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Research Article

Three Prenatal Developments in the Retina Allow for Cortico-Retinal Image Processing in Situ in the Eye

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Abstract

Image processing in the retina of the eye has thus far been mainly dealt with analogous to photographic ray optics i. e., imaging lens optics and photodiode arrays. However, it does not offer an answer to the questions that are crucial to human vision: WHAT a visible object invariantly represents conceptually (a house, a tree, etc.), WHERE it is located in relation to other objects in space or which RGB-colors and/or luminosities collaborate locally. For this purpose, ray optics needs to be supplemented by diffractive wave optics, which can be described as Fresnel near-field interference in cellular or spatial gratings. The fact that interference optics plays a decisive role in vision has already been proven by the fact that in binocular vision the image brightness is preserved when closing one eye. However, with the introduction of interference-wave-optics and especially with Fresnel Nearfield interference optics the cortico-retinal image processing now becomes possible in the eye, i.e. in the retina of the peripheral visual organ. Fresnel Nearfield interference optics especially allows multilayer proceeding and a better understanding of hierarchical imaging systems. It clearly becomes apparent in the di- and trichromatic proceeding and by the separation of color proceeding from invariant object form proceeding. Color - as an example - is not produced at the visual objects and also not in the cortex, but in the Fresnel space of the retina.

Keywords

Cortical Imageprocessing in the Retina, Introduction of Papilla, Fovea and Nuclear Layers, Human Vision, Retinex and Inverted Retina Concepts, Brain-in-the-Eye-Concept

1. Introduction

Wave-optical information processing in the retina of each eye is crucially enabled by three prenatal developments: the development of a papilla, a fovea as well as three retinal nuclear layers (INL-, MNL- and ONL: inner, middle and outer-nuclear-layer). They make the eye cortically intelligent. Since the previous optical explanations were insufficient, but on the other hand a collaboration of eye and brain could not be overlooked, retina and cortex were linked under the term "retinex" without further explanations offered. The photographic ray-tracing optics remained the same with the lenses, the lens-systems in the aperture-space of optical systems, and the photodiodes in image-space. [4]

The three prenatal developments of the papilla, the fovea, and the retinal nuclear layers start very early in the prenatal period and occupy almost the entire prenatal period, ending only in the seventh month with the development of the photoreceptors (cones and rods) behind the third, the ONL cell layer of the retina. The encroachment of such a large prenatal

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period alone proves the importance of these three developments. Without them, a cortical, i.e., intelligent, image processing of the eye would be impossible.

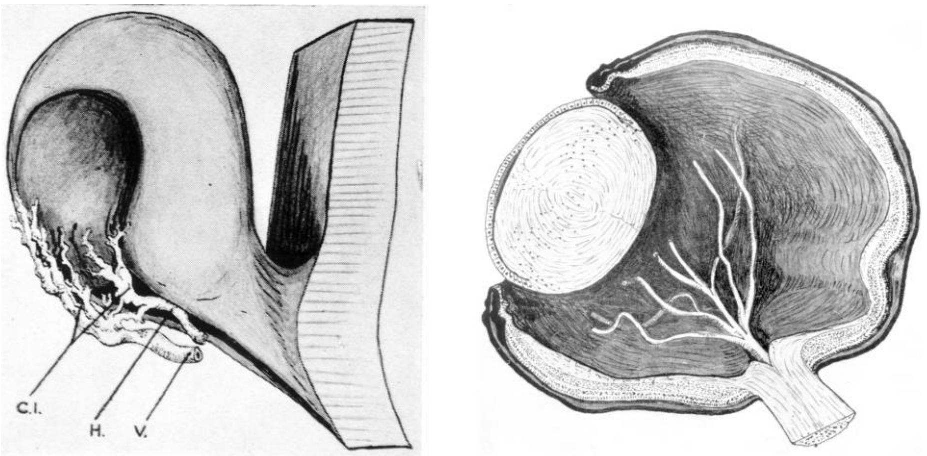

Figure 1. *(Left): An arterial bundle with multiple branches forces an opening into the invaginated retinal cup [13], 3rd prenatal month. (Right): The arterial bundle shifts its position toward the zenith of the retina [13].*

2. The Development of the Papilla

Invagination, i.e., invagination of the anterior hemisphere of the retinal surface epithelium into the retinal eye cup, initially results in the single-layer lattice-forming layer of ganglion cell nuclei (later called INL). However, it lacks an opening available in the direction of the brain.

