The visual pathway and field defects model

David A. Lotz

Pacific University
The visual pathway and field defects model

Abstract
A solid comprehension of the visual pathway is important in understanding and diagnosing the many pathologies that can have an effect on the way individuals perceive the world around them. Beginning with the retina and progressing through to the visual cortex of the brain, this literature review traces the distribution and flow of nerve fibers within the visual pathway as they are currently understood. The Field Defects Model, a representation of this pathway, demonstrates how various lesions or disturbances in the pathway can affect the perceived visual field. This paper and model were developed as training aids to effectively assist optometric students in gaining a thorough understanding of this most important pathway of vision.

Degree Type
Thesis

Degree Name
Master of Science in Vision Science

Committee Chair
Lee Ann Remington O.D.

Subject Categories
Optometry

This thesis is available at CommonKnowledge: https://commons.pacificu.edu/opt/891
THE VISUAL PATHWAY

AND

FIELD DEFECTS MODEL

BY

DAVID A. LOTZ

A thesis submitted to the faculty of the
College of Optometry
Pacific University
Forest Grove, Oregon
for the degree of
Doctor of Optometry
January 1989

Advisor:
Lee Ann Remington, O.D.
David A. Lotz has attended Pacific University and Portland State University. He received his B.S. degree from Pacific University College of Arts and Sciences in May 1987. From Pacific University College of Optometry, he will receive the O.D. degree in January 1989. He has purchased a solo private practice in the city of Suffolk, Virginia and will begin practicing full-scope optometry in February 1989.
Abstract:
A solid comprehension of the visual pathway is important in understanding and diagnosing the many pathologies that can have an effect on the way individuals perceive the world around them. Beginning with the retina and progressing through to the visual cortex of the brain, this literature review traces the distribution and flow of nerve fibers within the visual pathway as they are currently understood. The Field Defects Model, a representation of this pathway, demonstrates how various lesions or disturbances in the pathway can affect the perceived visual field. This paper and model were developed as training aids to effectively assist optometric students in gaining a thorough understanding of this most important pathway of vision.
I would like to thank my advisor, Dr. Lee Ann Remington, for the assistance and motivation she has provided me. I hope she will be able to put this project to the use for which it was intended.
Retinal Nerve Fiber Layer:

The visual pathway begins in the retinal nerve fiber layer. The first order neuron is the bipolar cell of the rod or cone. Its length is the thickness of the retina, about 0.1 - 0.5 mm. The second order neuron starts with the cell body of the ganglion cell. Its length is continuous from the retinal nerve fiber layer, through the optic nerve, optic chiasm and optic tract to the Lateral Geniculate Nucleus (LGN). The third order neuron has its cell body in the LGN and its length passes through the optic radiations to the visual cortex (1).

The vertical line of demarcation between nasal and temporal retinal hemispheres passes directly through the center of the macula. The division between superior and inferior retinal hemispheres is a horizontal line passing through the centers of the optic disc, macula and along the horizontal raphe'. Therefore, the macula serves as the intersection of a line that divides the retina into four quadrants:

1. superior nasal retinal quadrant
2. inferior nasal retinal quadrant
3. superior temporal retinal quadrant
4. inferior temporal retinal quadrant (2)

Nerve fibers from individual ganglion cells run parallel to the retinal surface and converge toward the optic disc in a constant and characteristic arrangement. There are five major divisions of these fibers:

1. papillo-macular (P-M) bundle - superior and inferior divisions pass directly from the macula to the optic disc
2. superior arcuate fibers - arise temporally from the horizontal raphe', arch over the P-M bundle and go to the optic disc
3. superior radiating bundle - arises nasally from the horizontal line of demarcation and passes through the superior nasal retinal quadrant to the optic disc
4. inferior arcuate fibers - arise temporally from the horizontal raphe', arch under the P-M bundle and go to the optic disc
5. inferior radiating bundle - arises nasally from the horizontal line of demarcation and passes through the inferior nasal retinal quadrant to the optic disc (3)

At the margins, the disc is thinnest temporally where the P-M bundle enters, thicker in the superior and inferior temporal quadrants and thickest in the superior and inferior nasal quadrants (4). Fibers from the peripheral retina lie deeper in the nerve fiber layer and enter more peripherally in the optic nerve. Central fibers lie nearer the vitreous and enter the optic nerve more centrally. The P-M bundle fibers enter the disc along 1/4 - 1/3 of its temporal margin (5).
Optic Nerve:

Being only 5 cm in total length (6), there are about 1.1 - 1.3 million afferent axons that make up the optic nerve (7). This accounts for about 40% of all afferent cranial nerves (8). Of these 1.1 - 1.3 million fibers, about 30% come from the macula (9). Optic nerve fibers can vary in diameter from 0.7 - 10 um. 92% of these fibers come from midget ganglion cells within the retina and are less than 1 um in diameter. Of the larger fibers which come from axons in the peripheral retina, most are about 2 um in diameter (10). These axons are arranged into small bundles of nerve fibers within the optic nerve and are separated from each other by tissue partitions called septa (11).

