiment, were, without great difference, about 33′, 1°10′ and 2.5° in diameter respectively. Nearly 50 per cent of normal subjects belong to this type. The other types are distinguished from one another according to the width of the clearing and the area of the central spot. Both clearing and central spot are lacking in type V. The clearing exists, but the spot is lacking in type VI.

Isobe, K. (1955). Maxwell's spot and local difference of colour response in human retina, Japanese Journal of Physiology, 5, 9-15. https://doi.org/10.2170/jjphysiol.5.9

Walls, G. L., & Mathews, R. W. (1952). New means of studying color blindness and normal foveal color vision, with some results and their genetical implications. Berkeley and Los Angeles: *University of California Publications in Psychology*, *7*(1), 1-172.

An image for observation of Maxwell’s spot (easy to observe with OLED)

https://www.psy.ritsumei.ac.jp/akitaoka/Maxwell_spot_illusion-paper-Figures.html

New!

Maxwell's spot:

Augmentation by color alternation

When the uniform blue and dark green images are alternated, blue appears darker and green appears lighter in the central vision.

The effect is greater when the images are alternated than when they are viewed individually uniformly. Alternation is essential to observe the illusion in the dark green image.

OLED for easy observation

Alternating colors (blue and dark green)

R: 0, G: 0, B: 255, x: 0.150, y: 0.060, Y: 0.072
L: 0.047, M: 0.087, S: 0.873
dLum: -1.501, dLM: -0.057, dSlum: 1.612

R: 0, G: 65, B: 0, x: 0.300, y: 0.600, Y: 0.038
L: 0.034, M: 0.040, S: 0.006
dLum: -1.604, dLM: -0.009, dSlum: -0.062

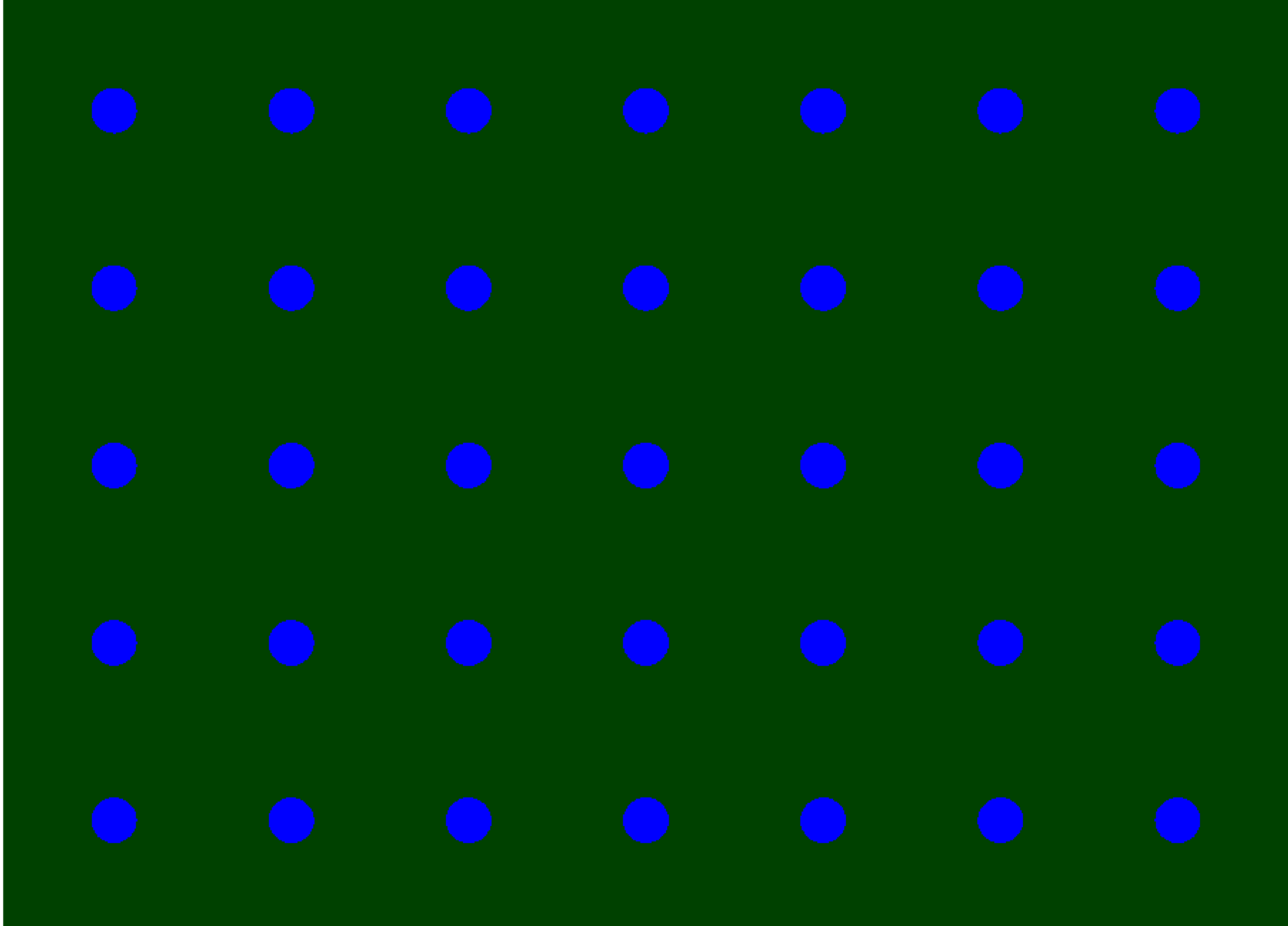
New!

