Modeling Avian Color Vision: Spectral Discrimination in Ultraviolet and Violet Sensitive Birds

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Introduction

The retina is covered in millions of light-sensitive **photoreceptors** which detect and transmit signals to the bran based on light reflected by visual stimuli.

These photoreceptors are organized in different classes, each sensitive to specific wavelengths of light (colors). **Peak sensitivity** is the wavelength which stimulates the photoreceptor the most.

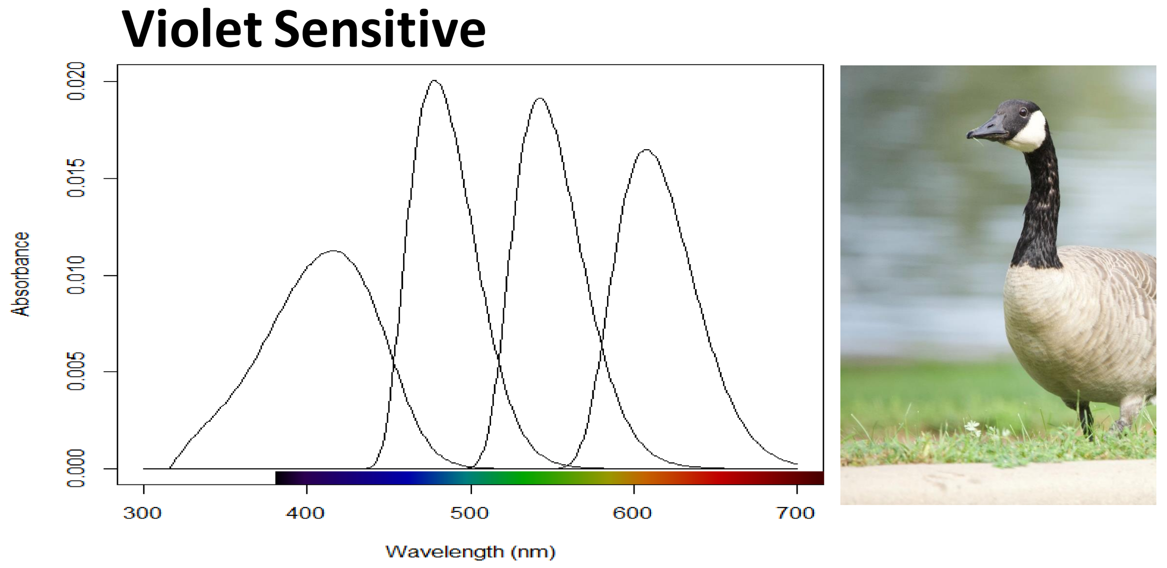
Figure 1: Examples of dichromatic, trichromatic and tetrachromatic species.

Based on the number of different photoreceptor types which contribute to color vision, dogs are **dichromats** (2 types of photoreceptors), and humans are **trichromats** (3 types of photoreceptors).

Birds are **tetrachromats**, meaning they have four different types of photoreceptors involved in color processing: LWS (blue sensitive), MWS (green sensitive), SWS (red sensitive), and UVS/VS (ultraviolet/violet sensitive).

The position of the UVS/VS photoreceptor peak sensitivity categorizes birds into two groups: ultraviolet sensitive (UVS) birds which include many smaller species, and violet sensitive (VS birds), including larger species.

