U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Understanding the Golden Eagle and Bald Eagle Sensory Worlds to Enhance Detection and Response to Wind Turbines

Project ID # M23

Presenter: TBD

On Behalf of the Purdue University Research Team

FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

M23 - Understanding the Golden Eagle sensory world to enhance detection and response to wind turbines

Technology Summary:

- Researchers at Purdue University designed, built, and tested portable devices **at 3 rehab facilities** needed to measure visual and auditory properties of bald and golden eagles

Period of Performance:

7/15/2017 - 10/1/2018 (extended to April 2020)

Technology Impact:

- Eagle deterrent technologies are nascent; there is a lack specific biological data necessary to optimize deterrents to maximally effective on eagles
- This equipment has been used to quantify a number of important visual and auditory properties of both golden and bald eagles to help improve the effectiveness of deterrents

Project Goals:

- To use an understanding of the sensory physiology of eagles to inform design of stimuli that can be used to alter or deter eagles flying near wind turbines

Partners:

- Avangrid Renewables

Technical Merit and Relevance

Goal: To keep eagles away from wind turbines, we intend to design stimuli tailored to the specific way eagles see and hear

- There is a current lack of understanding around the specific parameters of bald and golden eagle vision and hearing
- The project will meet industry needs by identifying stimuli that are designed to fit the sensory capabilities of eagles against different auditory and visual noise backgrounds
- The project has the potential to advance deterrent technology already in use on wind turbines

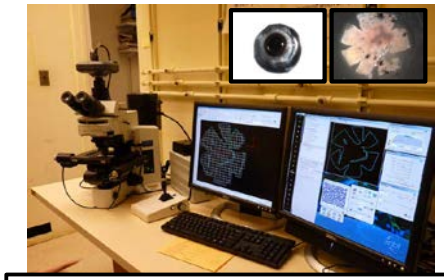
Approach and Methodology: Vision

The project uses a variety of techniques to determine how eagles see:

Color vision

Microspectrophotometry

Density of cone photoreceptors



Bright and fluorescent microscopy

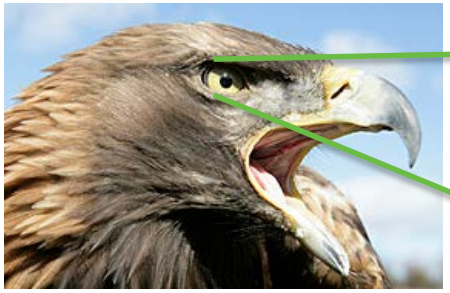
Visual coverage

Visual fields

- Researchers at Purdue University have over 15 years of experience measuring aspects of the visual system of birds using these techniques
- These visual system analysis techniques are well-established and have been used to measure animal vision for decades
- Purdue partnered with eagle rehab centers to salvage tissue for these techniques
- The first step is to collect the physiological information for golden eagles and bald eagles
- The second step is to use the physiological information to run mathematical algorithms based on how the bird visual system works (e.g., visual models) to explore the range of stimuli that would stimulate the eagle retina the most.

Process to select visual signals (LED lights) using physiological info and visual models

1) Extraction of whole retina gives information about density of photoreceptors (which indicates visual resolution), and sensitivity of photoreceptors to specific wavelengths (which indicates colors that maximally stimulate the visual system)
2) This information is used in a visual model to indicate optimal wavelengths for alerting light stimuli



Behavioral Stimulus

Candidate Light Signals

White

High Contrast (JND)

385nm

460nm

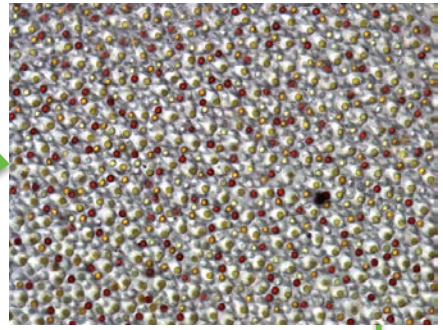
555nm

615nm

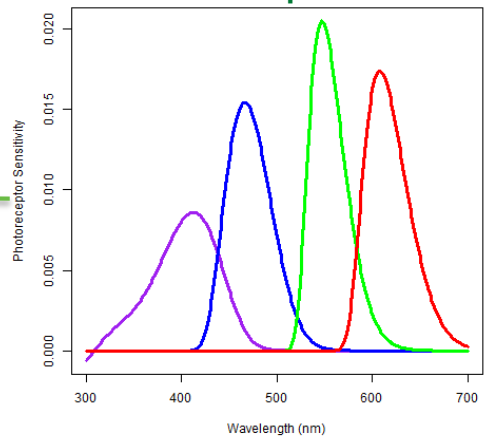
Eagle Visual Model

Whole Retina

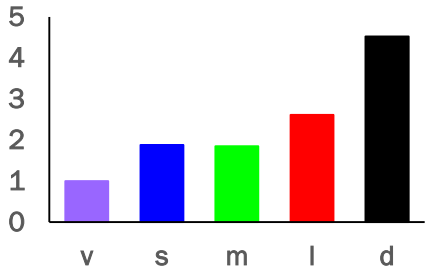
Photoreceptor Cells in Retina



Sensitivity of Photoreceptor Cells



Relative Density of Photoreceptor Cells



Approach and Methodology: Audiology

The task has 3 phases:

1. Measure auditory responses to a battery of sound stimuli using a well-developed technique (**auditory evoked potentials**)
2. Present sounds **with and without background noise** – helps understand range of conditions over which sound will be heard (white noise: noise over a broad range of frequencies; pink noise: noise loudest at lower frequencies)
3. **Choose a series of stimuli**, based on our physiological results, to broadcast to eagles and **record their behavioral respo**nses