Maxwell’s spot illusion (darkened blue illusion)

When blue dots are placed on a dark green background, blue appears darker in central vision.

This method makes it easy to observe Maxwell's spots.

OLED for easy observation



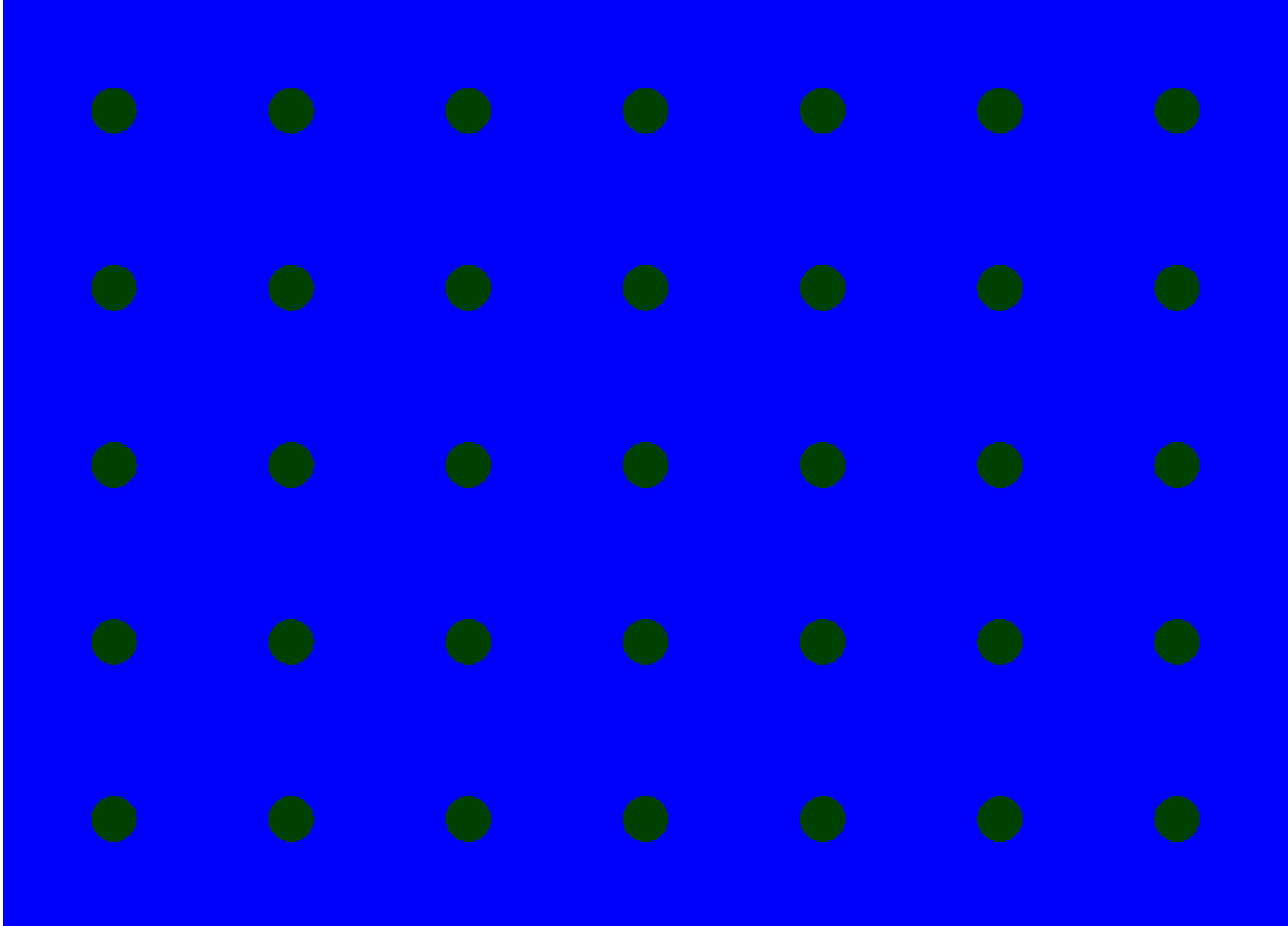
New!

Maxwell's spot illusion (brightened green illusion)

When dark green dots are placed on a blue background, green appears brighter in central vision.

The standard explanation for Maxwell's spots, that "blue appears darker in central vision because the macular pigment absorbs shorter wavelengths of light," does not explain this phenomenon.