Violet Sensitive



Ultraviolet Sensitive

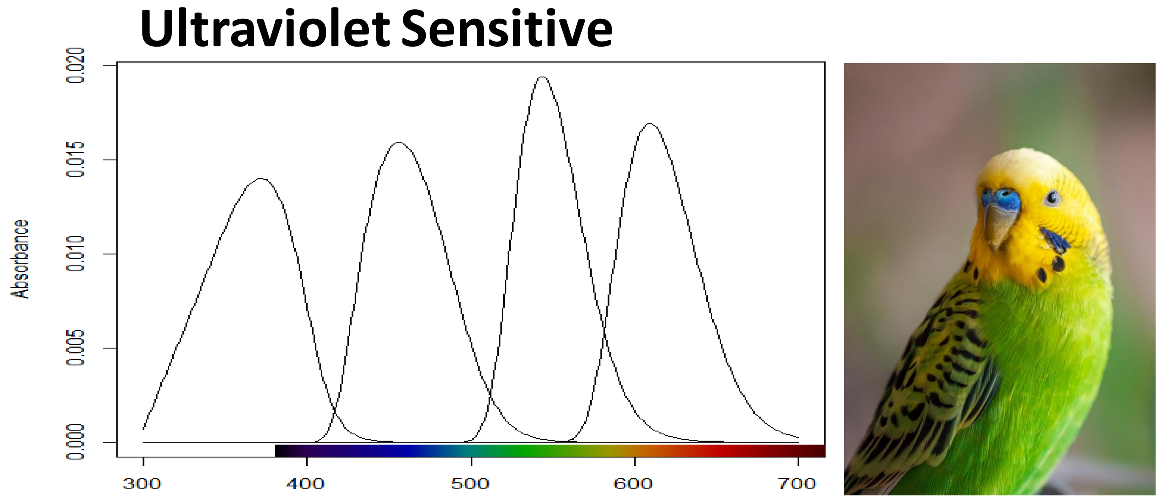


Figure 2: Photoreceptor peak sensitivities for the average VS and UVS birds.

Visual modeling serves as a powerful tool for exploring a species perception of visual stimuli. The acronym **ARTS** encompasses the four key components of visual modeling. DOI:10.2307/j.ctv22jnscm

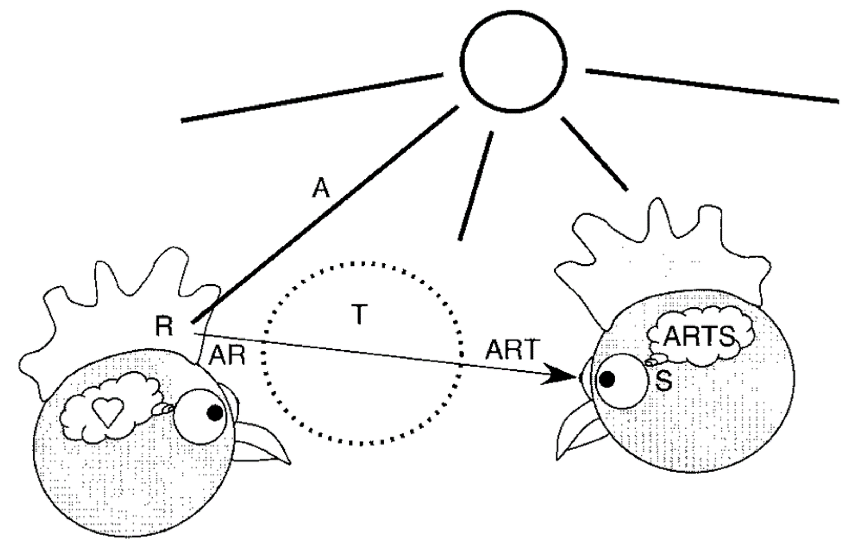


Figure 3: Visual depiction of ARTS acronym for visual modeling.

Spectral Discrimination is the ability to distinguish between spectral colors (i.e. colors across the light spectrum).

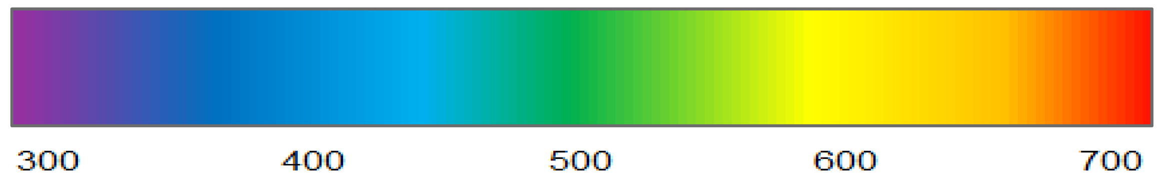


Figure 4: The visible light spectrum.

Spectral Discrimination Curves are a representation of a species' ability to discriminate between similar stimuli across the light spectrum. These curves display the minimum wavelength difference, measured in nanometers, required for a species to distinguish between two very similar lights. In essence, they display how different two colors need be for the animal to discriminate between them effectively. This visualization provides insight into the animal's overall color discrimination while also highlighting specific regions within the light spectrum where the species is best/worst able to discriminate between similar stimuli.