Near the eye, the distribution of nerve fibers in the optic nerve is exactly as found in the retina:

1. temporal retinal fibers are lateral in the optic nerve
2. nasal retinal fibers are medial in the optic nerve
3. superior and inferior retinal fibers are respective in the optic nerve
4. macular fibers are along the horizontal midline of the lateral optic nerve (12)

Near the optic chiasm, the peripheral fibers maintain their retinal orientation, but the macular fibers lose their bundle arrangement and spread diffusely throughout the optic nerve (13).

Optic Chiasm:

In general, three types of segregation occur within the optic chiasm:

1. by altitude: fibers from the superior retina and optic nerve are directed to the medial aspect of the optic tracts and fibers from the inferior retina and optic nerve are directed to the lateral aspect of the optic tracts.
2. by fiber diameter: small diameter fibers, primarily from the macula, are located superiorly in the optic chiasm and optic tract. Large diameter fibers from the peripheral retina are located inferiorly in optic chiasm and optic tract (14).
3. by visual field: fibers from both eyes carrying the left visual field are associated in the right optic tract and fibers from both eyes carrying the right visual field are associated in the left optic tract.

In brief, superior temporal fibers remain in the superior lateral portion of the optic chiasm, then swing into the medial aspect of the optic tracts. Inferior temporal fibers remain in the inferior lateral portion of the optic chiasm, then swing into the lateral aspect of the optic tracts. Superior nasal fibers cross in the superior posterior optic chiasm and swing into the medial aspect of the optic tracts. Inferior nasal fibers cross in the inferior anterior optic
chiasm and swing into the lateral aspect of the optic tracts. Macular fibers remain diffusely spread-out through the entire chiasm except for the anterior and inferior posterior aspects where no macular fibers are found (15).

As the temporal optic nerve fibers near the chiasm, they form into compact fascicles in the lateral quadrants of the optic nerve. Once into the optic chiasm, these fascicles open to allow the mingling of ipsilateral nasal fibers that are yet to cross and contralateral nasal fibers that have already crossed. The temporal fibers then continue to run posteriorly in the lateral optic chiasm with the superior temporal fibers remaining above the inferior temporal fibers. As the fibers enter the optic tract, the superior fibers rotate into the medial portion of the tract and the inferior fibers rotate into the lateral portion of the tract.

All of the nasal fibers cross in the optic chiasm to the contralateral optic tract. Superior nasal fibers from the medial optic nerve, mingle with the opened temporal fascicles in the chiasm and move posteriorly through the chiasm before crossing. The most lateral of these fibers form posterior loops in the anterior portion of the optic tract then cross in the most posterior portion of the optic chiasm. The superior nasal fibers cross in the superior posterior portion of the chiasm, mingle again with the opened temporal fascicles and then rotate into the medial aspect of the optic tract.

 Inferior nasal fibers from the medial optic nerve, mingle with the opened temporal fascicles then cross in the inferior anterior portion of the optic chiasm. The most medial of the inferior nasal fibers form anterior loops in the terminal portion of the opposite optic nerve after crossing in the most anterior portion of the optic chiasm. Once having crossed, inferior nasal fibers mingle again with the opened temporal fascicles and then rotate into the lateral aspect of the optic tract. The anterior and posterior loops cross adjacent fibers at right angles to form a basketwork of interlacing fibers. (16).

Fibers from the extreme nasal peripheral retina, forming the temporal crescent of the visual field, are found superior and inferior in the optic chiasm. These temporal crescents are monocular fields due to blockage of one field by the nose (17).