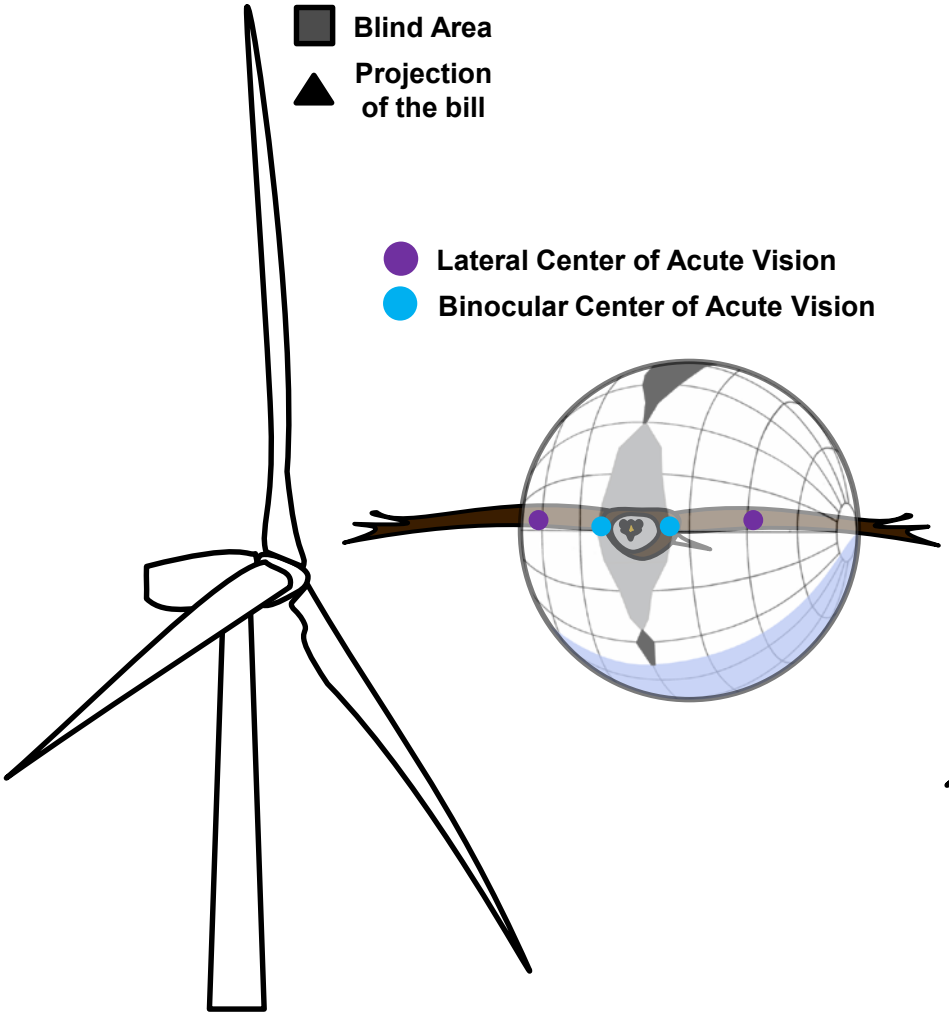
- The Purdue research team has over 13 years of experience measuring aspects of the auditory system of birds using this technology
- The auditory technique is well-established and has been used to measure hearing in humans for over 50 years
- Purdue partnered with eagle rehab centers to test birds, and who provided veterinary care for the birds during auditory tests (birds are anesthetized during the procedure)

The way bald eagles see can affect their ability to perceive the position of different elements of the wind turbine

Looking Forward

- Field of View from Individual Eyes
- Field of View from Both Eyes
- Blind Area
- Projection of the bill

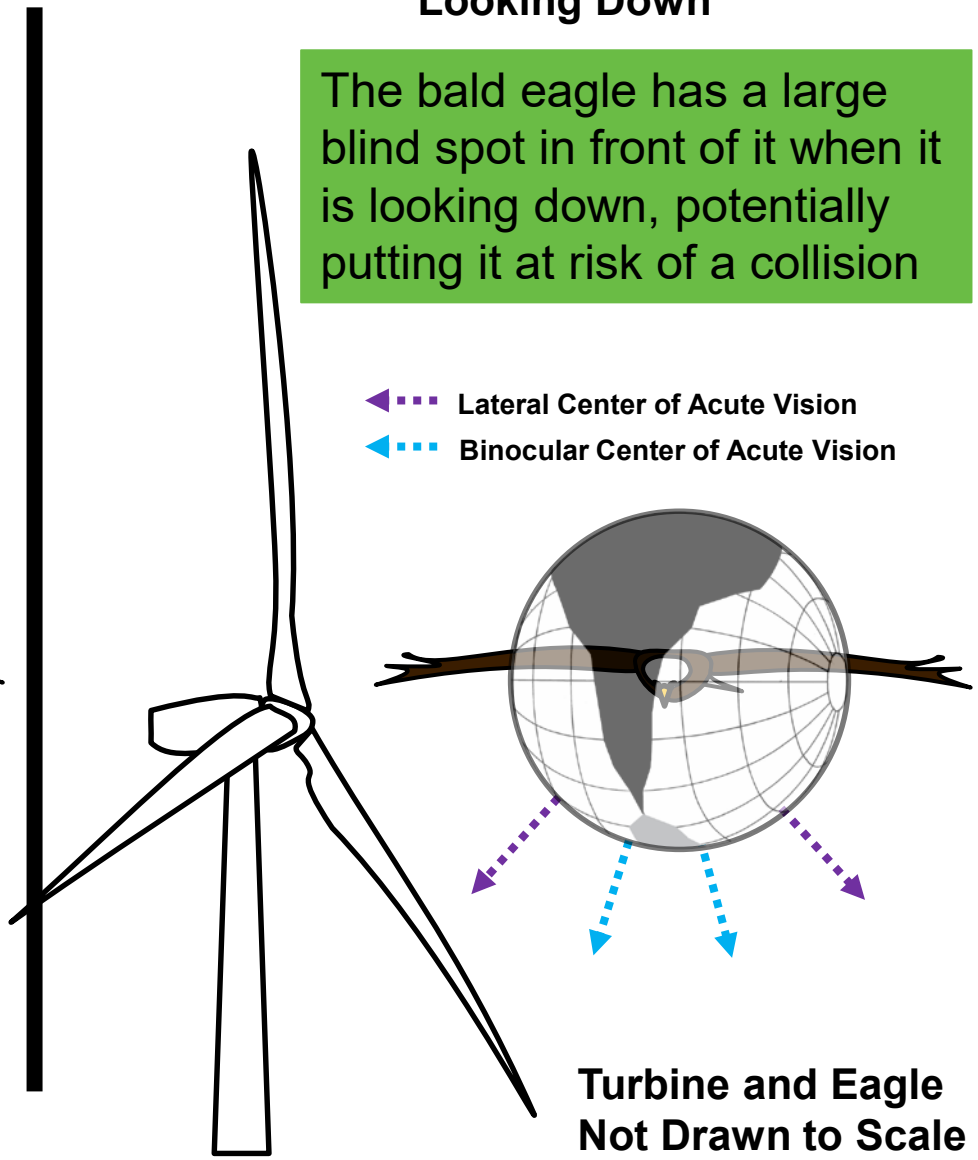
- Lateral Center of Acute Vision
- Binocular Center of Acute Vision