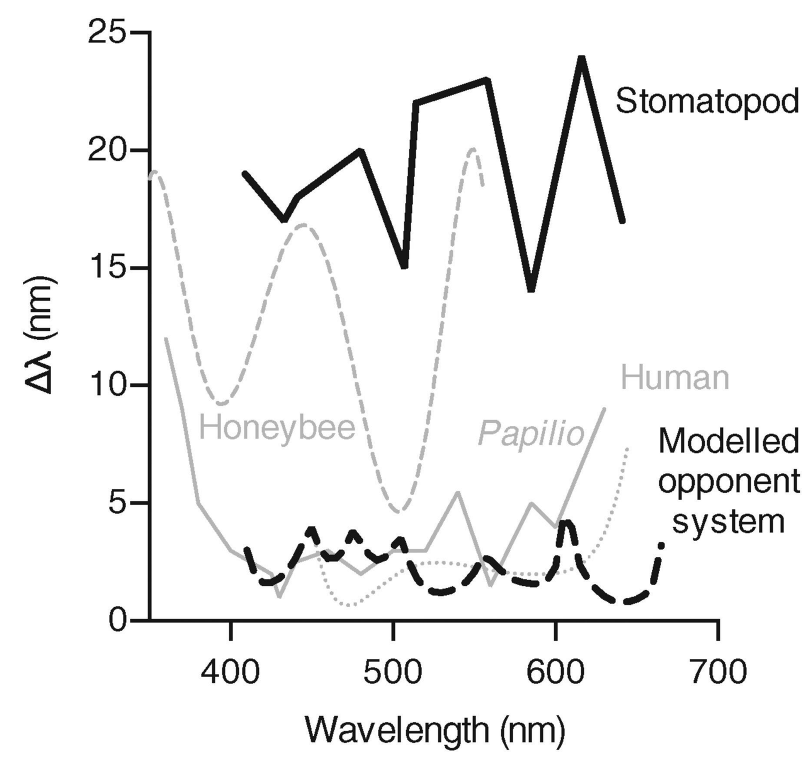


Figure 5: From A Different Form of Color Vision in the Mantis Shrimp, 2014 Used the Receptor Noise Limited Model to model spectral discrimination in the mantis shrimp. DOI: 10.1126/science.1245824

Research Objective

To investigate the spectral discrimination abilities of ultraviolet-sensitive species in comparison to violet-sensitive species.

Methods

The **receptor noise-limited model (RNL)** included in the R package **PAVO** is a framework for predicting discriminability of objects to a particular species based on a set of visual parameters (DOI:10.1111/2041-210X.13174).

The visual parameters required for the RNL, such as peak sensitivities and relative densities of photoreceptors, were sourced from a combination of published literature and data collected by our laboratory at Purdue University. This dataset comprises measurements from numerous UVS and VS bird species, enabling us to determine visual parameters representative of the "average" UVS and VS birds.

We ran the RNL to compare pairs of **narrow spectral stimuli** determining how discriminable each pair was from one another for the specified species.

