Vulture Vision: Database on vulture visual capabilities and implications for bird strike mitigation

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Bird Strikes & Vultures in U.S.

Black Vulture

- >80% of collisions cause damage[1]
- 11th riskiest avian species (civil craft)[2]
- 3rd most damaging species (military craft)[3]

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Turkey Vulture

- >75% of collisions cause damage[1]
- 3rd riskiest avian species (civil craft)[2]
- 5th most damaging species (military craft)[3]

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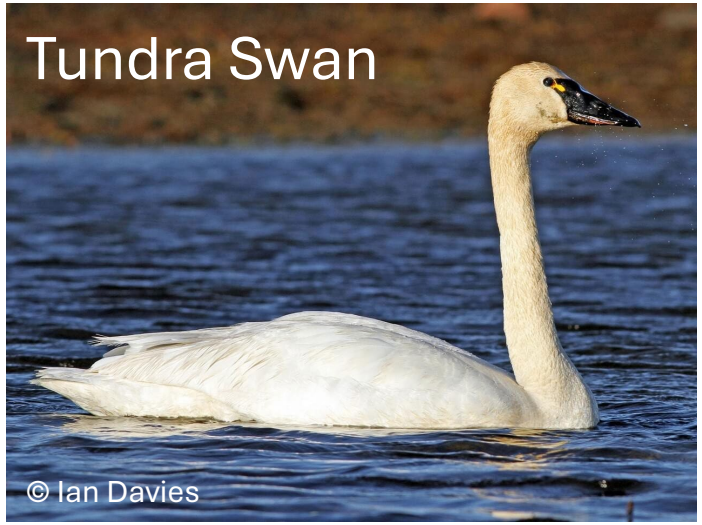
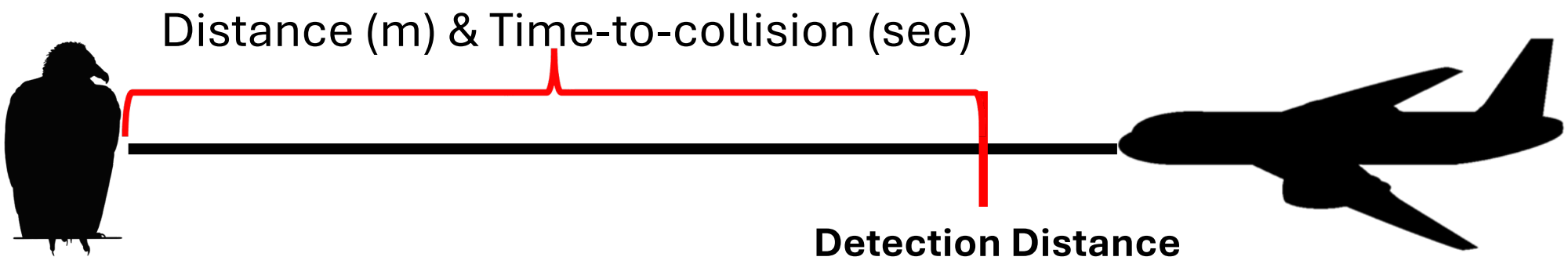
Birds with multiple strikes with >50% damage rate