Looking Down

The bald eagle has a large blind spot in front of it when it is looking down, potentially putting it at risk of a collision

- Lateral Center of Acute Vision
- Binocular Center of Acute Vision



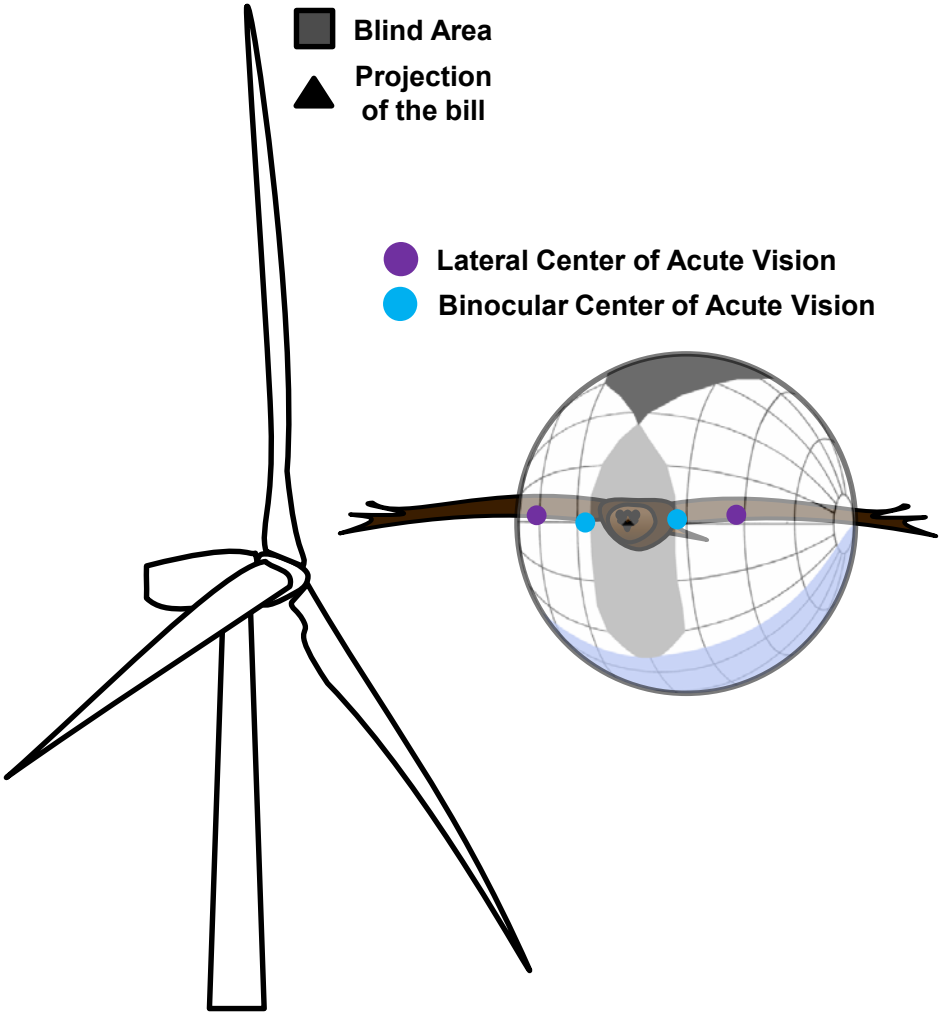
Turbine and Eagle Not Drawn to Scale

The way golden eagles see can affect their ability to perceive the position of different elements of the wind turbine

Looking Forward

- Field of View from Individual Eyes
- Field of View from Both Eyes
- Blind Area
- Projection of the bill

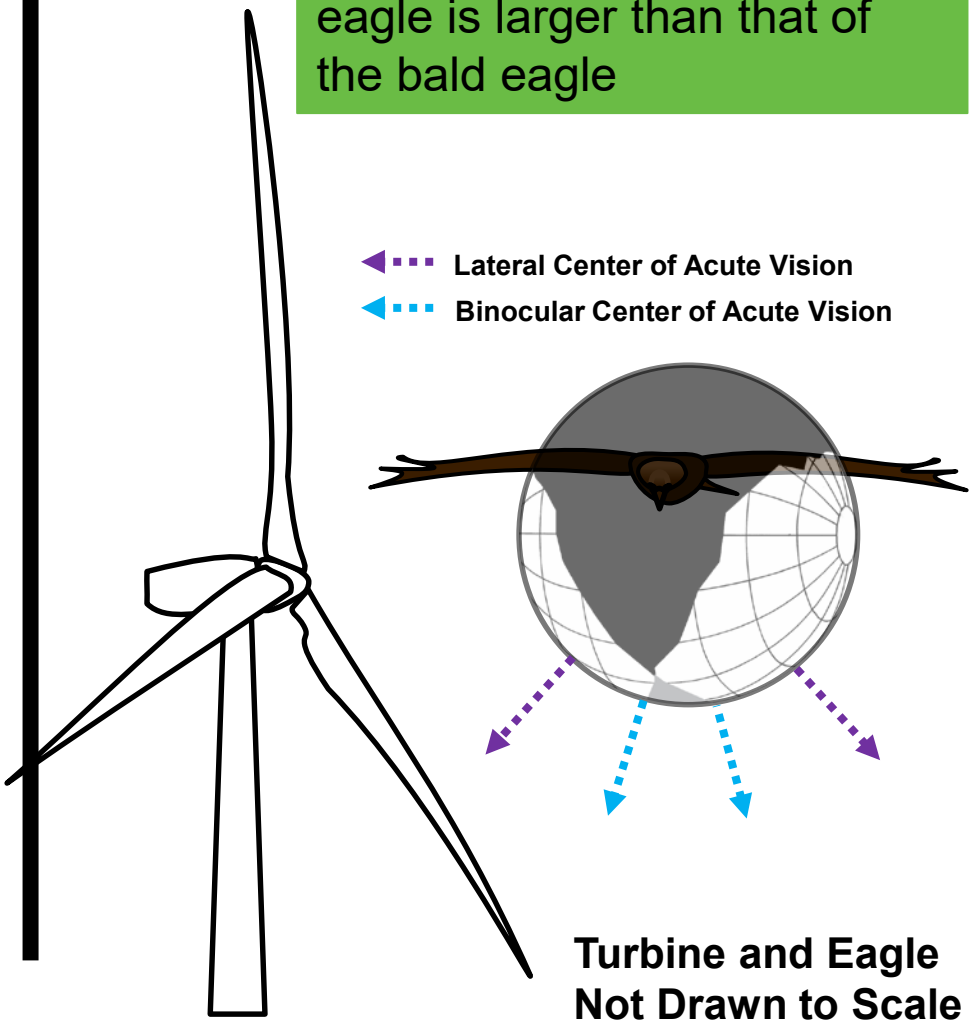
- Lateral Center of Acute Vision
- Binocular Center of Acute Vision



