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Research Report

Ganglion cell densities in normal and dark-reared turtle retinas

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Abstract

In dark-reared, neonatal turtle retinas, ganglion cell receptive fields and dendritic trees grow faster than normal. As a result, their areas may become, on average, up to twice as large as in control retinas. This raises the question of whether the coverage factor of dark-reared ganglion cells is larger than normal. Alternatively, dark rearing may lead to smaller-than-normal cell densities by accelerating apoptosis. To test these alternatives, we investigated the effect of light deprivation on densities and soma sizes of turtle retinal ganglion cells. For this purpose, we marked these cells using retrograde labeling of fixed turtle retinas with DiI (1,1′-dioctadecyl-3,3,3′,3′-tetramethylindocarbocyanine perchlorate). Control turtles were maintained in a regular 12-h light/dark cycle from hatching until 4 weeks of age, whereas dark-reared turtles were maintained in total darkness for the same period. Ganglion cells in the control and dark-reared retinas were found to be similar in density and soma sizes. These results show that the mean coverage factor of turtle dark-reared ganglion cells is larger than normal.

Theme: Sensory systems
Topic: Retina and photoreceptors

Keywords: Ganglion cell; Dark rearing; Retina; Turtle

1. Introduction

Visual deprivation during development dramatically alters the normal refinement of connections and function in the visual system. The alterations occur both in the retina [34,37,38] and in the rest of the brain [5,13,18,26]. In the former, visual deprivation interferes with the normal refinement of synaptic circuits that occur after exposure to light [39,37,41]. This synaptic refinement is reflected in changes of retinal ganglion cell connectivity and synaptic activity [37,38]. In addition, amplitudes of ganglion cell light responses in cat, ferret, and mouse increase after eye opening [39,37,41].

In normal turtle retinas, ganglion cell receptive field areas expand significantly as soon as the animal hatches. They stabilize to their mature size at about 4 weeks post-hatching, when the spontaneous bursting stops [34]. In contrast, in the dark-rearing animal, spontaneous bursting is stronger than normal from hatching and continues past 4 weeks for many months [24]. Moreover, receptive field areas grow faster than normal since hatching [34], becoming twice that in control animals by 4 weeks [34]. Exposure to light does not cause receptive fields to shrink after that [24]. There is a correlation between the exuberant expansion of receptive fields and that of dendritic trees in dark-reared turtle retinas [35].

The exuberant receptive field growth with dark rearing raises a question about the coverage factors of ganglion cells. Coverage factors, i.e., receptive field areas times cell densities, are normally relatively small (typically between 1 and 7) for different kinds of ganglion cells [6,7,28,43]. Coverage factor appears to be so important that, across species [28], it is invariant with development [15] and eccentricity despite wide variation of density [6,7,28,43].

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Invariances like this and developmental studies led to the suggestion that specific competitive mechanisms control the final size of ganglion cell dendritic trees [44]. Developmental studies suggest that this competition exists and is cell-class specific [44,22]. For instance, during a critical postnatal period of mammalian development, removing patches of ganglion cells induces dendrites of neighbor neurons of the same type to grow into the vacated territory [8,17,29]. Therefore, it is widely assumed that homotypic cells interact with one another to constrain the lateral extent of their dendritic fields [1,29,31,43].

In the present study, we investigated the cell number (and soma size) of ganglion cells in control and dark-reared turtle retinas using the lipophilic tracer DiI to test whether the mean coverage factor has been affected.

2. Materials and methods

2.1. Animals

We used ten 4-week-old turtles (*Trachemys scripta elegans*) of either sex for both control (five turtles) and dark-rearing (five turtles) experiments. We obtained retinas from 4-week-old animals because a previous study showed that normally reared ganglion cells stop bursting spontaneously and their receptive field reaches adult size by that time [34]. Before hatching, eggs were incubated in a 30 °C dark oven. This oven mimicked natural conditions, in which turtles bury eggs, leaving them in darkness before hatching. The oven temperature was between the extremes in which development is reasonably satisfactory [46]. Control turtles were fed and housed under cyclic 12-h light/12-h dark conditions from hatching. In turn, we fed and housed dark-reared turtles under completely dark conditions from hatching. Trained personnel conducted all procedures of daily monitoring and routine maintenance of dark-reared turtles under infrared illumination. (For this purpose, they used a pair of infrared sensitive goggles — B.E. Meyers and Co. Inc., Redmond, WA). All procedures were in conformance with the *Guide for Care and Use of Laboratory Animals* (National Institutes of Health). The University of Southern California Institutional Animal Care and Use Committee reviewed and approved all procedures.