This condition is put to an end very early by an artery gaining access to this hemisphere (Figure 1), and then inside the retina it shifts this opening to the zenith of the invaginated hemisphere (Figure 2).

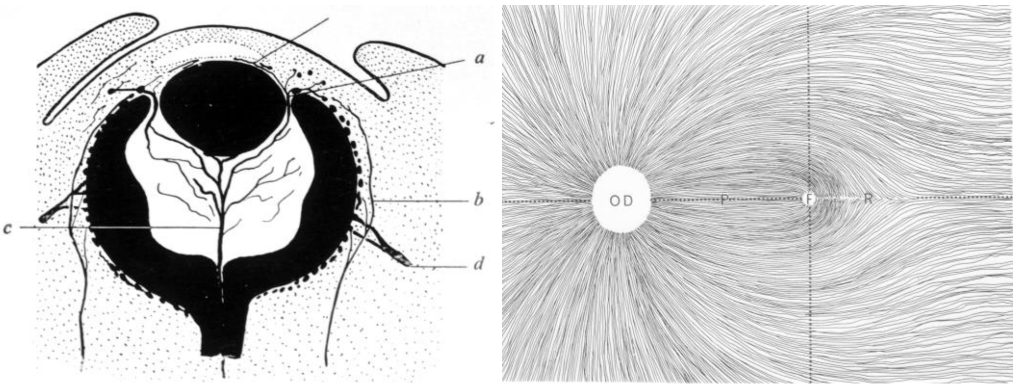

Figure 2. *(left): The arterial bundle shifts its position into the zenith of the retina. [13], 3rd prenatal month. (Right): Centripetal growth of the optic nerves from the ganglion cells of the peripheral retina to the papilla (OD=Optical Disc) and later insertion of the macula centered towards the fovea (F) into the central retina with centripetal insertion of the papillo-macular optic nerve bundle connected to the papilla [6].*

The opening of the retina thus achieved is attractive as a "nutritive pole" [3] for the optic nerves growing out of the ganglion cells of the surface epithelium of the entire retina. With a positioning of the papilla in the zenith of the retina, the development of a central fovea-centered visual field would be made impossible. Therefore, the further developmental steps lead to the shifting of the papilla. Its later position will be on the nasal side. Its function as a collection point of approx. one million nerves, bundled in the optic nerve, becomes there the later "blind spot" in vision. The optic nerve occupies the opening so that it cannot later be populated by photoreceptors. Thus, this first development secures the access of the optic nerves of the retina to the brain and enables the later communication between retina and cortex. It is initially unclear which data from the image space are transmitted brainward via the optic nerve.

3. Development of the Fovea

Very early in prenatal development, rapid proliferation of retinal cell bodies begins in the space between the two retinal limiting membranes. Towards the zenith of the retina, these reach their maximum accumulation. Where the papilla vacates its place in the zenith, new central areas become available temporal to the eye axis and a second pole in the retina is formed at the site of the highest cell density. Its center represents the first site of fixation of the retina at the pigment epithelium lying outside the retina. This fixation extends to the entire rest of the retina. It is accompanied by a re-centering of the ocular axes, with the fovea forming the zenith of the visual axis and establishing the subsequent direct path to the optically fixed visual object (FP in Figure 3).