Looking Down

The blind spot of the golden eagle is larger than that of the bald eagle

- Lateral Center of Acute Vision
- Binocular Center of Acute Vision



Turbine and Eagle Not Drawn to Scale

Accomplishments and Progress

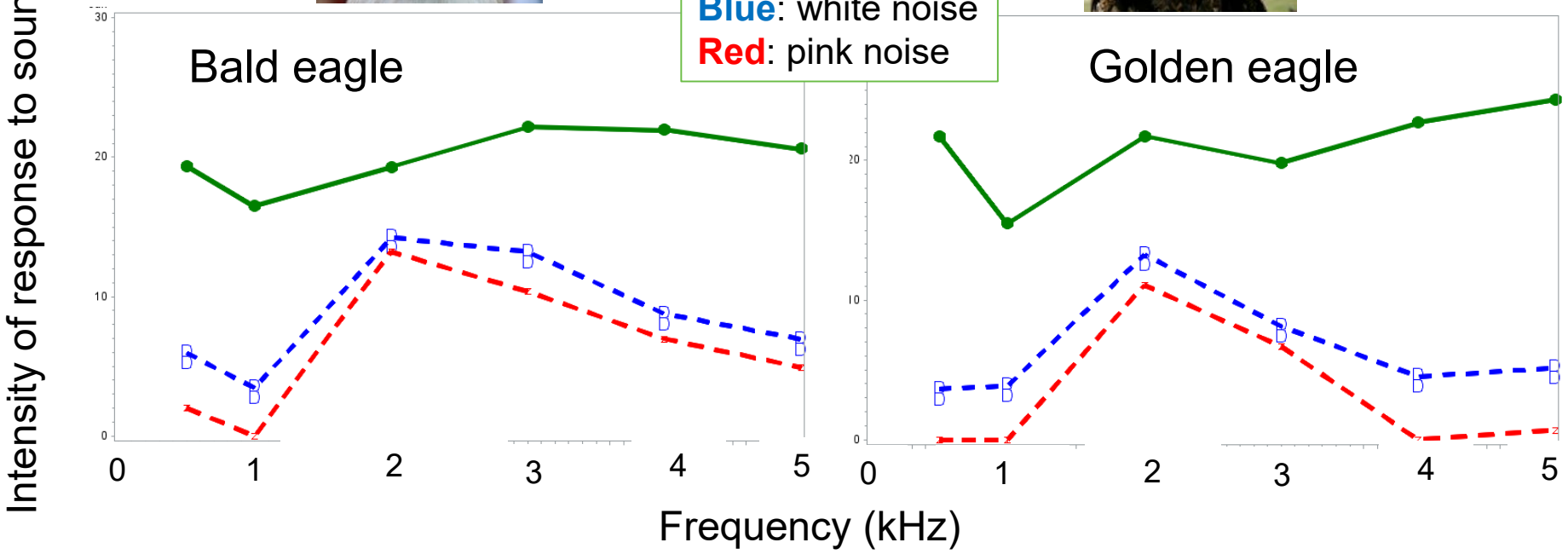
Auditory overview with new (2019) data on golden eagles and older bald eagle data:

1. tones are easily masked by noise for both species
2. bald eagles are surprisingly good at processing rapid sounds and at processing amplitude modulations, golden eagles are surprisingly ***bad*** at processing these types of sounds
3. sounds that may be useful for both species include complex sounds and sounds with fairly ***slow*** frequency modulations

Accomplishments and Progress
(with golden eagle data - FY19 work)

Pure Tones:

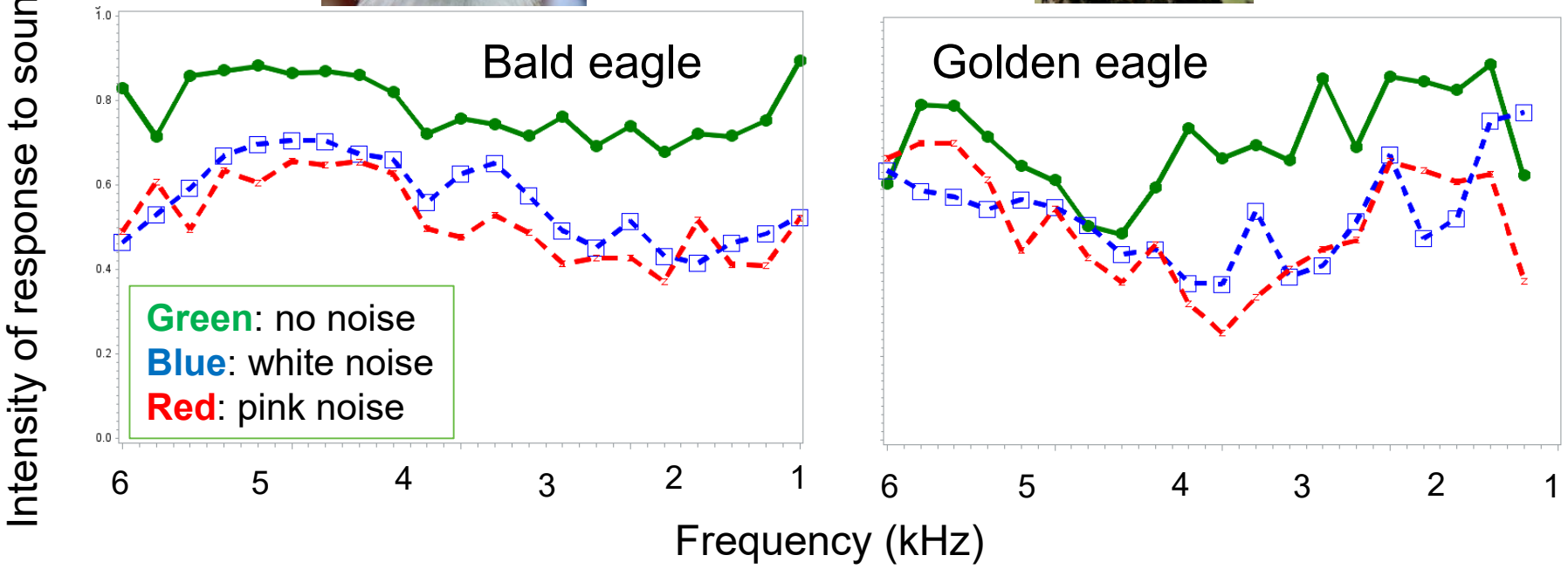
Both bald and golden eagles process pure tones without noise well, but their response is *strongly* impacted by noise