2.2. Tissue fixation and DiI labeling

Turtles were decapitated, pithed, and the eyes were removed. Afterwards, we fixed the eyes by immersion in 4% paraformaldehyde in 0.1 M phosphate buffer (PB), pH 7.4, for 1 week. Following fixation, we made an incision in the optic nerve stump and implanted crystals of the lipophilic tracer DiI (1,1′-dioctadecyl-3,3,3′,3′-tetramethylindocarbocyanine perchlorate) (Molecular Probes, Eugene, OR) within the nerve cut. After 8 weeks, we removed whole retinas from the eyes and cover-slipped with 10% glycerol in 0.1 M PB. We observed retinal images with a fluorescence microscope (Leica Microsystems; Leica DM LB2, Bannockburn, IL) at an excitation wavelength of 560 to 590 nm (rhodamine filter). We then imported images into Adobe Photoshop version 7.0 (Adobe Systems, Mountain View, CA). For presentation, we carried out all manipulations equally on all images (brightness and contrast only).

2.3. Hematoxylin staining

The anterior segments of the eyeballs were removed, and the eyecups were fixed in 4% paraformaldehyde in 0.1 M

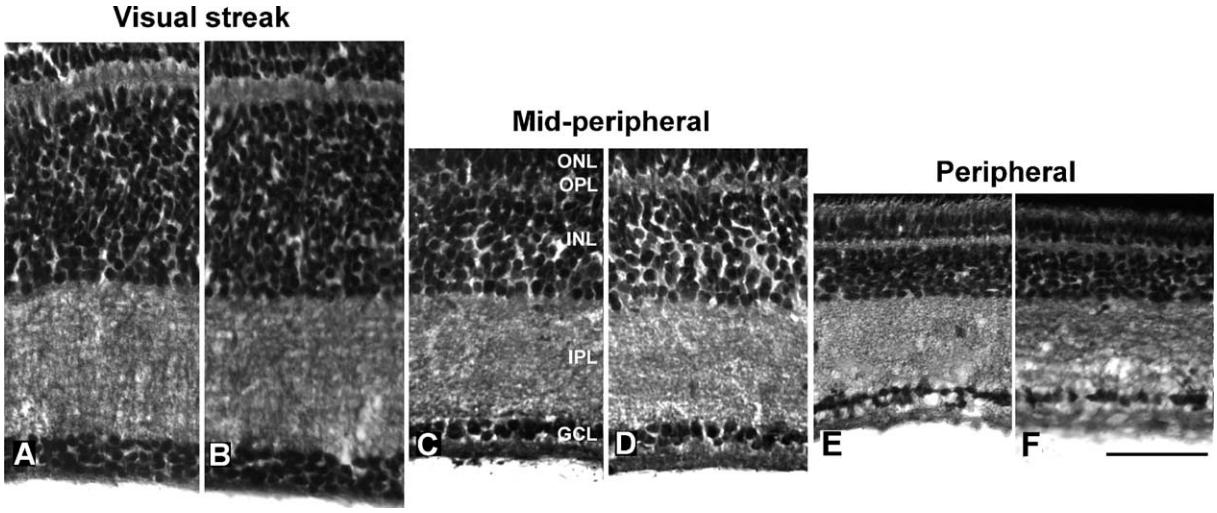

Fig. 1. Light micrographs taken from 15-μm-thick vertical cryostat sections processed by hematoxylin staining. Hematoxylin staining in visual streak (A, B), mid-periphery (C, D), and periphery (E, F) of control (A, C, E) and dark-reared retinas (B, D, F) is seen. Dark rearing induces no detectable changes in the thicknesses of retinal layers. GCL, ganglion cell layer; INL, inner nuclear layer; IPL, inner plexiform layer; ONL, outer nuclear layer; OPL, outer plexiform layer. Scale bar, 50 μm.

phosphate buffer, pH 7.4 (PB) for 2 h at 4 °C. Following fixation, eyecups were then washed by several changes of PB and transferred to 30% sucrose in PB for 5 h at 4 °C. We then embedded eyecups in OCT embedding medium (Tissue-Tek, Elkhart, IN). They were next fast-frozen in liquid nitrogen and sectioned along the vertical meridian on a cryostat at a thickness of 15 μm. We collected sections on gelatin-coated slides for hematoxylin staining. We dipped them in hematoxylin for 5 min. They were then washed in tap water, dehydrated in alcohol, cleared in xylene, and mounted in xylene-based medium (Richard-Allan Scientific, Kalamazoo, MI).