Abb. 3:

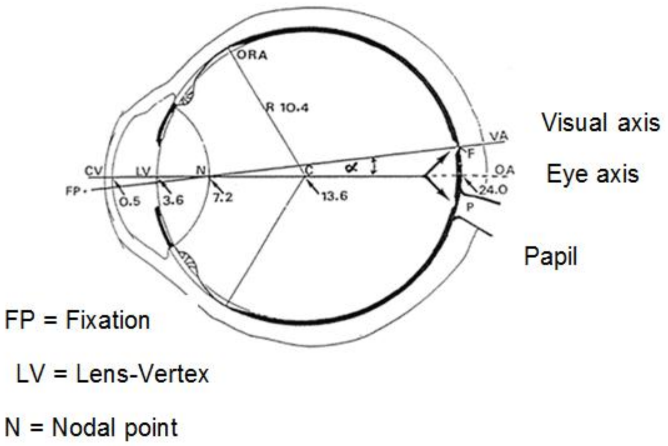

Figure 3. *Supplement of the mechanical eye axis (CV-Eye axis) by the visual axis (F-FP).*

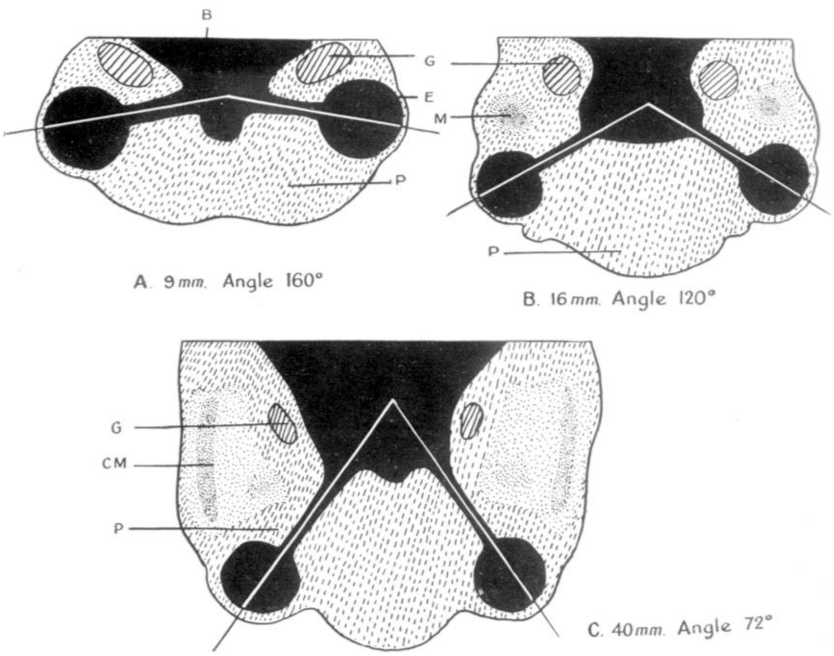

Figure 4. *Reduction of the angles between the bilateral eye axes from 160 ° to 72 °.*

The enlargement of the central area of the retina with its fovea is also made possible by the fact that during the development of the human face, the forehead muscle reduces the angle between the two ocular axes and thus a papillo-macular optic nerve bundle (Figure 4 and Figure 2 right) is embedded in each eye. This succeeds in achieving delayed access to the already successfully formed peripheral optic nerve bundle. Thus, the two central poles of the retina are established early and the cell populations in the retina can advance their further differentiation into the three retinal nuclear layers.

4. The Development of the Retinal Nuclear Layers

Also very early in prenatal development, the initially only single-layered INL nuclear layer produces a strong multiplication of its cells, with increasingly smaller cell bodies filling the layers. I. Mann attributes this role to the Chievitz filters in the retina [9] p. 81. Gradually, these cell clusters differentiate into separate stratifications (Figure 5) thus laying the foundation for cellular grids and spatial lattices, which may have a diffractive role and functionality. A prominent point in this cell body grid is the so-called foveal funnel which illustrates the tensile forces acting in the central retina and at the same time reduces the multilayered grids to a single cellular grid (Figure 6). This cellular layering in the retina takes place exclusively within the two limiting membranes of the retina, and only with their completion does the development of the cones and rods as photoreceptors begin, as they to grow out from the ONL layer of the cellular spatial lattice behind the retina (Figure 7). Thus, it is not until the seventh prenatal month that the basis for photodiode-based imaging is achievable. The late achievement of this photodiode development again proves the importance of the temporally preceding developments which turn the retina into the cortico-retinal peripheral visual sensory organ.