OLED for easy observation



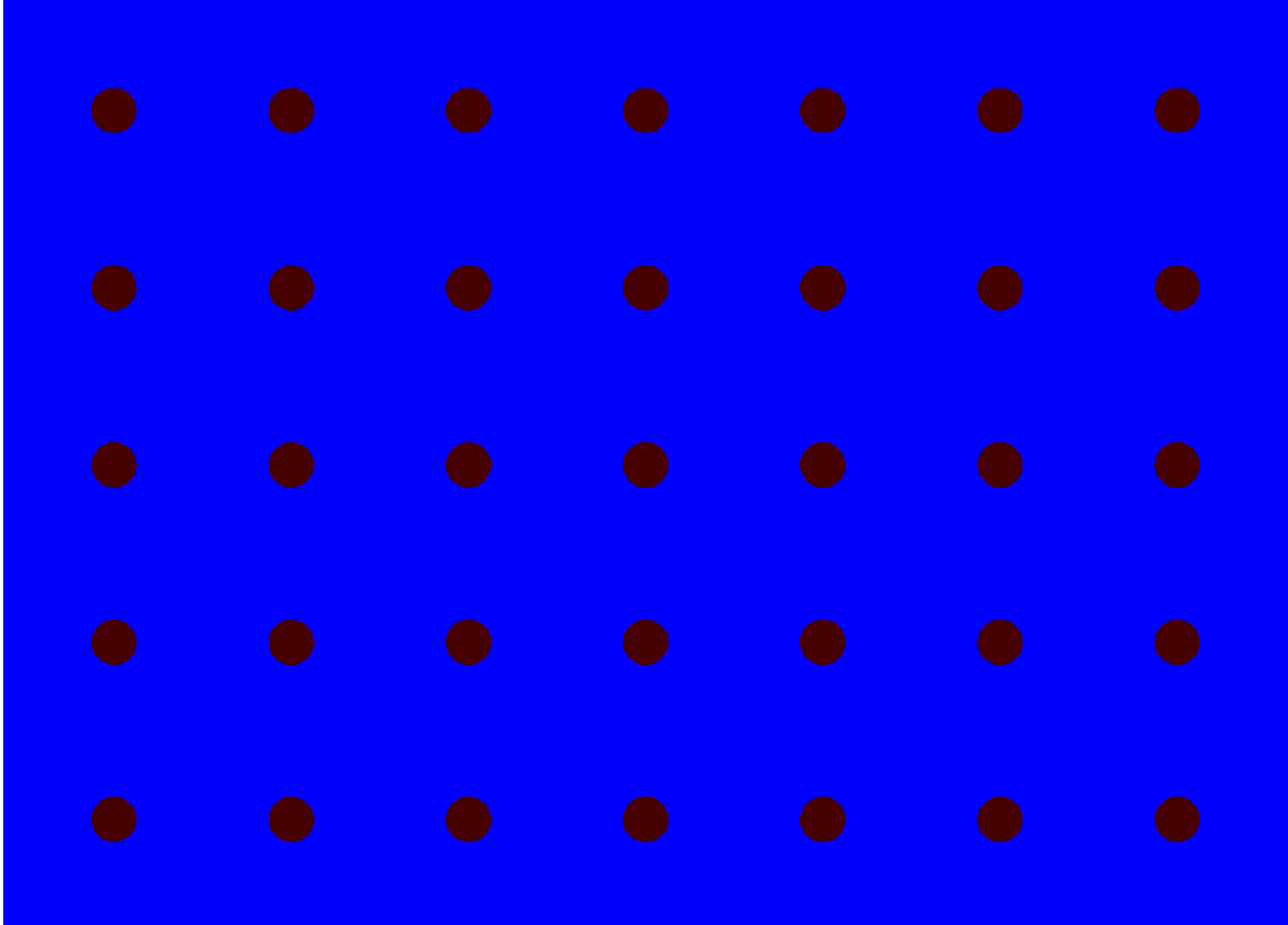
Cf.

Maxwell's spot illusion (brightened red illusion)

When dark red dots are placed on a blue background, red appears brighter in central vision.

The effect seems to be smaller than the brightened green illusion.

OLED for easy observation



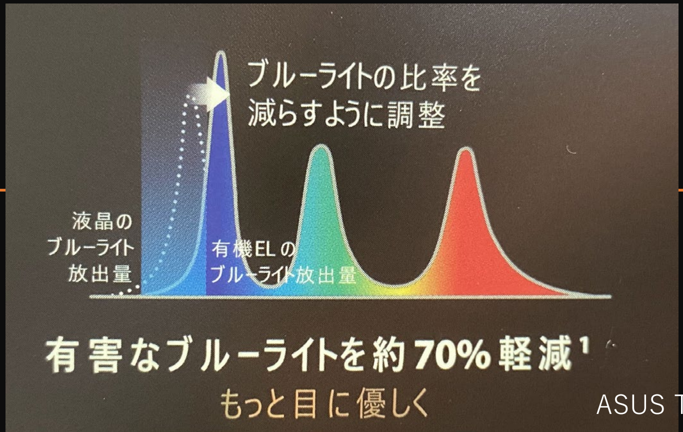
Why does green appear brighter?

Some additional opponent mechanism may be involved in the Maxwell's spot phenomenon.