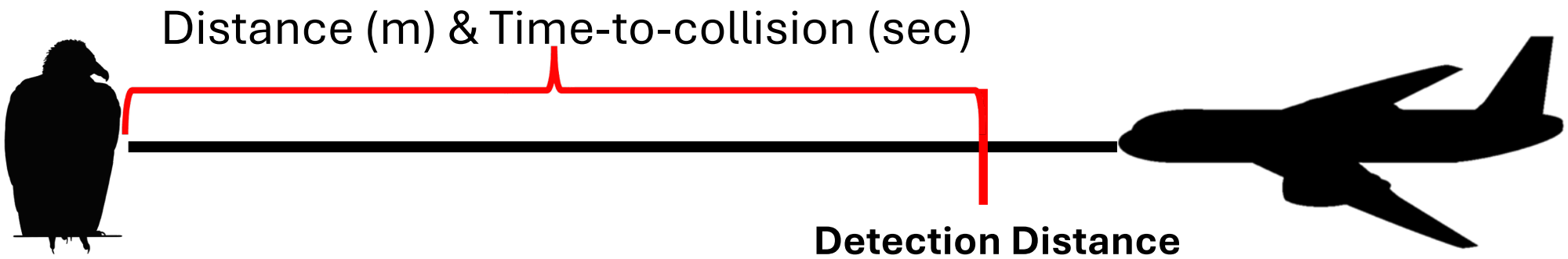
Avian Vision

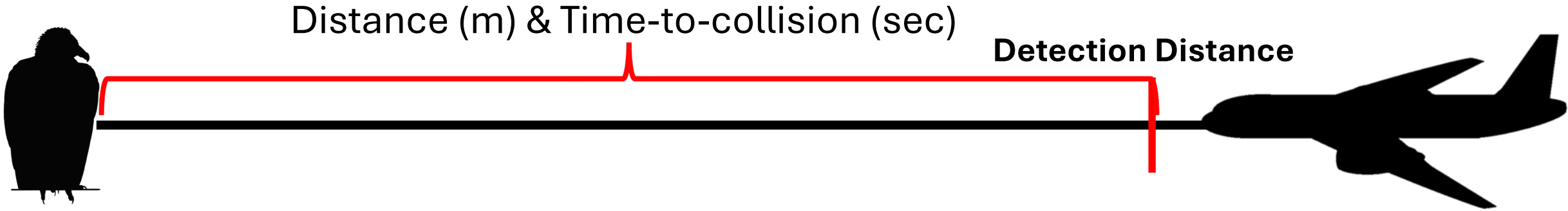
- Birds can only respond to threats they can detect.



Avian Vision

- Longer detection distances allow for more time and space for the bird to escape.





Visual Characteristics

1. Visual Fields – Is the aircraft in a location a bird can see?

2. Visual Acuity – At which distance can aircraft be detected?

3. Achromatic Contrast Sensitivity
4. Cone Sensitivity

} Is the aircraft different enough from the visual background to be detected?