2.4. Topography and quantitation

We analyzed and quantified the topography of ganglion cells in DiI-stained retinas from eyes of control and dark-reared turtles. The data for the density topography maps were plotted using conventional microscopy. For the density maps, a field of 200 μm × 200 μm was sampled in 1-mm steps on the retina in superior-to-inferior and nasal-to-temporal directions. By using an image analyzer (Diagnostic Instruments Inc; Spot advanced software program, Sterling Heights, MI), soma size was measured in eighty DiI-labeled cells. We made these measurements in control and in dark-

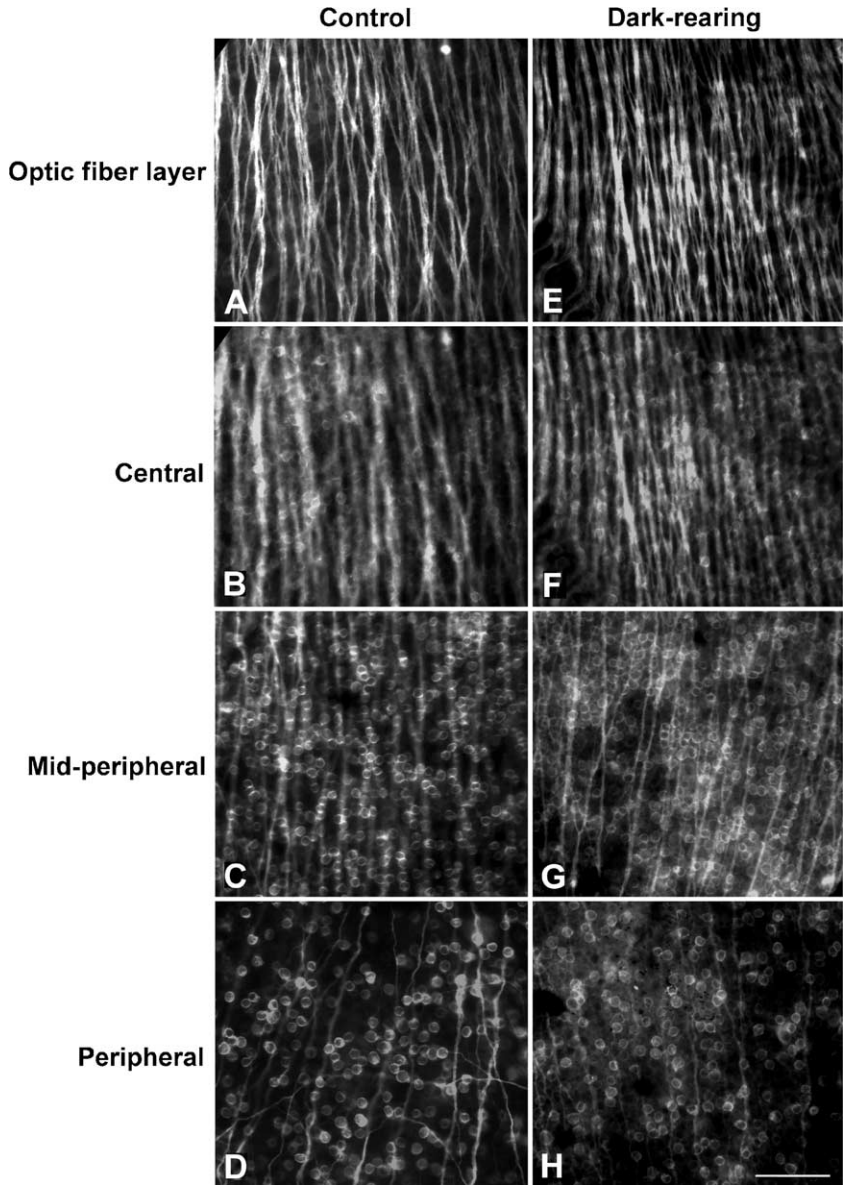

Fig. 2. Light microphotographs taken from whole-mount preparations of control (A–D) and dark-reared (E–H) retinas near the visual streaks of the optic fiber (A, E) and ganglion cell (B, F) layers, mid-periphery of the ganglion cell layer (C, G), and periphery of the ganglion cell layer (D, H). In panels (A) and (E), numerous ganglion cell axons are visible. Panels (A) and (E) are taken at a focal plane just below the focal plane used for panels (B) and (F), in which numerous DiI-labeled cells are seen. In panels (C) and (G), fewer DiI-labeled cells appear compared to area near the visual streak. In panels (D) and (H), fewer DiI-labeled cells appear compared to the mid-periphery. Scale bar, 50 mm.

reared retinas, in both central and peripheral regions. In this paper, means of densities and soma sizes across retinas and regions give representative values. One may under sample ganglion cells from incomplete DiI uptake at the optic stump due to short incubation times [12,36]. Therefore, this methodological restriction does not allow the quantification of the total number of ganglion cells in either control or dark-reared retinas. However, these effects should impact cell number in control and dark-reared retinas equally. Finally, we do not correct densities and sizes for shrinkage of the tissue during the mounting process because this shrinkage is negligible with our methods.