Accomplishments and Progress
(with golden eagle data - FY19 work)

Tonal down sweep:

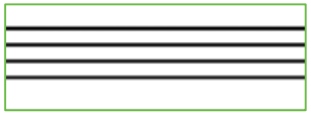
Both bald and golden eagles process a relatively slow down sweep tone with less noise effect than pure tones



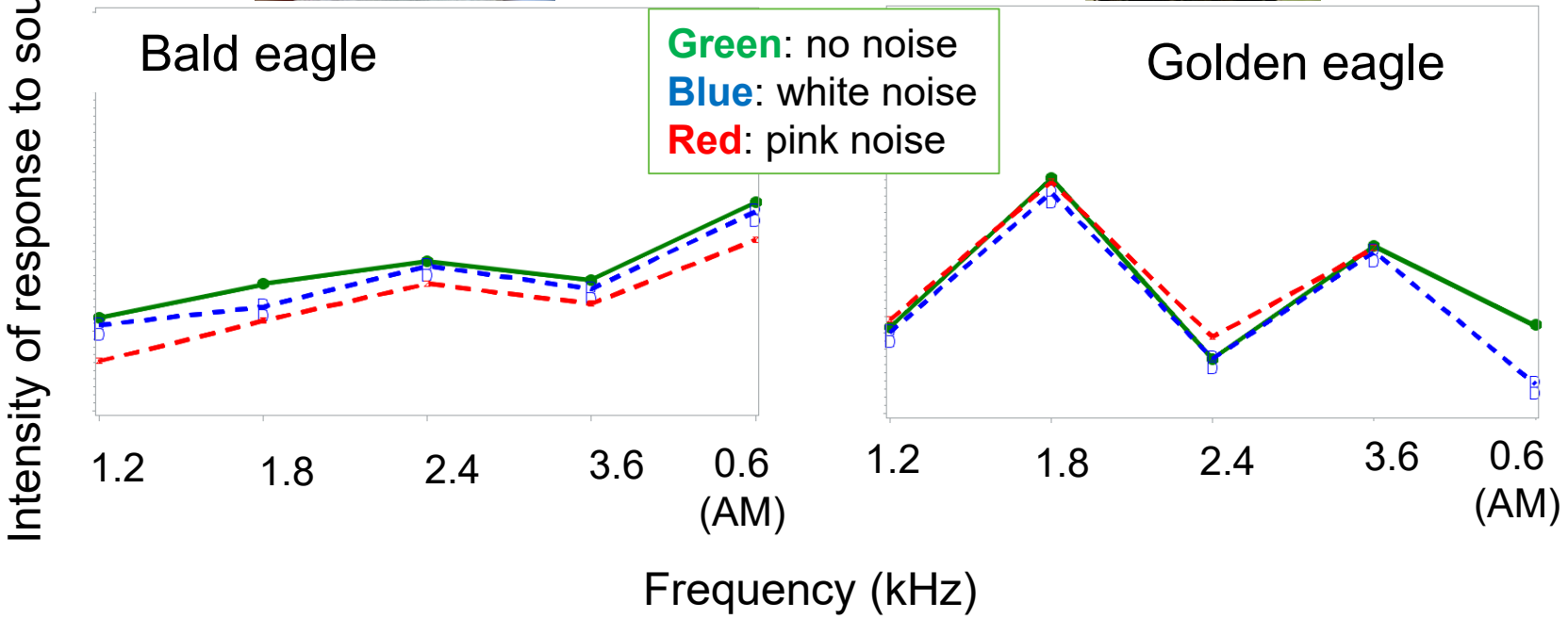
Accomplishments and Progress

(with golden eagle data - FY19 work)

Complex sounds - chords:



Pure harmonics without the lower tone (which results in beating or amplitude modulation): golden eagles process most tones better than bald, but they do not hear the beating part (0.6AM) as well. Also, there is very little effect of noise on this sound



Communication, Coordination, and Commercialization

The Purdue research team has participated in a number of Conferences to present their work:

- **2-6 Aug Animal Behavior Society Conference.**
  - Jeffrey Lucas, Benjamin Goller, Patrice Baumhardt, Todd Katzner, Ernesto Dominguez, Peach VanWick, Esteban Fernandez-Juricic. Contributed talk "Using sensory information to keep eagles out of wind turbines: (1) The auditory system"
- **10 Nov. Sensorium Conference. Co-organized meeting at Purdue University.**
  - Poster: B Goller, P Baumhardt, T Katzner, J Lucas & E Fernandez-Juricic. "Visual fields and retinal morphology of bald and golden eagles"
    - Talk: J Lucas, B Goller, P Baumhardt, T Katzner, E Dominguez, P VanWick, E Fernandez-Juricic. "Using sensory information to keep eagles out of wind turbines: (1) the auditory system"
- **27-30 Nov 12th NWCC Wind Wildlife Research Meeting.**
  - Talk by E Fernandez-Juricic, B Goller, P Baumhardt, E Dominguez-villegas, T Katzner, J Lucas. "Measuring eagle visual and auditory sensory perception to enhance deterrent technology for wind turbines"

Publications: While the visual component of the project is still in progress, we have complete data from seven Golden and five Bald eagles on the configuration of the visual field or the extent of their vision in space that is of publication quality. We have also been able to measure eye size metrics, the location of retinal specializations, and the spectral properties of a photoreceptor structure called the oil droplet for both species of eagle. To publish these data we still need to measure light absorbing properties of all photoreceptors, light transmitting properties of the eagle eye, and the distribution of different types of cells in eagle retinas. We hope to get the fresh eye tissue needed to make these final measurements before completion of the project.