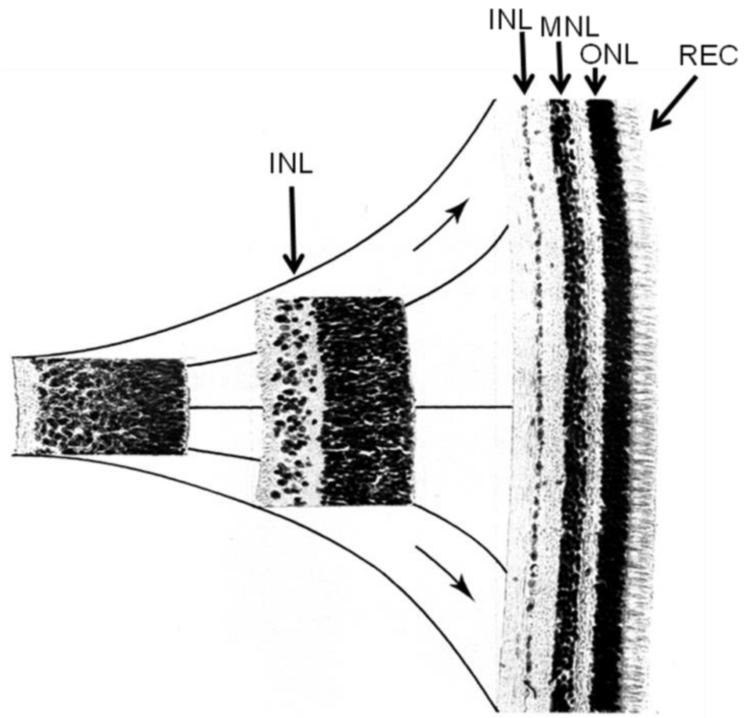

Figure 5. *Differentiation of three retinal cell nuclei layers.*

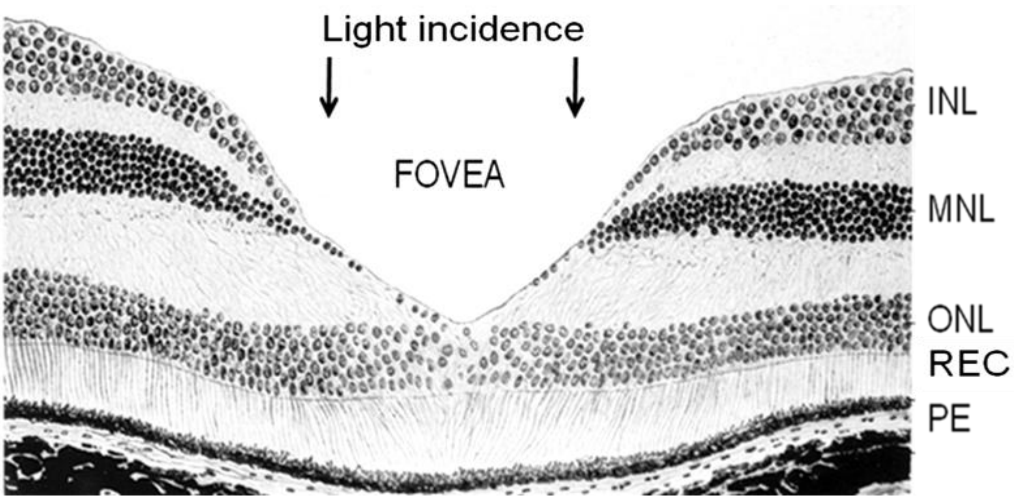

Figure 6. *Reduction of the three grain layers to the ONL layer, which remains upstream of the photoreceptor layer [2, Figure 654, p. 709].*