5. Temporal Visual Resolution – Can the bird process visual information quickly enough to detect, assess, and flee?

Visual Fields

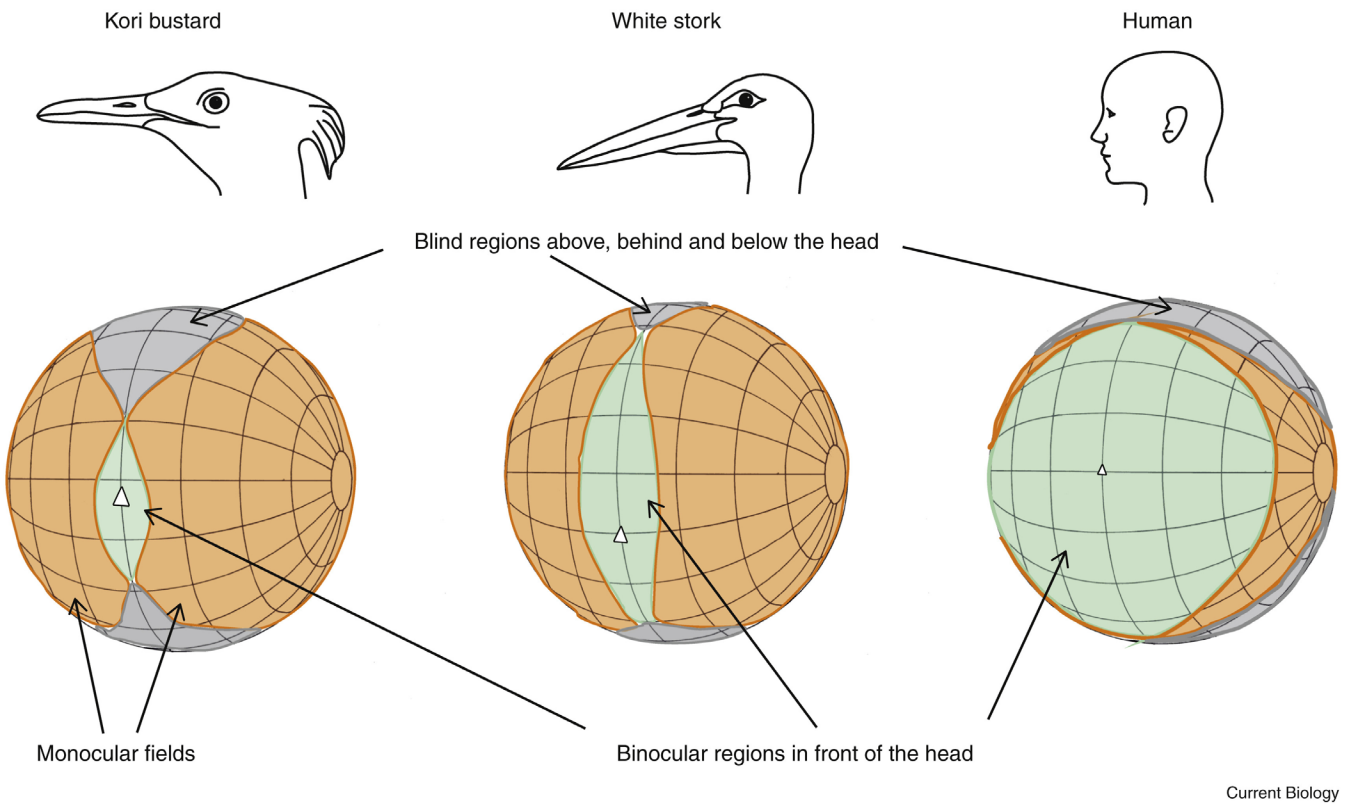
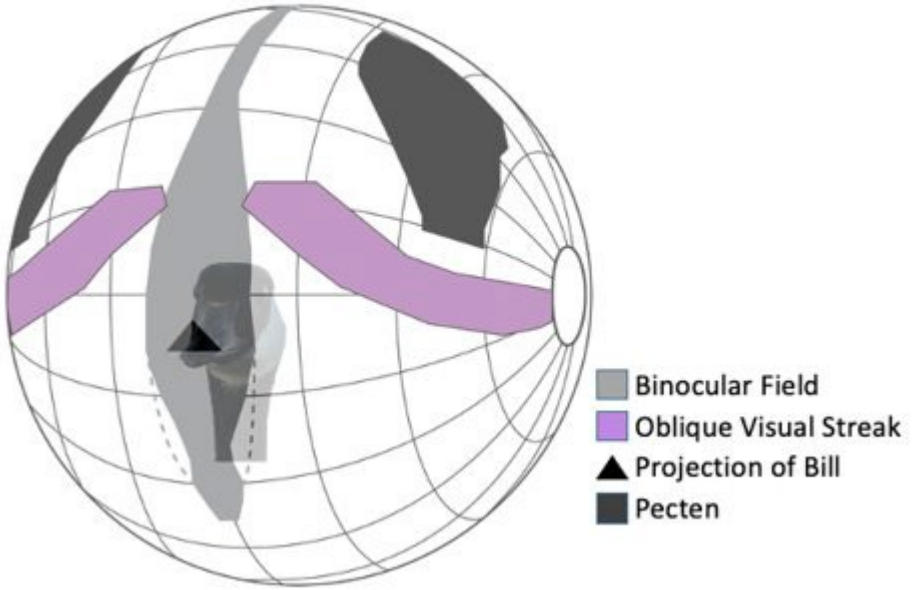


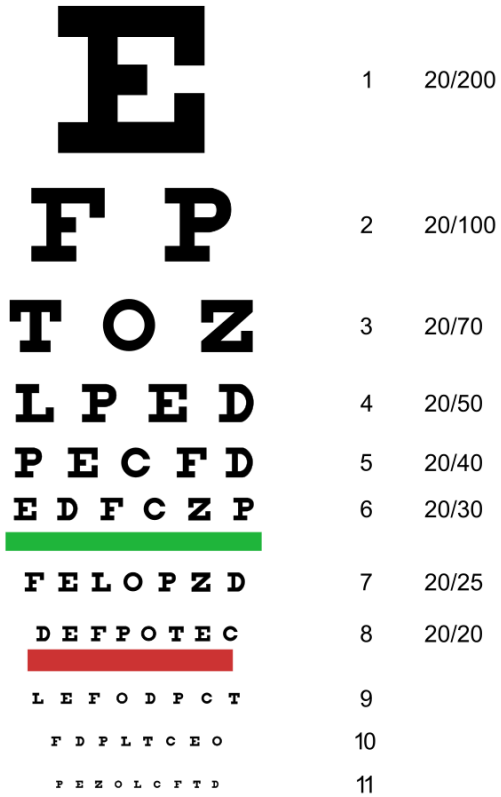
Image from Martin 2022[4]