3. Results

If dark rearing caused large changes in neuron number, then one would expect modifications in the thicknesses of retinal layers. Hence, we first set out to check whether these thicknesses changed. The thickness of the outer nuclear (ONL), inner nuclear (INL), and ganglion cell layers (GCL) appeared similar between control (Figs. 1A, C, E) and dark-reared (Figs. 1B, D, F) retinas. This held for the retinal visual streak (Figs. 1A, B), mid-periphery (Figs. 1C, D), and periphery (Figs. 1E, F). In addition, there seemed to be no changes in the thickness of the retinal inner and outer plexiform layers. Therefore, dark rearing induces no detectable changes in the thicknesses of retinal layers. However, measuring thicknesses alone is not a sufficiently sensitive test because of their dependence on the angle of the section. This angle can vary across retinas, adding a degree of uncertainty to the results.

To test whether the mean density of ganglion cells was different in control and dark-reared retinas, we labeled ganglion cells throughout the retina with the retrograde labeling marker DiI. Because DiI is highly lipophilic, it immediately intercalates into the axon membranes. Subsequently, intramembranous DiI diffusion occurs into the soma (Figs. 2A–H). We achieved retrograde labeling of axons and somas, both in control (Figs. 2A–D) and dark-reared (Figs. 2E–H) ganglion cells, within 8 weeks. Therefore, we examined cells in this study 8 weeks after application of the dye. In retinal regions with several layers of ganglion cells, we observed them by using different focal planes of the microscope.

For quantitative analysis, we sampled regions along the superior-to-inferior axis at 3 mm temporally from the retinal optic disc and along the nasal-to-temporal axis along the optic disc (Fig. 3A). We used three retinas from control and three retinas from dark-reared turtles. In the superior-to-inferior sections of control retinas, the DiI-labeled ganglion cell density peaked at 12,300 ± 300 cells/mm^2 around the visual streak. In contrast, the density was minimal at the retinal periphery, with 2840 ± 120 cells/mm^2 (Fig. 3B). In comparison, in dark-reared retinas, the dye labeled 11,400 ± 400 cells/mm^2 within the visual streak and 2770 ± 100 cells/mm^2 within the periphery. In turn, in the nasal-to-temporal section, of control retinas, the DiI-labeled ganglion cell density peaked at 4800 ± 200 cells/mm^2 around the optic disc. Again, the density was minimal at the retinal periphery, with 1890 ± 150 cells/mm^2 (Fig. 3C). In comparison, in dark-reared retinas, the dye labeled 4700 ± 300 cells/mm^2 around the optic disc and 2040 ± 90 cells/mm^2 within the periphery. Consequently, dark-reared densities were not significantly different from those from control retinas, regardless of retinal section.