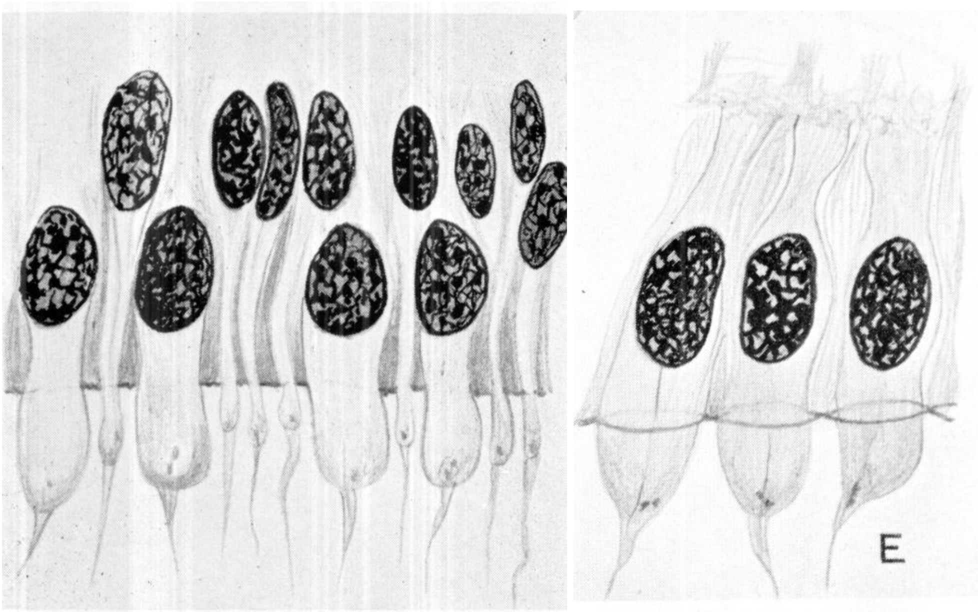

Figure 7. *Outgrowth of photoreceptors (cones and rods) from the ONL layer of the retina [13, Figure 84, p. 103, source: Bach & Seefelder [1]].*

The space lattice optical calculation [10, 11] (Figure 8) was carried out with the elementary hexagonal space lattice cell, in which the lattice constants are located close to the wavelength of light. This approach corresponded to the basis of crystal optics which led to the diffractive diffraction patterns of matter waves due to the dimensional proximity of the atomic distances and the wavelength of the X-ray light [8]. This approach led to three RGB diffraction orders for daylight vision (at 559 nm R, 537 nm G, and 447 nm B) whose peaks are identical to those of the spectral luminosity measured at cones (Figure 9). The corresponding RGB interference maxima are located on six concentric circles. An unexpected feature is that the R and G maxima are located on separate circles, so that no mutual overlaps occur.

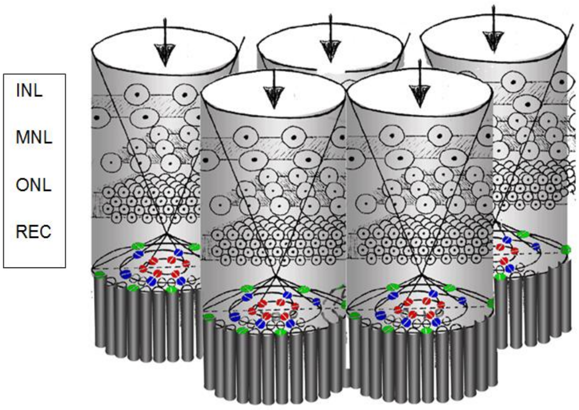

Figure 8. *Space-grating optical image processing in three-grain layers with Fresnel near-field interferences for RGB processing.*