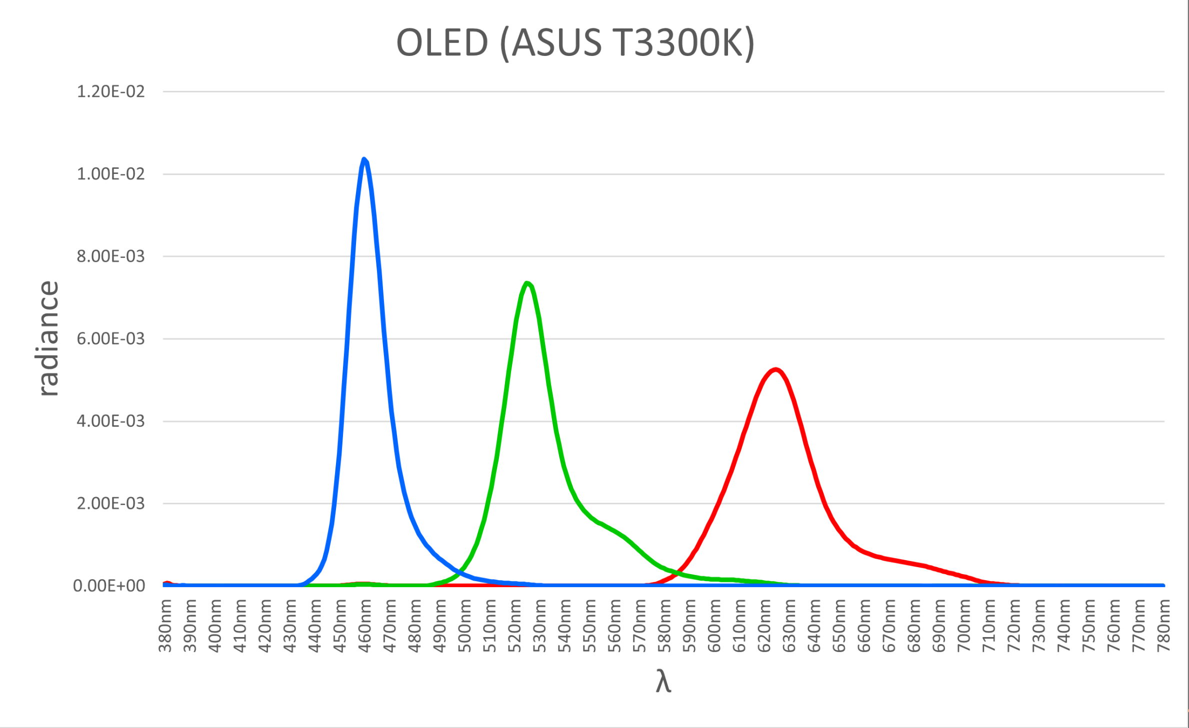
春は、あけぼの。や
て、紫だちたる雲の細
夏は、夜。月のころ
がひたる。また、た
くもをかし。雨など降
秋は、夕暮れ。夕日
の寝どころへ行くとて
さへあはれなり。ま
ゆるは、いとをかし。
はた言ふべきにあらず
冬は、つとめて。雪
のいと白きも、また、
して、炭持て渡るも、
ゆるびもていけば、火

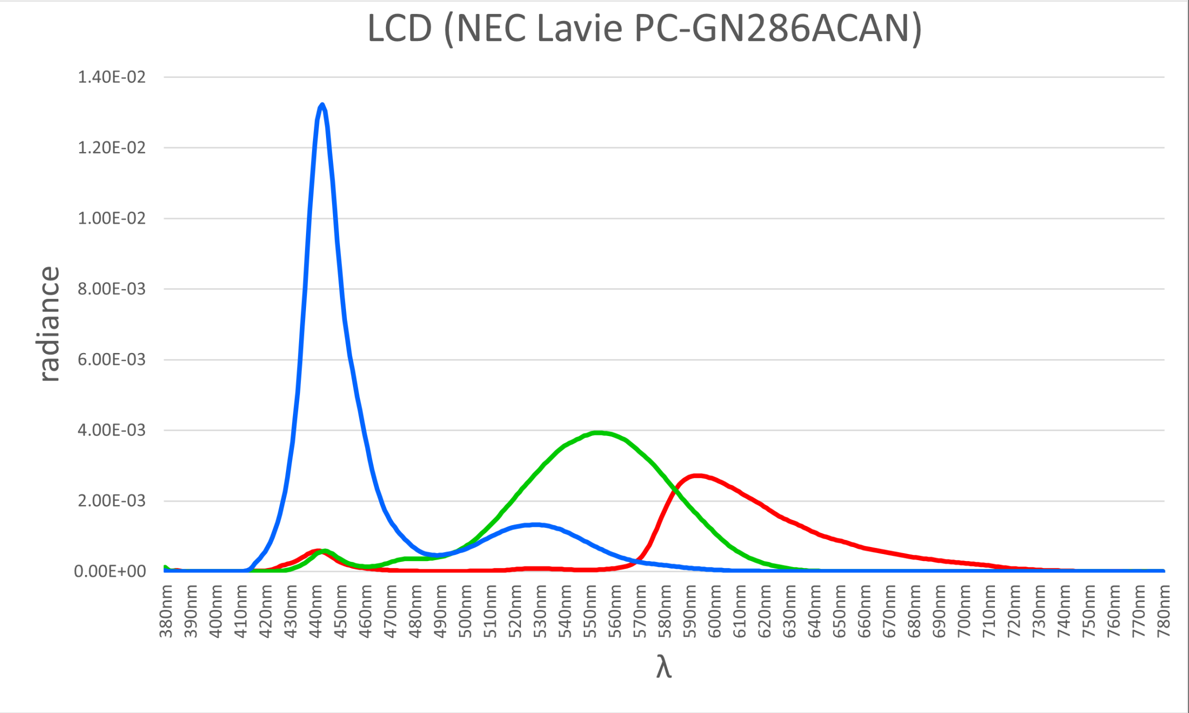
Why is it easy to observe Maxwell's spot illusion with OLEDs?