We may also have enough auditory data for a publication with the recent addition of auditory evoked potentials from two golden eagles. While we hope to get data from another golden eagle or two, we plan to start developing this paper in about a month (after doing more behavioral tests) with the potential of having a draft by the end of the summer.

The behavior trials are quite preliminary at this point. Our expectation is to have a complete data set on behavior by September with a manuscript finished by the end of December.

Upcoming Project Activities

- Data collection and analysis completed by Dec. 31, 2019. Final report by May 2020.
- We planned to conduct a preliminary auditory analysis incorporating the blood lead levels in eagles from the hearing experiments to explore the potential impact of elevated lead blood levels, or lead poisoning, on eagle hearing responses. Eagles frequently ingest lead and it is common for eagles admitted to rehab centers or wildlife hospitals to be tested for blood lead levels upon admission, in case they need to be treated for lead poisoning. Lead has well-known impacts at both the peripheral (e.g. Lasky et al. 1995. Neurotoxicol Teratol 17:633) and higher (e.g. Bertoni & Sprenkle 1988. Neurotoxicology 9:235) auditory levels. Detection of a lead effect on hearing will likely require a sample size larger than our current number of eagles (on the order of 10 of each species), but given the ubiquity and importance of these effects, this is a direction that Purdue sees as worth pursuing.
- Adding auditory evoked potential data for golden eagles and additional bald eagles (accomplished February 2019) – described above.
- Testing live birds
- Collection of surrogate visual data from red-tailed hawks - in lieu of additional bald and golden eagle eye tissue samples

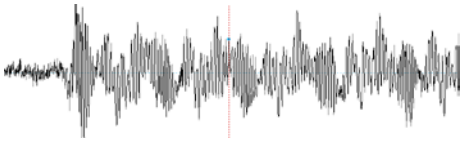
Accomplishments and Progress

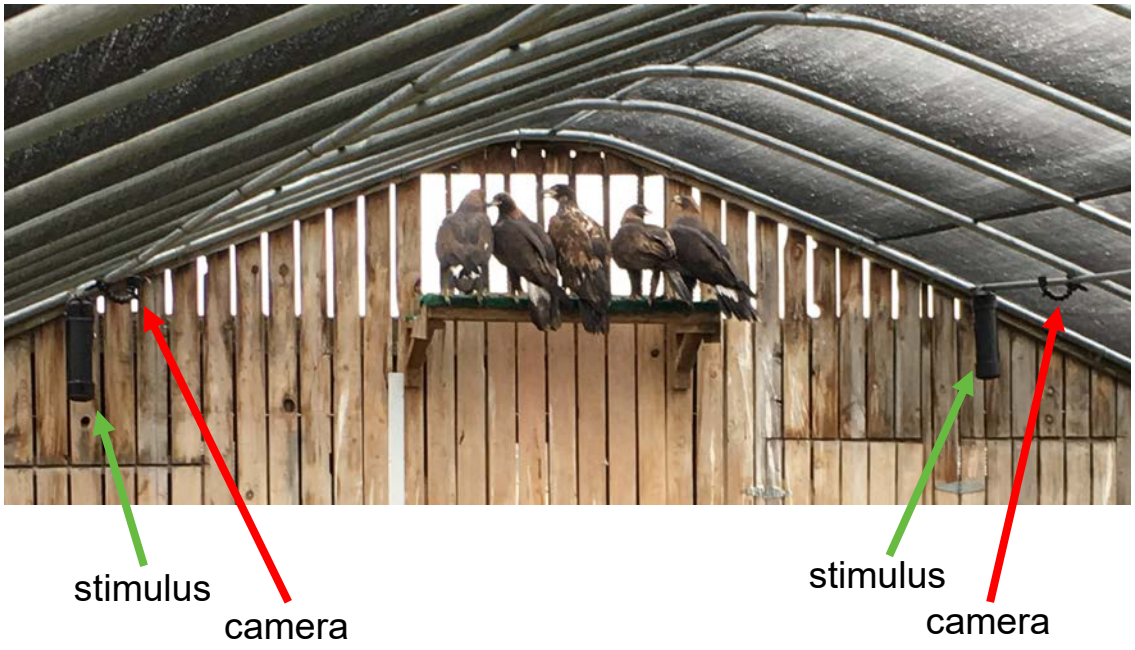
Behavioral experiments are now being done using select candidate lights and sounds based on eagle physiology data.

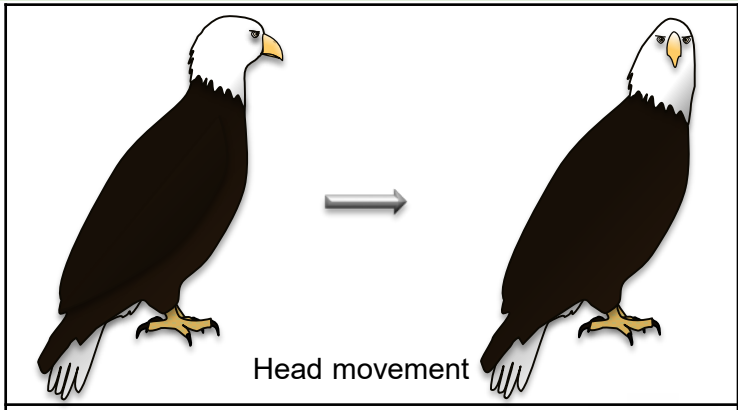
5 different LEDs (specific wavelengths selected from visual modeling)

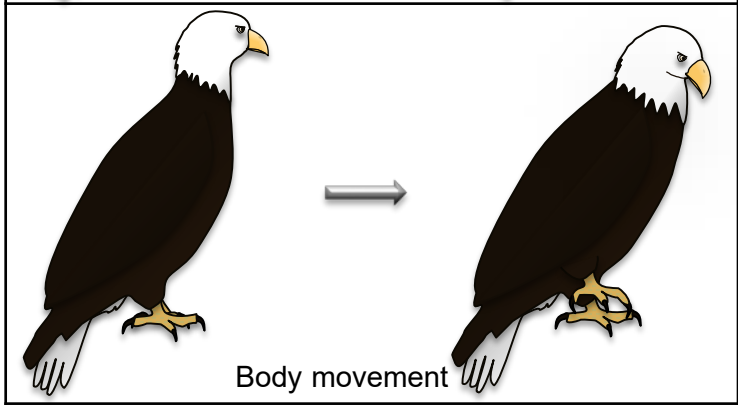
Broad spectrum | 385 nm | 460 nm | 555 nm | 615 nm