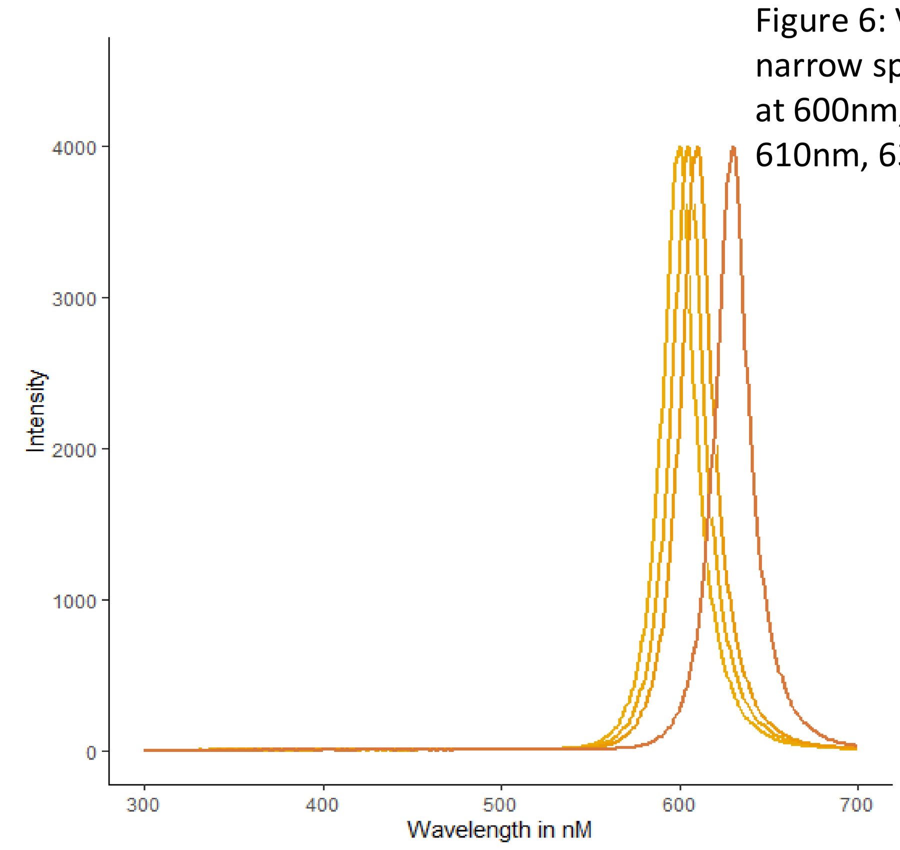


Figure 6: Visualization of narrow spectral stimuli at 600nm, 605nm, 610nm, 630nm

Results

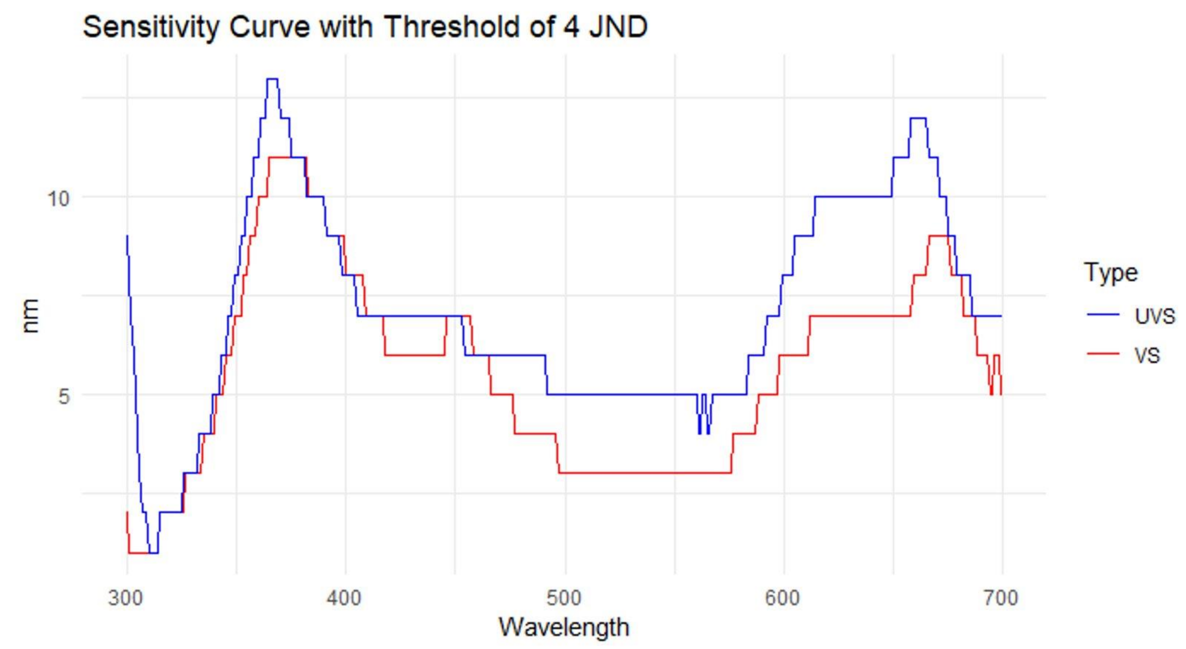


Figure 7: The spectral sensitivity curves for the average UVS and VS birds.
X-axis: monochromatic lights 300-700 nm.
Y-axis: How many nanometers away a peak must shift from the wavelength on the x axis to be discriminable.