- The peak blue wavelength of OLEDs is around 460 nm, which is close to the peak wavelength of light absorption in the macula.
- The reason why this illusion does not tend to be clearly visible with LCDs may be because the peak wavelength of blue in LCDs is on the shorter wavelength side than 460 nm.



ASUS T3300Kのポップより

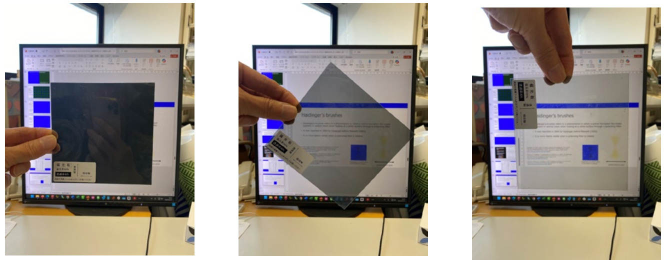




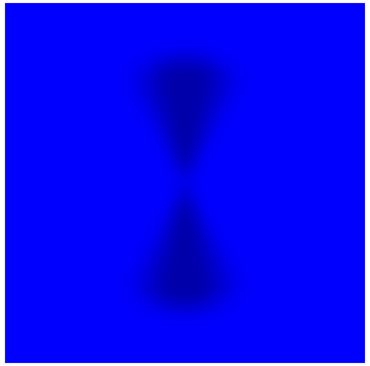
Displays	Display types	Peak of blue	Visibility of the spot[1)]
LED Vision[2)]	LED display	467 nm	Visible
ASUS T3300K	OLED	461 nm	Clearly visible
Apple iPhone 11 Pro	OLED	460 nm	Clearly visible
AKRACING OL2701	OLED	458 nm	Clearly visible
EIZO EV2736W	LCD	456 nm	Clearly visible[3)]
SONY VGN-Z91YS	LCD	455 nm	Clearly visible
SHARP PN-E703	LCD	455 nm	Clearly visible
EIZO EV2785	LCD	453 nm	Weakly visible
SONY SX14	LCD	452 nm	Weakly visible
SONY GDM-F520	CRT	452 nm	Weakly visible
DELL U2410[4)]	LCD	451 nm	Visible
DELL UltraScan P780	CRT	450 nm	Visible
EIZO EV2730Q	LCD	449 nm	Weakly visible
Apple iPad2	LCD	449 nm	Visible
SONY XPERIA Z2	LCD	448 nm	Visible
SHARP PN-L703B	LCD	448 nm	Weakly visible
Panasonic CF-FZ6	LCD	448 nm	Invisible
TOSHIBA T654/78LW	LCD	447 nm	Visible
Diginnos Critea DX4	LCD	447 nm	Invisible
EPSON EB420	LCD projector	444 nm	Weakly visible
NEC PC-GN286ACAN	LCD	443 nm	Invisible
DELL Latitude E5400[5)]	LCD	437 nm	Invisible

Haidinger’s brushes

polarizing filter



- Haidinger’s brushes refers to a phenomenon in which a yellow hourglass-like shape appears in central vision when looking at a white surface through a polarizing filter.
- It was reported in 1844 by Haidinger before Maxwell (1856).
- It is more clearly visible when a polarizing filter is rotated.



Haidinger’s brushes when a blue plane is viewed.