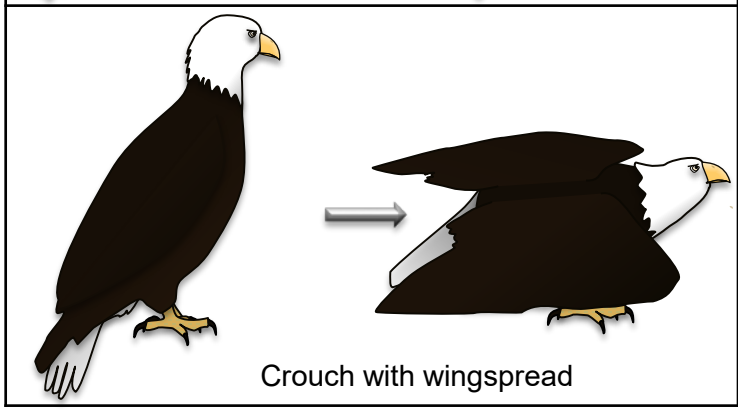
4 different sounds (eagles hear these well even in noisy conditions)







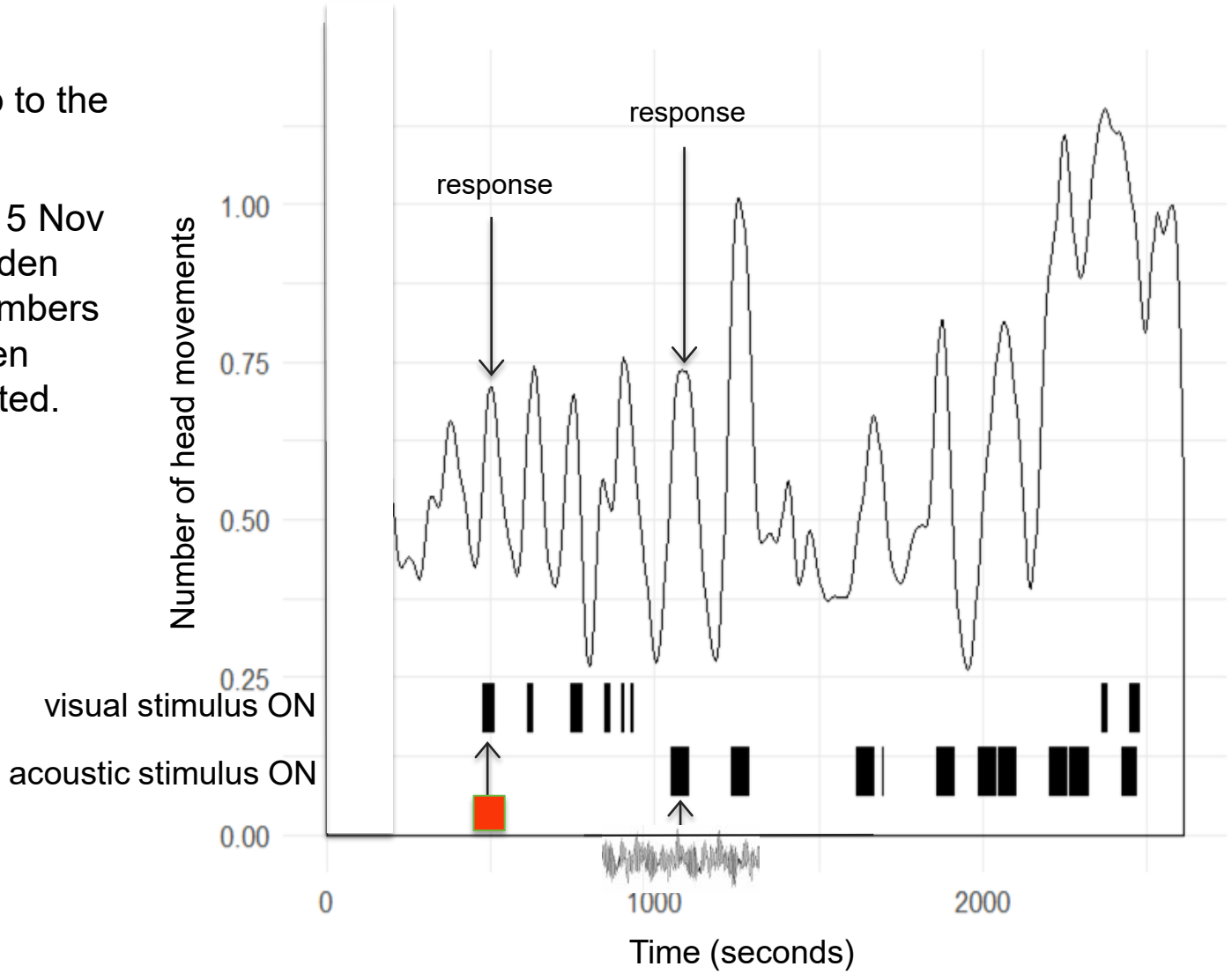




Accomplishments and Progress

Purdue is tracking the occurrence of specific behaviors in relationship to the presentation of stimuli.

Preliminary results (14-15 Nov 2018) show that this golden eagle exhibits higher numbers of head movements when stimuli are being presented.



Accomplishments and Progress: an overview with some explicit results

Pure Tones:

- Bald eagles process pure tones without noise well, but their response is *strongly* impacted by noise

Tonal down sweep:

- Bald eagles process a relatively slow down sweep tone well and with less noise effect than pure tones