Disclaimer: Please note that the region spanning from 300nm to 310nm is considered an artifact attributable to the data processing involved in generating spectral discrimination curves.

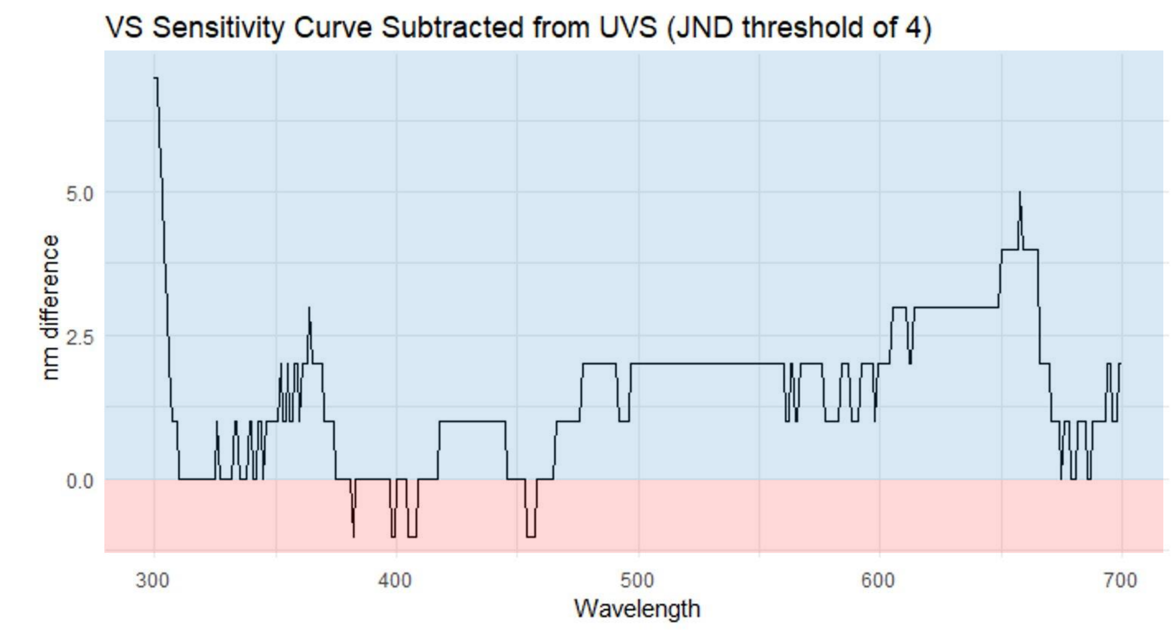


Figure 8: The UVS spectral sensitivity curve subtracted from the VS.
X-axis: monochromatic lights 300-700 nm.
Y-axis: How many nanometers away a peak must shift from the wavelength on the x axis to be discriminable for VS subtracted from UVS.

Conclusions

The resulting Spectral Discrimination Curves suggest that the average VS species would exhibit better discriminability between narrow spectral stimuli in specific portions of the spectrum (500-575 nm, 610-660 nm) compared to their UVS counterparts**.**

This result challenges previous assertions in the literature, particularly those based on color space analysis using natural reflectance, which suggested superior discriminatory ability in UVS birds. Furthermore, despite the expectation that UVS birds have heightened sensitivity to ultraviolet stimuli due to the positioning of their ultraviolet photoreceptor peak sensitivity, our results indicate comparable discriminatory abilities in the ultraviolet range (310-360 nm, 375-425 nm) between the two subsets.

This discovery holds implications for reducing collisions between birds and buildings, suggesting that ultraviolet-based deterrent methods (window decals) which were originally presumed to be ineffective for VS species, may exert similar effects across all species.

Figure 9: Bird Safe glass with ultraviolet reflective patterns meant to prevent bird-building collisions.

Future Directions

What are the contributing factors to the observed difference in spectral discrimination between UVS and VS birds?

Our plan for future exploration consists of systematically varying visual parameters, including photoreceptor peak values and photoreceptor peak overlap, to dissect the specific contributions of each factor to spectral discrimination.