polarization axis

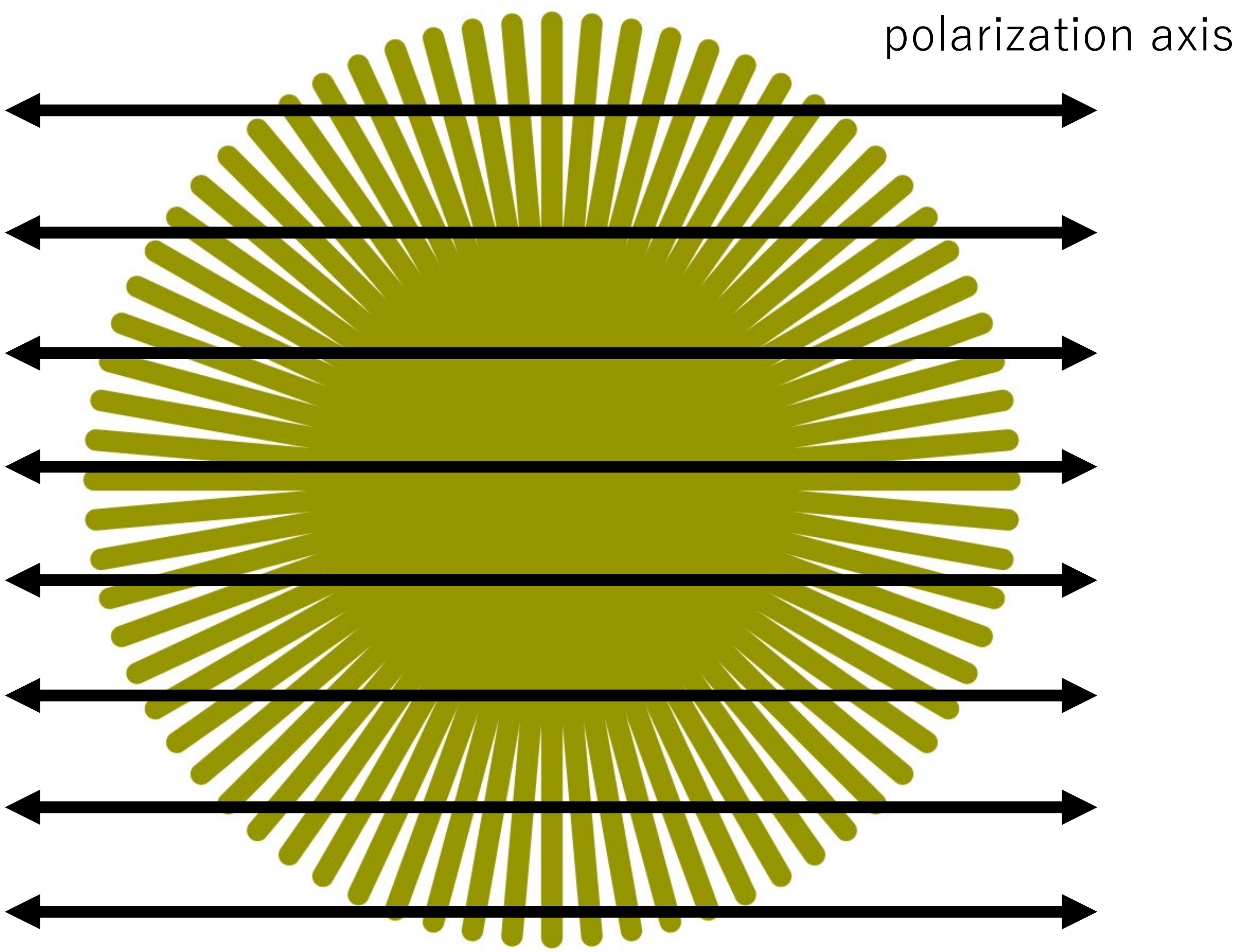
Haidinger, W. (1844). Ueber das directe Erkennen des polarisirten Lichts und der Lage der Polarisationsebene (On direct observation of polarized light and the orientation of the plane of polarization). Annalen der Physik. 139(9), 29–39. https://doi.org/10.1002/andp.18441390903

Misson, G. P., Heitmar, R., Armstrongm R., & Anderson, S. J. (2023). The differential contribution of macular pigments and foveal anatomy to the perception of Maxwell's Spot and Haidinger's Brushes. Vision, 7, 11. https://doi.org/10.3390/vision7010011

Mottes, J., Ortolan, D., & Ruffato, G. (2022). Haidinger's brushes: Psychophysical analysis of an entoptic phenomenon. Vision Research, 199, 108076. https://doi.org/10.1016/j.visres.2022.108076

A white image for observation of Haindinger’s brushes

A blue image for observation of Haindinger’s brushes



When the polarization axis is horizontal, Haidinger's brush is vertical. This finding suggests that the absorption of blue light is maximum when the polarization axis is orthogonal to the orientation of Henle's fibers (axons of photoreceptors).