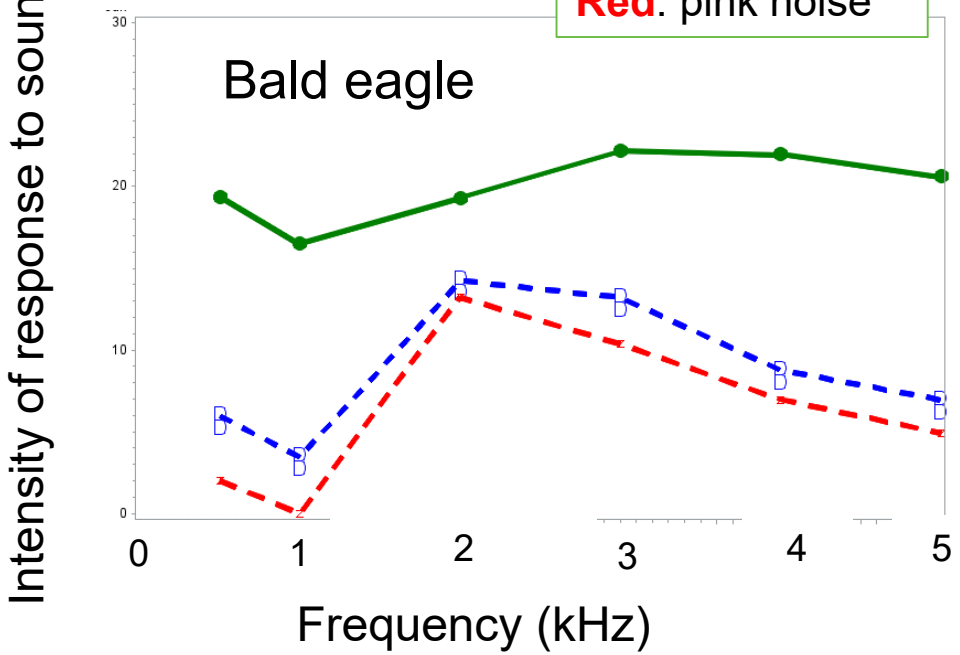
Complex sounds - chords:

- ***Pure harmonics without the lower tone*** (which results in beating or amplitude modulation): bald eagles process this chord relatively well, and they are particularly good at processing the beating component. Also, there is very little effect of noise on processing of this sound.

Accomplishments and Progress: an overview with some explicit results

PURE TONES:

- **Bald eagles process pure tones without noise well, but their response is *strongly* impacted by noise**

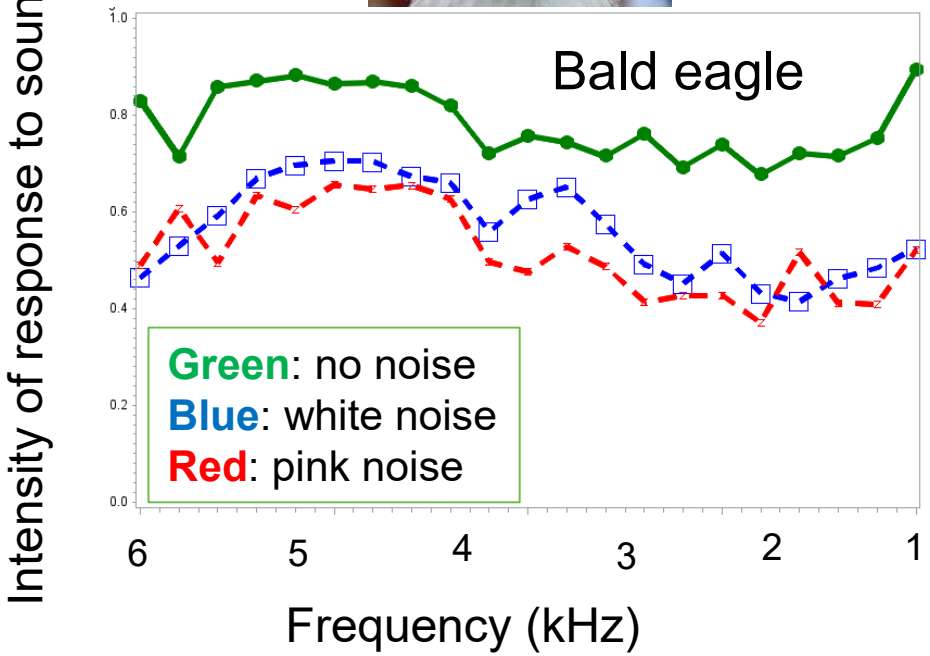


These data show the intensity with which the auditory system responds to pure tones from 0.5 to 5 kHz. The three lines represent different noise backgrounds

Accomplishments and Progress

Tonal down sweep:

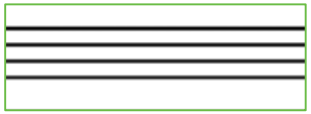
- **Bald eagles process a relatively slow down sweep tone well and with less noise effect than pure tones**



These data show the intensity with which the auditory system responds to a shifting frequency. The three lines represent different noise backgrounds

Accomplishments and Progress

Complex sounds - chords:



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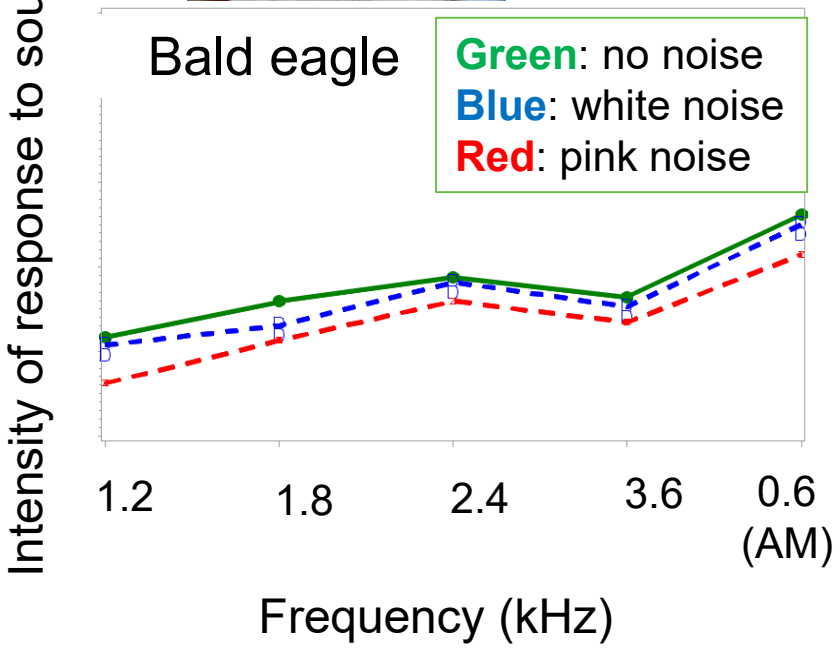

These data show the intensity with which the auditory system responds to a 4-tone chord (1.2 – 3.6 kHz) that also has a 0.6 kHz regular change in loudness (i.e. AM=amplitude modulation)