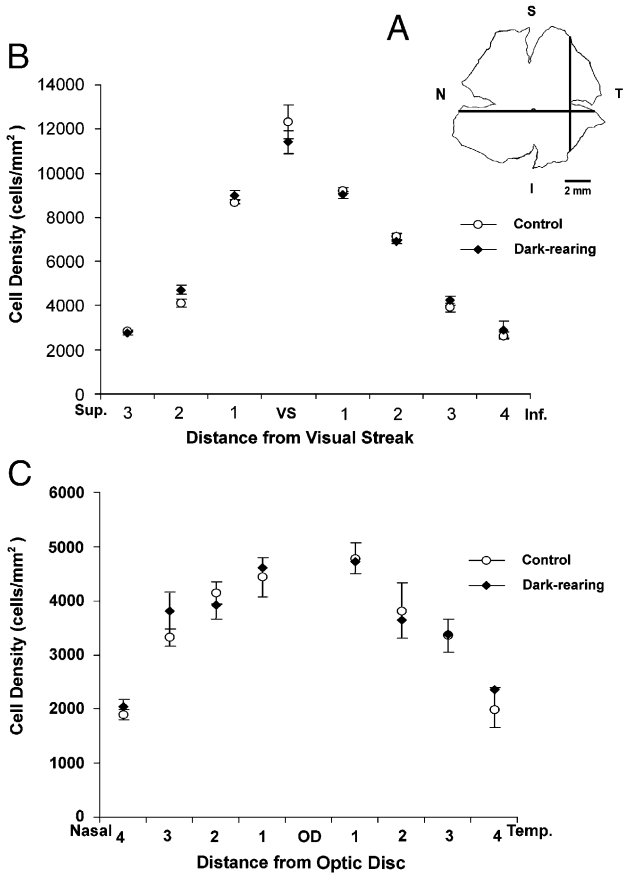

Fig. 3. Density of DiI-labeled cells in whole mounts of control and dark-reared retinas. The black lines in the map of the whole mount indicate the directions along which the density measurements were taken. (A) A map of the whole mount. (B) Ganglion cell densities from superior region to inferior region in control and dark-reared retinas. (C) Ganglion cell densities from nasal region to temporal region in control and dark-reared retinas. The data show that dark rearing does not affect the ganglion cells' density topography. S, superior; T, temporal; I, inferior; N, nasal. Scale bar, 2 mm.

That we did not find changes in the density of ganglion cells and in retinal layer thicknesses suggests that dark rearing also does not affect soma sizes. Sizes of DiI-labeled ganglion cells were thus analyzed in control and dark-reared retinas. Soma sizes were measured from DiI-labeled ganglion cells located in central (Fig. 4A) and peripheral (Fig. 4B) regions. In both control and dark-reared retinas, the mean soma diameter of DiI-labeled cells in the central region was 8 ± 1 μm. In periphery, the soma diameter was

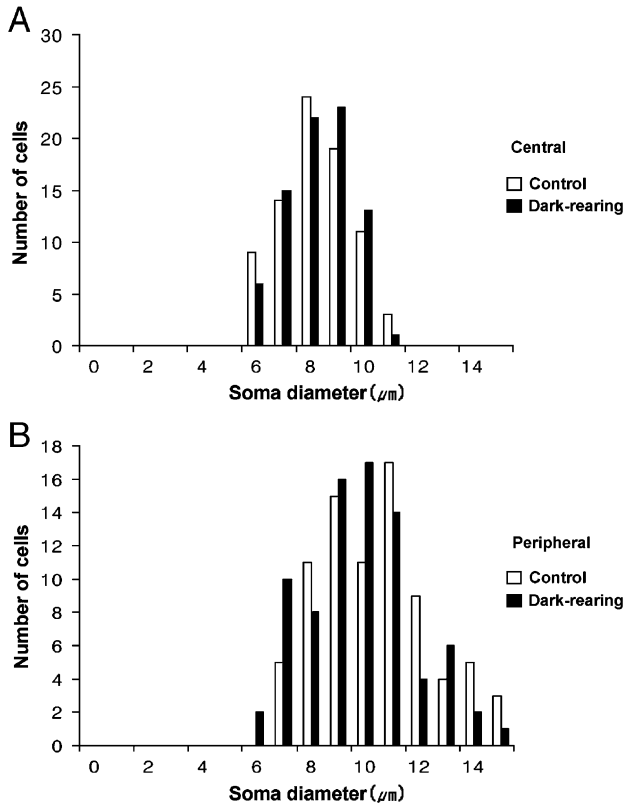

Fig. 4. Soma diameter histograms for ganglion cells in control and dark-reared turtle retinas. DiI-labeled cells were sampled from the GCL at central (A) and peripheral (B) regions of whole-mount retinas. Dark rearing does not affect the distributions of sizes of somas of ganglion cells.

10 ± 2 μm in both control and dark-reared retinas. Hence, the GCL thickness does not change with dark rearing because neither the density nor the cell size varies.

4. Discussion

Our results demonstrate the absence of significant changes in mean ganglion cell density in any region of the dark-reared retina compared to that of the control retina. In other words, retinal density topography is maintained despite dark rearing. The density of ganglion cells from superior to inferior retina has a peak in the visual streak, and the density of ganglion cells from nasal to temporal retina has a peak around the optic disc. These densities reach minima in the periphery in both control and dark-reared retinas. The control result is consistent with prior density measurements from the same species obtained with horseradish peroxidase staining [30]. However, the horseradish peroxidase density gradient was somewhat different from our results. Peterson and Ulinski [30] showed a less precipitous gradient between the streak and the ventral periphery of the retina. The discrepancy between their results and ours may be due to miscounting of ganglion cells, which may overlap in high-density areas of control and dark-reared retinas. Nevertheless, both DiI and horseradish peroxidase label more than 80% of ganglion cells in the retina [30,40]. Therefore, results from both studies showed no significant difference in number of ganglion cells.