Comparison between Haidinger’s brushes and Maxwell’s spot illusion

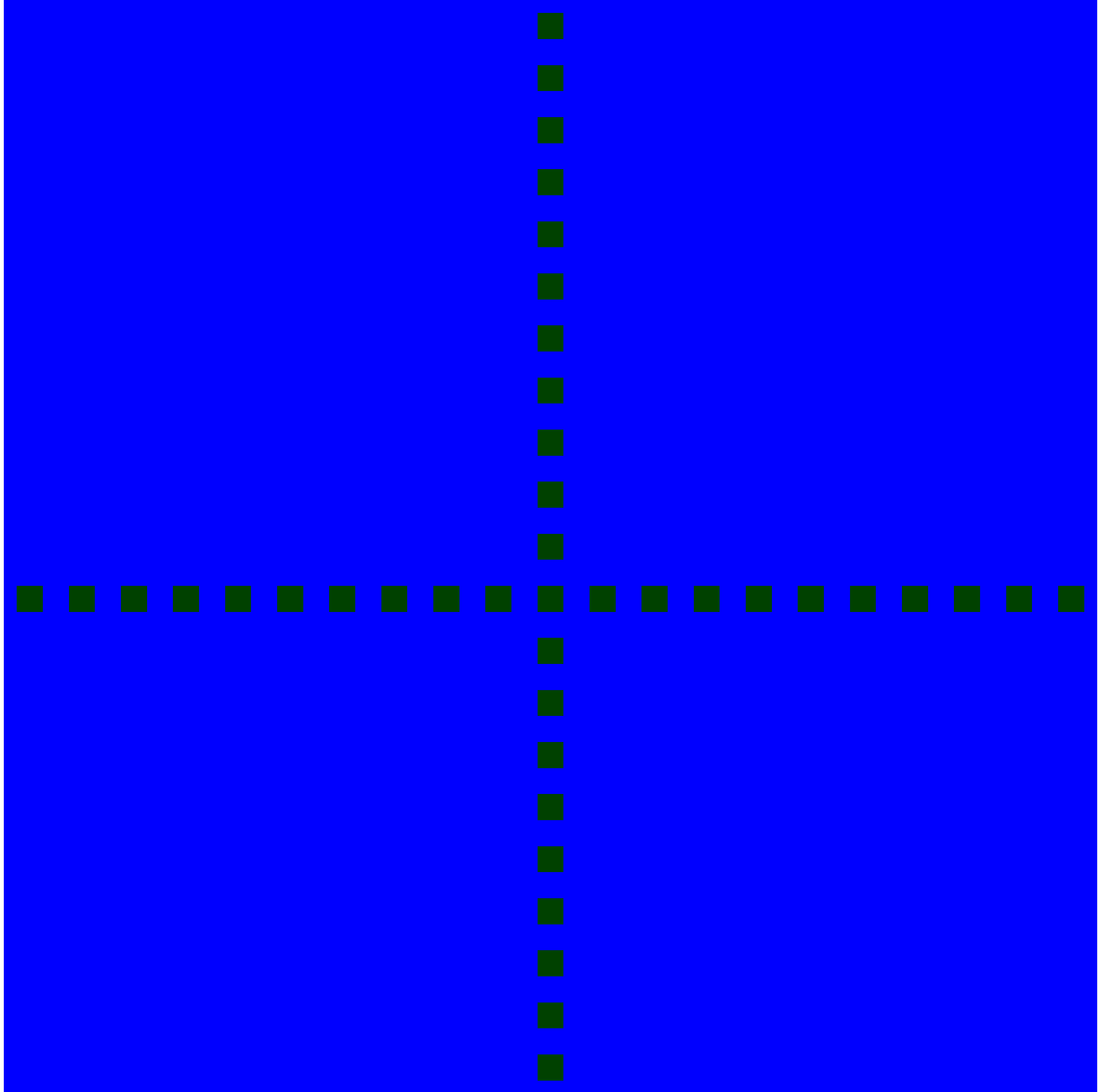
Haidinger's brushes are visible when the frame is blue, but they are not visible when the frame is green.

Haidinger's brushes appear to fit within Maxwell's spot or are slightly protruding.

OLED for easy observation

Comparison between Haidinger's brushes and the brighten green illusion of Maxwell's spot illusion

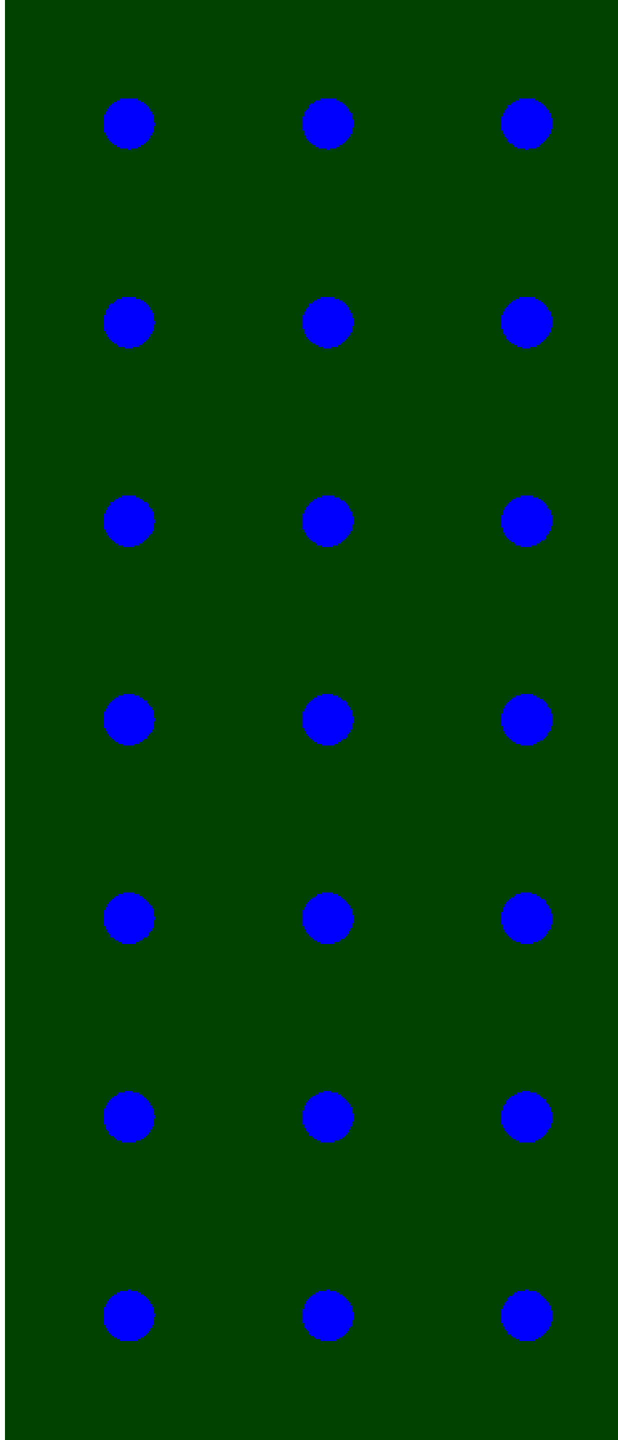
It seems that the green illusion is independent of Haidinger's brushes, so it is suggested that Haidinger's brushes cannot be said to be a product cut out from Maxwell's spot.



