Some assembly required: building a hands-on model of a single receptive field in the retina

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Abstract

Many students struggle to understand the sometimes counterintuitive and complicated organization of the retina. As soon as they begin to grasp these complex relationships, we add another confusing concept: the organization of receptive fields of individual ganglion cells. Publishers provide figures in textbooks and videos, but like many topics in physiology, students may learn more effectively using hands-on models. This article provides instructions for building a three-dimensional model of a single retinal receptive field using inexpensive craft supplies. In alignment with the principles of universal design, this model will make the material easier to comprehend and more accessible to learners of all abilities. This activity provides a framework for students to begin exploring the structures and functions of cells of the retina and the organization of receptive fields in the visual system and provides a foundation for explaining other types of sensory systems.

INTRODUCTION

The structure and organization of the human retina are topics covered in most physiological psychology courses. Many texts cover the retina in early chapters as it is one of the most broadly studied systems and can be used as a reference point when discussing other sensory systems (1). Like most sensory systems, retinal cells follow a hierarchical organization, starting with the sensory receptors (photoreceptors) that synapse onto bipolar relay cells. The bipolar cells then synapse and summate onto a ganglion cell, which in turn may or may not generate an action potential, depending on whether the signal from the bipolar cells is excitatory or inhibitory (2). This hierarchical organization is relatively well represented using two-dimensional figures and videos that accompany most textbooks. However, in my experience, students often struggle with several concepts related to these structures. For example, they have difficulty understanding that light must pass through other layers of cells before activating the photoreceptors and the relay of graded potentials from the receptor to the ganglion cell. Additionally, students struggle to understand how the concentric rings of receptive fields summate onto individual ganglion cells. Building a three-dimensional model can help them understand the functional anatomy of the visual system.

Previous research has shown that building three-dimensional models makes learning more enjoyable and improves understanding of complex physiological concepts (3, 4). Additionally, by following the principles of universal design, models can provide a more inclusive approach to teaching the material (5). For example, visually impaired students may benefit from using models they can explore using their hands (tactile senses) instead of relying on two-dimensional figures and videos. The use of simple models constructed of reusable materials also aligns with the goals of developing nondisposable assignments because their use extends beyond the initial lesson, and the materials can be reused in subsequent courses (6).

The activity described here addresses all of the above criteria by having students assemble a model of a single on/off receptive field out of simple, inexpensive, and reusable materials. The final model provides students with a three-dimensional representation of the cells of the retina. Students learn the retina’s anatomy by identifying the structures as they build the model and discussing their functions once it is complete. The model also gives them a way to explore the three-dimensional organization of the on/off receptive field for an individual ganglion cell that two-dimensional figures and videos cannot provide. Although this activity includes step-by-step instructions for assembling the receptive field, it could be adapted to be more inquiry based or exploratory. For example, the students could follow instructions to assemble the cell units and then use reference material to puzzle out how they go together, answer questions on a worksheet, start with a completed model and deduce each structures identity and function, or teach the concept to their classmates. Additionally, these models can then be used in various lessons throughout the course and retained (either assembled or disassembled) for future classes.
The activity described here was initially developed to teach the organization and function of cells in the human retina to introductory physiological psychology students. The activity has also been used to reinforce these concepts in upper-level undergraduate sensation and perception courses. Between these two courses, I have used this activity at least eight different times over 5 years, making incremental improvements with each iteration. Additionally, it could be used to teach these concepts in a variety of physiology and neuroscience courses and adapted to apply to other receptor systems.

## MATERIALS AND METHODS

### Materials

Figure 1 shows the items used to construct the models. They are inexpensive and can be purchased through the internet or at a local craft store. Links to instructional videos, additional figures, the template for the receptive field, and step-by-step instructions on how to assemble the model were reviewed and published on Life Science Teaching Community (LifeSciTRC) site and can be found by following this link: https://www.lifescitr.org/resource.cfm?submissionID=12170.

Figure 2A shows an example of the completed model, and Fig. 2B shows the hierarchical arrangement of the retinal cells.

### Method: Classroom Management

The building of these models usually takes place during a laboratory period that follows an hour-long didactic lecture. The lecture covers the structures of the eye and the pathway that light must travel to activate the photoreceptors. Two-dimensional figures and videos introduce the students to the hierarchical organization of the retinal cells, and the signaling pathway involved in phototransduction. These activities provide a foundation for discussing the structures and their functions in the laboratory. Covering the topic of receptive fields usually requires an additional 30- to 60-min instructional period, which could either be covered during the class period or as an introduction to the laboratory activity. When the students use step-by-step instructions, they can complete the model in one hour or less.

Once the students are familiar with the retinal structures and the organization of the receptive fields, they may begin constructing the model with their laboratory partner. Typically, I start by providing students with the instructions.
SOME ASSEMBLY REQUIRED: BUILDING A HANDS-ON MODEL

It is important to note that this model is oversimplified. As constructed, it only represents a single bipolar cell (on or off) for each photoreceptor, whereas we know that there ought to be both on and off bipolar cells synapsed to each photoreceptor. However, I have found that this model is an excellent way to introduce the basic structures and their functions, providing scaffolding to discuss more complex concepts. For example, if students have the opportunity to learn the general organization of how the neurons are wired together and summate onto the bipolar and ganglion cells, then it is easier for them to grasp how these cells can work together to create the receptive fields. Invariably, I will have a student ask about the overlap of receptive fields. This is when I will introduce the idea that the photoreceptors that make up the “on center” area of this particular receptive field are also likely part of the “off surround” of a neighboring ganglion cell. Typically, they will follow up with “So they have to have an off bipolar cell too?” and that is when the “ah-ha” moments start to happen, especially for the upper level sensation and perception students who are learning about simple and complex cells in the primary visual cortex.

In future iterations, I plan to add worksheets to help the students quiz themselves over the material as they are building the model. Another approach could be to give the students a completed model and have them deduce each structure’s name and function based on the two-dimensional illustrations. A third alternative is to give the students the materials and have them puzzle out how to build the model using only textbook figures and descriptions. Additionally, I plan to collect pre- and postdata in my future classes to obtain a more objective assessment of this activity’s effectiveness.

Overall, it is my impression that the students find this activity to be both enjoyable and enlightening. Many students keep their models to use in other courses or demonstrate their knowledge to their roommates and family members. I have also had graduates tell me that they still have their models and that it has helped them better understand the concept of receptive fields for other structures and systems. This is one of my favorite activities, and I am pleased to have this opportunity to share it with other educators.

DISCUSSION AND LIMITATIONS

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

K.S. conceived and designed research; K.S. performed experiments; K.S. interpreted results of experiments; K.S. prepared figures; K.S. drafted manuscript; K.S. edited and revised manuscript; K.S. approved final version of manuscript.

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