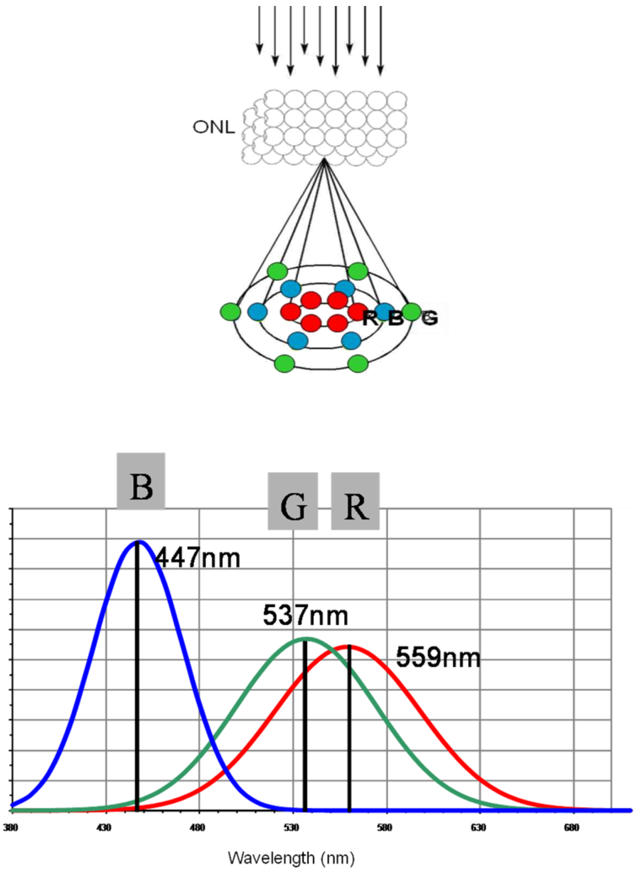

Figure 9. *(left): Light entering the ONL spatial lattice is distributed among three RBG diffraction orders with each being located on their own circular zones. (right): Three RGB luminous sensitivity curves of the cones with their maxima.*

At the same time, it was shown that the space-grating optical diffraction orders cause the G and R diffraction orders to merge at 512 nm when the third grating constant of the space grating is reduced, so that this can explain the Purkinje-shift between daytime and twilight vision. Figure 10 illustrates the loss of colors in the diffraction orders B and G. The transition from twilight to daytime vision results in the corresponding split into G and R.

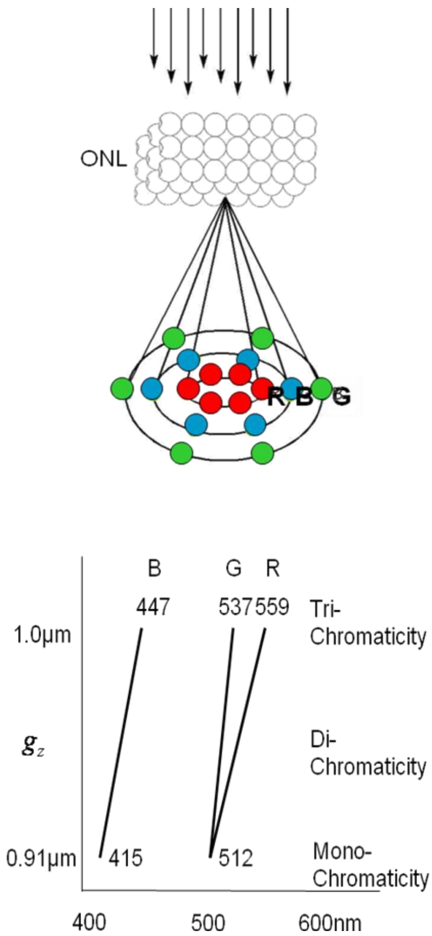

Figure 10. *In twilight vision, adaptation of the third spatial lattice constant causes R to shift from 537 nm G + 559 nm R to 512 nm, the peak of the spectral brightness sensitivity of twilight vision. As a result, the red rose in daylight appears shifted towards the blue color.*

Thus, the space-grating optical calculation explains the fact that - as Figure 6 illustrates - the ONL cell nuclear layer represents the decisive carrier of the trichromatic perception in daytime vision.

The cortical invariant " optical melody" of the visible objects, their pre-verbal conceptual apprehension.

The decisive advantage of cognitive object apprehension is to be found mainly in the fact that the invariant conceptuality of the visible object is apprehended first of all, i.e. already in the INL layer of the retina; this takes place before the spatial or color localization of the same. Figure 11 on the left shows by the example of two triangles how the invariance of the two triangles in their identical "optical melody" is preverbally apprehended by means of the polar vector analysis.

As in acoustics the melody represents an invariant, so in optical image processing the melody of a visual object becomes apprehensible. Figure 11 on the right illustrates how the triangle is apprehended in its invariance and how it is determined and transmitted by means of log-polar object apprehension [5] (Figure 12). More details on this topic can be found in N. Lauinger [9].