Discussion

- I have developed a very simple way to observe Maxwell's spot.
- The fact that we can see Haidinger's brushes means that we humans can perceive polarization.
- What is the function for?

- Haidinger's brushes are used for clinical purpose (e.g. Foster, 1954).



Forster, H. W. (1954). The clinical use of the Haidinger's brushes phenomenon. American Journal of Ophthalmology, 38(5), 661-665. https://doi.org/10.1016/0002-9394(54)90291-3

Note: Able (1982)

Over 100 animal species are known to be able to perceive the plane of polarization of linearly polarized light.

Most of these are arthropods but several molluscs and vertebrates, including man, share this ability.

At least five aquatic vertebrates (three fish, a salamander and a larval frog) are capable of oriented movement based on the E-vector of linearly polarized light.

Pigeons (Columba livia) have been conditioned to discriminate between rotating and stationary polarized light and between widely separated stationary E-vectors, but the behavioural significance of this ability remains unknown.

I report here that the migratory orientation of the white-throated sparrow (Zonotrichia albicollis), a nocturnal migrant, is affected by manipulations of the axis of skylight polarization.

These data provide the first evidence that polarized light may be a relevant cue in migratory orientation.

Able, K. P. (1982). Skylight polarization patterns at dusk influence migratory orientation in birds. Nature, 299 ,550-551. https://doi.org/10.1038/299550a0

Possible clinical use of Maxwell’s spot

（1） Macular field examinations in neuro-ophthalmic practice

(Forster, 1954; Hattori, Wakasugi, Isashiki, & Hirai, 2011; Perenin, & Vadot, 1981)

（2） Pleoptic therapy in amblyopia

(Müller et al., 2016; Wick, 1976)

※All the references are about the examination of Haidinger’s brushes

Forster, H. W. (1954). The clinical use of the Haidinger's brushes phenomenon. American Journal of Ophthalmology, 38(5), 661-665. https://doi.org/10.1016/0002-9394(54)90291-3

Hattori, M., Wakasugi, K., Isashiki, Y., & Hirai, T. (2011). Trial of vision screening using Haidinger's brushes. Japanese Orthoptic Journal, 40, 85-90 (in Japanese with English abstract). https://doi.org/10.4263/jorthoptic.040F107

Müller, P. L., Müller, S., Gliem, M., Küpper, K., Holz, F. G., Harmening, W. M., & Issa, P. C. (2016). Perception of Haidinger brushes in macular disease depends on macular pigment density and visual acuity. Retina (Investigative Ophthalmology & Visual Science), 57(3), 1448-1456. https://doi.org/10.1167/iovs.15-19004

Perenin, M. T., & Vadot, E. (1981). Macular sparing investigated by means of Haidinger brushes. British Journal of Ophthalmology, 65(6), 429-435. https://doi.org/10.1136/bjo.65.6.429

Wick, B. (1976). A home pleoptic method. Optometry and Vision Science, 53(2), 81-84. https://doi.org/10.1097/00006324-197602000-00006

Isobe, K. (1955). Maxwell's spot and local difference of colour response in human retina. Japanese Journal of Physiology, 5, 9-15. https://doi.org/10.2170/jjphysiol.5.9 (p. 11)

Postscript

Walls reported that protanopes and protanomals saw Maxwell's spot, whereas the majority of his deuteranopes and deuteranomals did not. Our investigation also shows that all of 4 protanopes and all of 3 protanomals saw Maxwell's spot, while no trace of it could be found in 8 deuteranopes and in 5 out of 8 cases of deuteranomals.

- Isobe (1955) reported that deuteranopes do not see Maxwell's spot.
- Deuteranopes lack M cones.

Murray, E. (1954). New means of studying color blindness and normal foveal color vision with some results and their genetical implications by Gordon L. Walls and Ravenna W. Matthews. American Journal of Psychology, 67(1), 182-188.

Walls, G. L., & Mathews, R. W. (1952). New means of studying color blindness and normal foveal color vision, with some results and their genetical implications. Berkeley and Los Angeles: University of California Publications in Psychology, 7(1), 1-172.

- Macular pigments are located in axons of photoreceptors.
- Therefore, macular pigments are located in axons of M cones.
- Is this true?

Thank you!