The lack of density change with dark rearing may seem obvious. This is because, at least in mammals, the number of cells is already established before eye opening [10,11]. However, this lack of change is not so obvious as, for example, Benevento et al. [3] found a higher density of total cells in all visual cortical layers of dark-reared rats. Our observation also appears to be different from similar findings in cats by Mower et al. [27]. Nevertheless, Mower attributed most of the difference to decreased thickness of the cortical mantle and not to an increase in cell number. Our results are in line with Mower's interpretation, i.e., that dark rearing does not affect cell number.

This independence of density and density topography with light exposure is accompanied by a similar independence of ganglion cell soma size. This result was not so obvious a priori because receptive fields and dendritic trees grew exuberantly with dark rearing (Introduction). It was not clear that an exuberant growth in dendritic tree would not require growth in soma size. One of the implications of the constancy of soma size is that retinal nuclear layers should not change anywhere in the retina. Our measurements confirm this result directly.

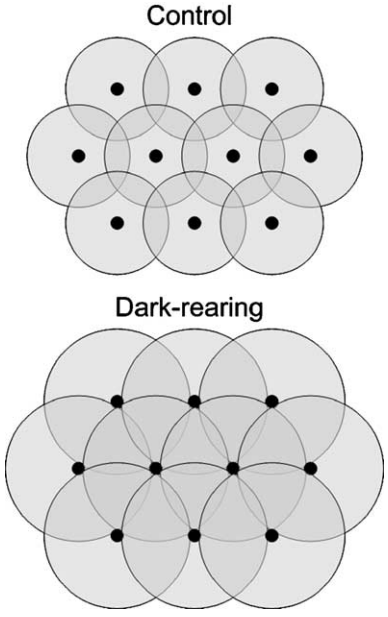

Fig. 5. Schematic drawing of the lattice of ganglion cell receptive fields in control and dark-reared retinas. The black spots indicate the middle of receptive fields, showing that the lattice is the same in both conditions, and the transparent gray disks indicate receptive field spans. While receptive fields are small in the control retina, they are large in the dark-reared retina. In this schematic, coverage factors are 1.53 and 3.06 (i.e., double) under control and dark-rearing conditions respectively. In other words, receptive fields in the dark-reared retina show excessive overlap compared to the control retina. This is illustrated by the difference in the abundance of darker (overlap) areas.

However, with the data in this paper, we cannot settle the question of whether some classes of ganglion cells have their density or soma size changed. Our data show that the soma diameter is diverse in central and peripheral regions of the retina. Soma diameters range from 6 μm to 14 μm in each region. The variety of soma sizes in each region is probably due to different types of ganglion cells present. It is possible that the relatively rare types of ganglion cells undergo changes that cannot be detected with our methods. In support of this possibility, we recently reported that the detectable levels of some classes of amacrine cells change with dark rearing [25].

In contrast to density and soma size, light exposure controls the development of the size of ganglion cell receptive fields and dendritic trees in turtle [34,35]. In the retina, ganglion cells are divided into classes based on differences in function and morphology. The somata of ganglion cells within a class are evenly spaced, and dendrites of neighboring cells fill the available space with efficient overlap (Introduction). In other words, their coverage factor is relatively small. The retina achieves small coverage factors during development by competition mechanisms that cause an inverse correlation between density and dendritic-field size even before exposure to light [4,20,32,33,42]. Because the density of ganglion cells is not changed by dark rearing, the larger retinal ganglion cell receptive fields found after dark rearing imply a change of the mean coverage factor (Fig. 5).

Changes of dendritic trees and coverage factors suggest that some cytoskeletal elements that constrain, direct, and mediate the cellular response to environmental signals are abnormal in the dark-rearing condition. Those signals may include secreted growth factors, extracellular matrix molecules, or membrane-bound or activity-dependent signaling provided by other cells in the vicinity. These cells may include afferents and homotypic neighbors [16,19,23,45]. However, we did not examine a specific cell type of ganglion cell in this study. Therefore, we do not know whether overlapping receptive fields and dendritic trees are formed within homotypic cell types, heterotypic cell types, or both. Recent reports showed that, for certain cells, dendritic tree size is independently determined from homotypic cells and/or cell number in the mouse retina [9,21].

The increase in coverage implies that dark rearing leads to lower visual spatial acuity. Perhaps, in darkness, the visual system gives up some acuity to capture more of the scarce photons. The system may do this by increasing the size of the integration area, i.e., the size of the retinal receptive field. This hypothesis has parallels in recent theories for retinal adaptation [2,14]. Therefore, overlapping retinal receptive fields may lead to an undesirable, but possibly necessary, redundancy in the neural representation of visual space in the dark-reared turtle's visual system.