Since the reduction to the invariants leads to a considerable reduction of the information to be transmitted, it becomes understandable that the number of sensors involved in the image processing can be considerably lower than the number of chromatic photosensors involved in it. The division of labor between the INL and ONL layers, i.e., between shape and color analysis, is reflected in the thus more complex cortico-retinal image processing [12]. The answer about the relative location of the objects in relation to each other is then probably by means of the three retinal grain layers a less difficult addition which however does not come anywhere close to the binocular spatial vision. The presented image processing is significantly more complex than the previously valid photographic retinal image processing. However, it does not require a construct of an "inverted" retina.

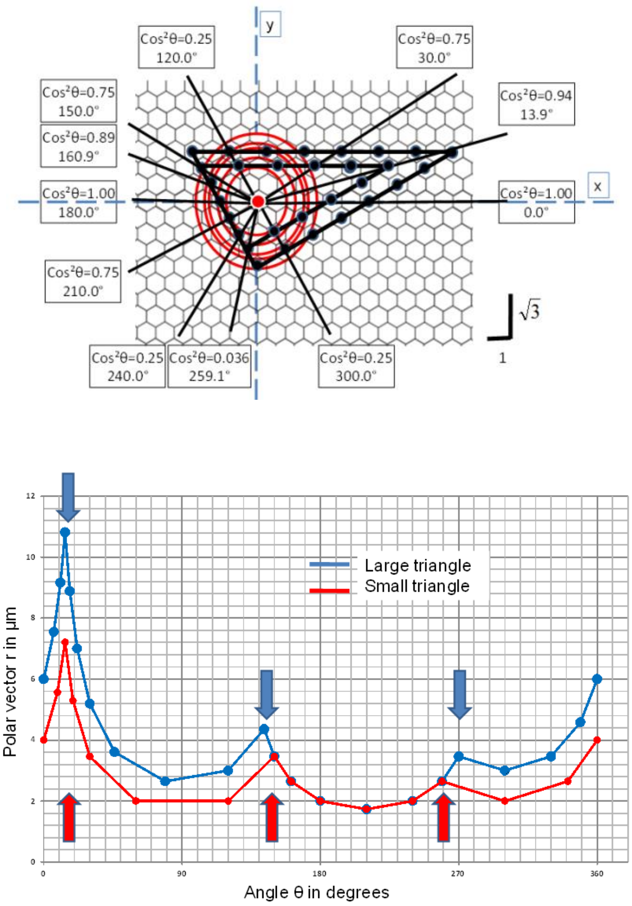

Figure 11. *(left): Polar vector analysis captures the invariant "optical melody" of a triangle by means of another triangle. (right): Thus cortical conceptual object apprehension is achieved.*