Images courtesy of Ryan Lunn

Visual Acuity

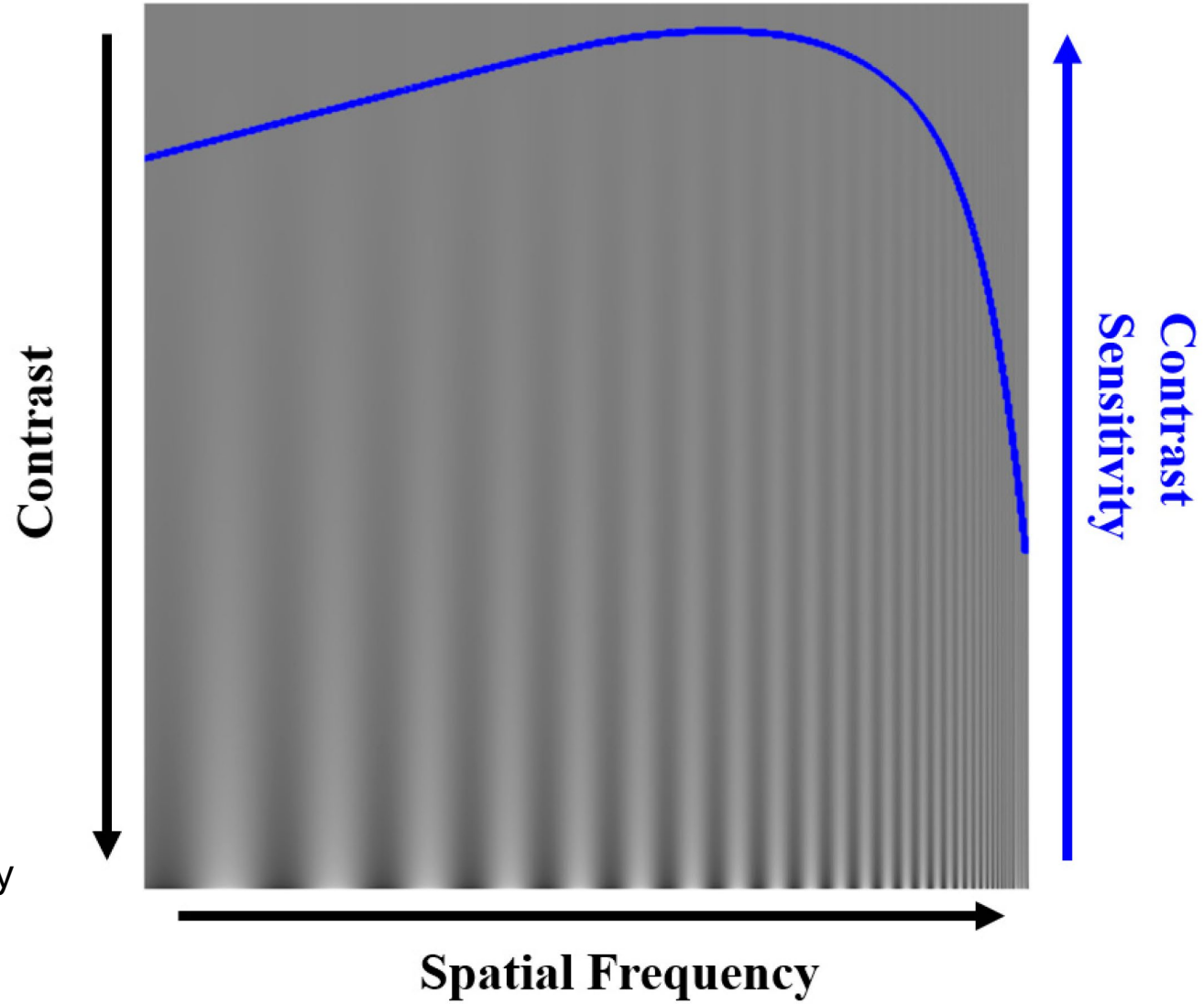
- How far away can a bird see an approaching aircraft?



The Snellen Chart is a tool to measure visual acuity in humans.

Achromatic Contrast Sensitivity

- What size of object can be resolved from a given visual background?