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References

[1] F.R. Amthor, C.W. Oyster, Spatial organization of retinal information about the direction of image motion, Proc. Natl. Acad. Sci. U. S. A. 92 (1995) 4002–4005.
[2] R.M. Balboa, N.M. Grzywacz, The role of early retinal lateral inhibition: more than maximizing luminance information, Vis. Neurosci. 17 (2000) 77–89.
[3] L.A. Benevento, B.W. Bakkum, R.S. Cohen, Gamma-aminobutyric acid and somatostatin immunoreactivity in the visual cortex of normal and dark-reared rats, Brain Res. 689 (1995) 172–182.
[4] A. Cellerino, E. Novelli, L. Galli-Resta, Retinal ganglion cells with NADPH-diaphorase activity in the chick form a regular mosaic with a strong dorsoventral asymmetry that can be modelled by a minimal spacing rule, Eur. J. Neurosci. 12 (2000) 613–620.
[5] M. Cynader, D.E. Mitchell, Prolonged sensitivity to monocular deprivation in dark-reared cats, J. Neurophysiol. 43 (1980) 1026–1040.
[6] D.M. Dacey, Monoamine-accumulating ganglion cell type of the cat's retina, J. Comp. Neurol. 288 (1989) 59–80.
[7] D.M. Dacey, The mosaic of midget ganglion cells in the human retina, J. Neurosci. 13 (1993) 5334–5355.
[8] U.T. Eysel, L. Peichl, H. Wässle, Dendritic plasticity in the early postnatal feline retina: quantitative characteristics and sensitive period, J. Comp. Neurol. 242 (1985) 134–145.
[9] R. Farajian, M.A. Raven, K. Cusato, B.E. Reese, Cellular positioning and dendritic field size of cholinergic amacrine cells are impervious to early ablation of neighboring cells in the mouse retina, Vis. Neurosci. 21 (2004) 13–22.
[10] L.J. Fisher, Development of retinal synaptic arrays in the inner plexiform layer of dark-reared mice, J. Embryol. Exp. Morphol. 54 (1979) 219–227.
[11] L.J. Fisher, Development of synaptic arrays in the inner plexiform layer of neonatal mouse retina, J. Comp. Neurol. 187 (1979) 359–372.
[12] P. Godement, J. Vanselow, S. Thanos, F. Bonhoeffer, A study in developing visual systems with a new method of staining neurons and their processes in fixed tissue, Development 101 (1987) 697–713.
[13] J.A. Gordon, M.P. Stryker, Experience-dependent plasticity of binocular responses in the primary visual cortex of the mouse, J. Neurosci. 16 (1996) 3274–3286.
[14] N.M. Grzywacz, R.M. Balboa, A Bayesian framework for sensory adaptation, Neural Comput. 14 (2002) 543–559.
[15] P.F. Hitchcock, Constant dendritic coverage by ganglion cells with growth of the goldfish's retina, Vis. Res. 27 (1987) 17–22.
[16] J.Y. Hua, S.J. Smith, Neural activity and the dynamics of central nervous system development, Nat. Neurosci. 7 (2004) 327–332.
[17] M.A. Kirby, L.M. Chalupa, Retinal crowding alters the morphology of alpha ganglion cells, J. Comp. Neurol. 251 (1986) 532–541.
[18] A. Kirkwood, M.C. Rioult, M.F. Bear, Experience-dependent modification of synaptic plasticity in visual cortex, Nature 381 (1996) 526–528.
[19] A.G. Leventhal, J.D. Schall, S.J. Ault, Extrinsic determinants of retinal ganglion cell structure in the cat, J. Neurosci. 8 (1988) 2028–2038.
[20] B. Lia, R.W. Williams, L.M. Chalupa, Formation of retinal ganglion cell topography during prenatal development, Science 236 (1987) 848–851.