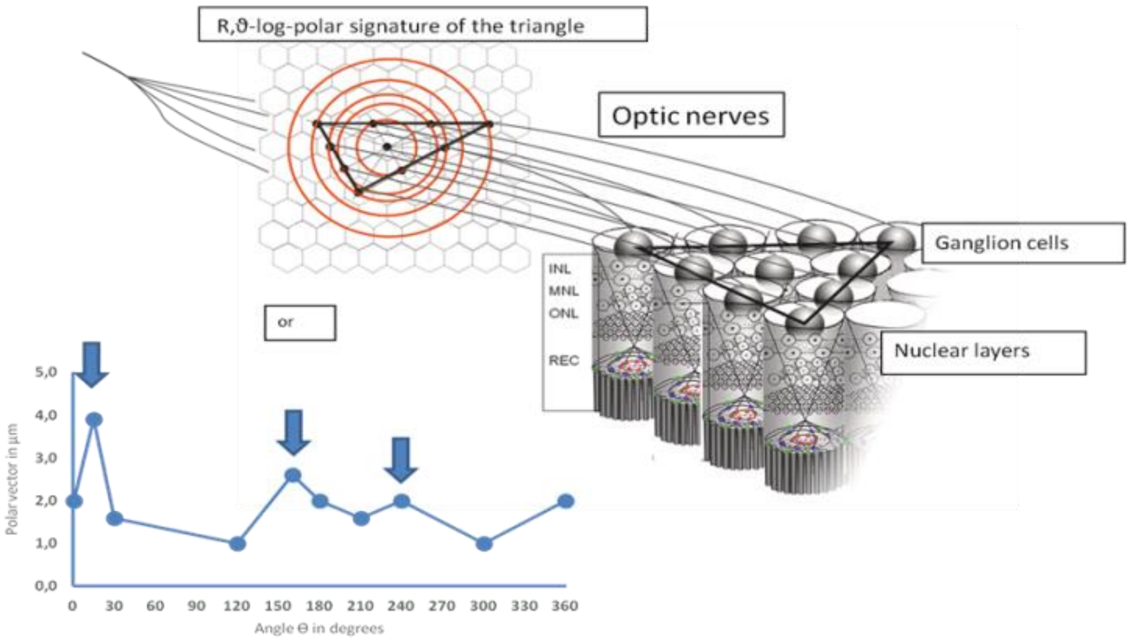

Figure 12. *The invariant "optical melody" of any triangle is transferred into the optic nerve by the nuclei of the INL layer. Further image analysis with respect to object, color or brightness and with respect to the object location in the 3D space is performed in the layers downstream of the INL layer. The amount of data is thus considerably reduced by the INL layer.*

5. The Hierarchy of the Cortico-Retinal Functionalities

If one now tries to establish a connection between the results of the three prenatal developments in the retina and the optical requirements in vision, one encounters partly logical and partly hitherto experimentally not verifiable facts.

The answer to the question WHAT something visible represents invariantly has the highest priority in vision. It could therefore result from the cortical logpolar spatial frequency analysis in the first nuclear layer of the retina. However, it would have to be equally available to daytime and twilight vision because the invariance of visual objects is preserved when switching between the two modes of vision. The only difference would be the difference of 1.0 - 1.4 in the central area of day vision and the visual acuity of 0.2 - 0.6 in the ring zone of the highest rod density. Thus, the invariance of both visual modes would result from the same cell grid of ganglion cells in the INL layer of the retina. Logically, a "house" would remain a house; a "tree" would remain a tree when switching between the two types of vision.

The answer to the question WHERE the visual objects are located relative to each other in the object space, i.e., how the 3rd dimension of the visual object locations is captured, could be provided by two of the remaining nuclear layers (ONL + MNL or MNL + INL) or by all three. Even though binocular vision is better at spatially capturing visual objects than monocular vision, it is still true that the 3rd dimension of visual objects does not completely disappear when one eye is closed. E. Lau proved a corresponding grating-optical functionality by means of two gratings [7].

The third grating optical functionality concerns the production of colors in daytime (photopic) and luminosities in twilight (scotopic) vision. The cellular spatial lattice of the ONL nuclear layer leads by means of the Fresnel near-field interferences to three interference optical diffraction orders (Figure 9), which correspond in daytime vision to the RGB maxima of spectral brightness (559 nm red, 537 nm green, 447 nm blue) and in twilight vision to the two RG maxima of spectral luminance (512 nm) (Figure 10). Both visual modes interact luminance-adaptively in the so-called Purkinje shift when switching from photopic to scotopic vision.

The logical sequence of these three grating-optical functionalities proceeding simultaneously in time and location in the image space of each visual object in the grating optics of the retina, provides a new picture of the histological layout of the structure of the cortico-retinal retina which essentially corresponds to the laws of Fresnel near-field interference and would complement the unchanged laws of ray optics. This logical analysis of double optical image processing does not replace a necessarily experimental treatment of this subject, which was started in the bmbf research project NAMIROS (Nano- and Micro- space-grating Optical Sensing) in 2006 - 2013 under the author's leadership, but was only partly completed. However, it is suitable to end the explanatory attempts regarding an "inverted" retina.

Abbreviations

INL-, MNL- and ONL: inner, middle and outer-nuclear-layer

Conflicts of Interest

The authors declare no conflicts of interest.

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