Macular and central retinal fibers occupy most of the central optic chiasm superior to the decussating peripheral nasal fibers. Macular fibers enter somewhat centrally in the anterior portion of the lateral chiasm. Crossing macular fibers separate from non-crossing macular fibers and pass obliquely as a group posterior and superior in the optic chiasm to decussate with macular fibers from the contralateral retina. The macular fibers that do not cross continue posteriorly in the superior portion of the lateral chiasm (18).
Optic Tract:

Uncrossed superior temporal fibers are grouped with superior nasal fibers from the contralateral retina and travel in the medial portion of the optic tract. Inferior temporal fibers are grouped with the inferior nasal fibers from the contralateral retina and travel in the lateral portion of the optic tract. Macular fibers from the ipsilateral and contralateral retinas spread out in the superior optic tract and mix, medially and laterally, with the superior and inferior nasal and temporal fibers (19).

The anterior portion of the optic tract is shaped like a rounded band, but becomes flattened as it passes the cerebral peduncles (20). The posterior (medial) portion of the optic tract develops a shallow sulcus which divides into lateral (geniculate) and medial (colliculus) roots. Fibers in the medial root pass close to the LGN, but have no known visual function in man. Fibers in the lateral root spread over and end in the LGN. The sulcus between the roots runs into the hilum of the LGN to form a definite cleft. Fibers in the optic tract go to the:

1. LGN - to be relayed to the visual cortex as a continuation of the visual pathway
2. pretectal nuclei - as part of the pupillo-constrictor pathway
3. superior colliculi - for pupillary light reflex responses (21)

Lateral Geniculate Nuclei:

The optic tract enters the LGN at the anterior aspect of its rim. Most of the LGN is hidden in the pulvinar. A sagittal section through the LGN shows fibers of the optic tract dividing into two layers - inferior and superior. The inferior layer is in the white layer of the hilum and the superior layer is in the dorsal portion of the saddle. The optic radiations exit the dorsal LGN into the area of Wernicke (22).

Fibers from the superior peripheral retina go from the medial optic tract to the medial portion of the LGN. Fibers from the inferior peripheral retina go from the lateral optic tract to the lateral portion of the LGN. All these peripheral fibers appear more anteriorly in the LGN. The macular area is roughly cuneiform and is confined to the posterior 2/3 of the LGN (23).

The LGN has six layers or laminae, showing a high level of organization and some amount of inter-neuronal processing. These laminae are like six irregular, stacked cones numbering 1 to 6 from inferior to superior (ventral to dorsal). They contain the nerve cell bodies of the third order neurons, with synapses from the retinal nerve fibers, that project their axons to the visual cortex via the optic radiations (24).
Except for the macula, there is a regular point to point localization between the retina and LGN. The six laminae alternately receive contralateral and ipsilateral retinal fibers. Layers 1, 4 & 6 receive contralateral fibers and layers 2, 3 & 5 receive ipsilateral fibers. With this arrangement, fibers from corresponding retinal areas are located in similar parts of adjacent layers. However, no fusion results - only relay and processing of information (25).

In the posterior LGN, the four dorsal layers (3 - 6) are parvocellular or small cell layers and the two ventral layers (1 & 2) are magnocellular or large cell layers. Layers 4 & 6, from the contralateral retina, fuse into a single dorsal parvocellular layer in the anterior LGN. Layers 3 & 5, from the ipsilateral retina, fuse to form a single ventral parvocellular layer in the anterior LGN. Layer 1 receives contralateral input and layer 2 receives ipsilateral input, but these two layers are not subdivided (26).

Optic Radiations (of Gratiolet):

The optic radiations, also called the geniculo-calc当地 pathway, carry visual impulses to the visual cortex - an area of thin cortex in the occipital lobe (less than 1.4 mm thick). This area is also called the stria due to its white stripe when seen in cross section (27).

The optic radiations extend to the superior and inferior lips of the calcarine fissure (Brodman's area 17 - or the area striata) and are composed of fiber bundles in a parallel arrangement that can be anatomically subdivided into three branches:

1. dorsal horizontal branch - arises from the medial portion of the LGN carrying fibers from the superior retina to the superior (dorsal) lip of the calcarine fissure. Fibers from the superior peripheral retina are located anteriorly along the fissure and central retinal fibers are located more posteriorly along the fissure.

2. ventral horizontal branch - arises from the lateral portion of the LGN carrying fibers from the inferior retina (28) and passes anteriorly around the tip of the temporal horn of the lateral ventricle to form the temporal loop of Flechsig-Archambault-Meyer, commonly called Meyer's Loops (29). This branch then goes to the inferior (ventral) lip of the calcarine fissure. Again, fibers from the inferior peripheral retina are located anteriorly along the fissure and central retinal fibers are located more posteriorly along the fissure.

3. perpendicular or intermediate branch - arises from the large middle segment of the LGN carrying superior and inferior macular fibers and goes to the occipital pole (30).