[21] B. Lin, S.W. Wang, R.H. Masland, Retinal ganglion cell type, size, and spacing can be specified independent of homotypic dendritic contacts, Neuron 43 (2004) 475–485.
[22] C. Lohmann, R.O. Wong, Cell-type specific dendritic contacts between retinal ganglion cells during development, J. Neurobiol. 48 (2001) 150–162.
[23] B. Lom, J. Cogen, A.L. Sanchez, T. Vu, S. Cohen-Cory, Local and target-derived brain-derived neurotrophic factor exert opposing effects on the dendritic arborization of retinal ganglion cells in vivo, J. Neurosci. 22 (2002) 7639–7649.
[24] D.K. Merwine, N.M. Grzywacz, F.R. Amthor, Persistent effects of dark rearing on the development of turtle retinal ganglion cells, Neuroscience 24 (1998) (E-Abstract 1518).
[25] D.K. Merwine, E.J. Lee, L.B. Mann, N.M. Grzywacz, Alteration of retinal cholinergic circuitry by dark rearing, Invest. Ophthalmol. Visual Sci. 46 (2005) (E-Abstract 4023).
[26] G.D. Mower, The effect of dark rearing on the time course of the critical period in cat visual cortex, Brain Res. Dev. Brain Res. 58 (1991) 151–158.
[27] G.D. Mower, R. Rustad, W.F. White, Quantitative comparisons of gamma-aminobutyric acid neurons and receptors in the visual cortex of normal and dark-reared cats, J. Comp. Neurol. 272 (1988) 293–302.
[28] L. Peichl, Alpha ganglion cells in mammalian retinae: common properties, species differences, and some comments on other ganglion cells, Vis. Neurosci. 7 (1991) 155–169.
[29] V.H. Perry, R. Linden, Evidence for dendritic competition in the developing retina, Nature 297 (1982) 683–685.
[30] E.H. Peterson, P.S. Ulinski, Quantitative studies of retinal ganglion cells in a turtle, *Pseudemys scripta elegans*: I. Number and distribution of ganglion cells, J. Comp. Neurol. 186 (1979) 17–42.
[31] B.E. Reese, M.A. Raven, S.B. Stagg, Afferents and homotypic neighbors regulate horizontal cell morphology, connectivity, and retinal coverage, J. Neurosci. 25 (2005) 2167–2175.
[32] R.W. Rodieck, D.W. Marshak, Spatial density and distribution of choline acetyltransferase immunoreactive cells in human, macaque, and baboon retinas, J. Comp. Neurol. 321 (1992) 46–64.
[33] R. Scheibe, J. Schnitzer, J. Rohrenbeck, F. Wohlrab, A. Reichenbach, Development of A-type (axonless) horizontal cells in the rabbit retina, J. Comp. Neurol. 354 (1995) 438–458.
[34] E. Sernagor, N.M. Grzywacz, Influence of spontaneous activity and visual experience on developing retinal receptive fields, Curr. Biol. 6 (1996) 1503–1508.
[35] E. Sernagor, V. Mehta, The role of early neural activity in the maturation of turtle retinal function, J. Anat. 199 (2001) 375–383.
[36] S. Thanos, J.M. Rohrbach, H.J. Thiel, Postmortem preservation of ganglion cells in the human retina. A morphometric investigation with the carbocyanine dye DiI, Retina 11 (1991) 318–327.
[37] N. Tian, D.R. Copenhagen, Visual deprivation alters development of synaptic function in inner retina after eye opening, Neuron. 32 (2001) 439–449.
[38] N. Tian, D.R. Copenhagen, Visual stimulation is required for refinement of ON and OFF pathways in postnatal retina, Neuron 39 (2003) 85–96.
[39] J.S. Tootle, Early postnatal development of visual function in ganglion cells of the cat retina, J. Neurophysiol. 69 (1993) 1645–1660.
[40] M. Vidal-Sanz, M.P. Villegas-Perez, G.M. Bray, A.J. Aguayo, Persistent retrograde labeling of adult rat retinal ganglion cells with the carbocyanine dye diI, Exp. Neurol. 102 (1988) 92–101.
[41] G.Y. Wang, L.C. Liets, L.M. Chalupa, Unique functional properties of on and off pathways in the developing mammalian retina, J. Neurosci. 21 (2001) 4310–4317.
[42] H. Wässle, Dendritic maturation of retinal ganglion cells, Trends Neurosci. 11 (1988) 87–89.
[43] H. Wässle, L. Peichl, B.B. Boycott, Dendritic territories of cat retinal ganglion cells, Nature 292 (1981) 344–345.
[44] A.J. Weber, R.E. Kalil, L.R. Stanford, Dendritic field development of retinal ganglion cells in the cat following neonatal damage to visual cortex: evidence for cell class specific interactions, J. Comp. Neurol. 390 (1998) 470–480.
[45] R.O. Wong, A. Ghosh, Activity-dependent regulation of dendritic growth and patterning, Nat. Rev., Neurosci. 3 (2002) 803–812.
[46] C.L. Yntema, A series of stages in the embryonic development of Chelydra serpentine, J. Morphol. 125 (1968) 219–251.