Example of a contrast sensitivity curve. Image from Qian et al. 2023[5]

Achromatic Contrast Sensitivity

- How well the eye can distinguish objects from the background

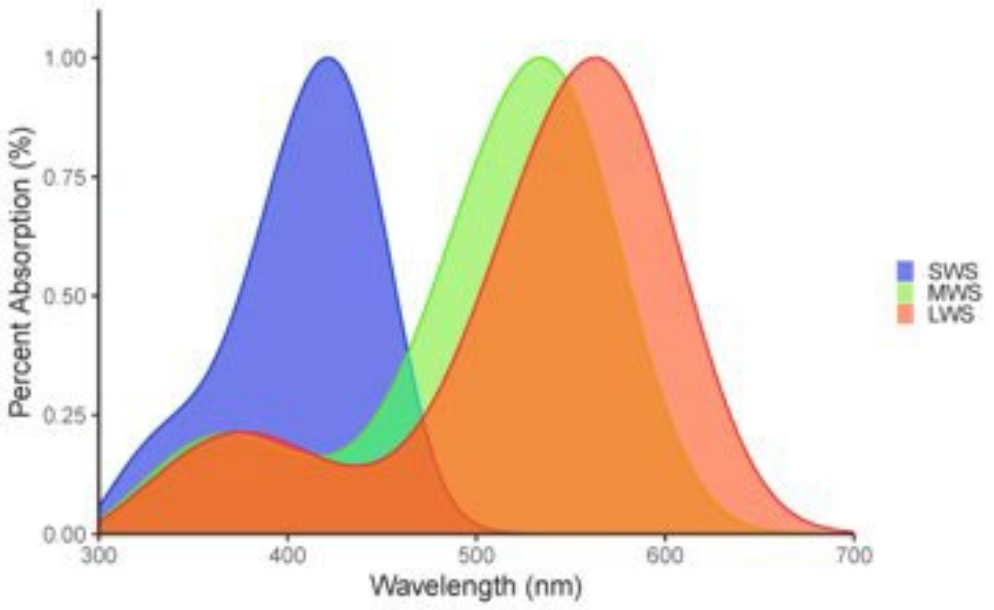
- Birds typically have lower contrast sensitivity than other vertebrates (mammals)

Low Contrast

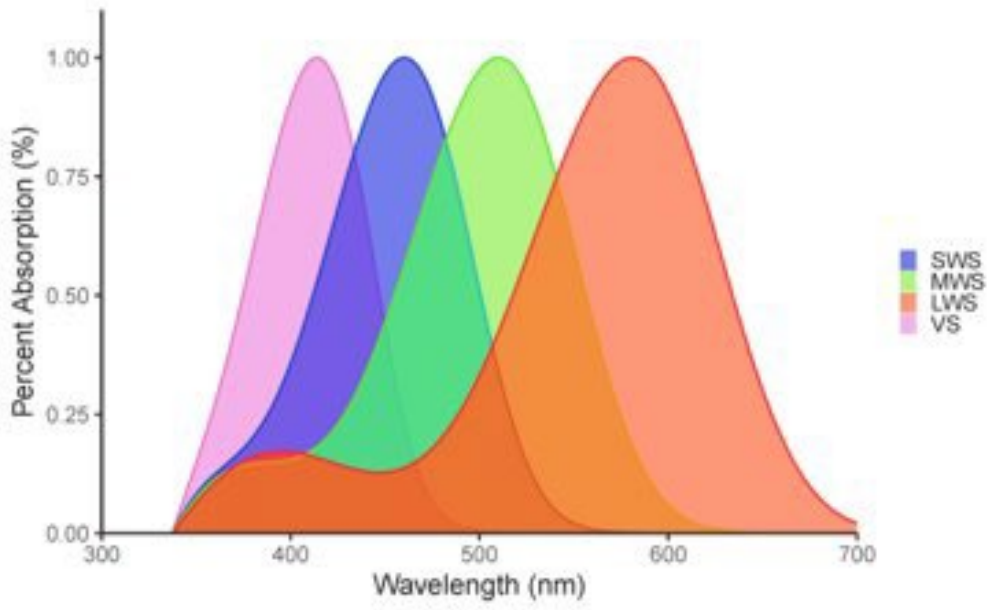
High Contrast

Cone Sensitivities

- Birds have 4 color photoreceptors (cones)
  - Red, Green, Blue, Violet/Ultraviolet



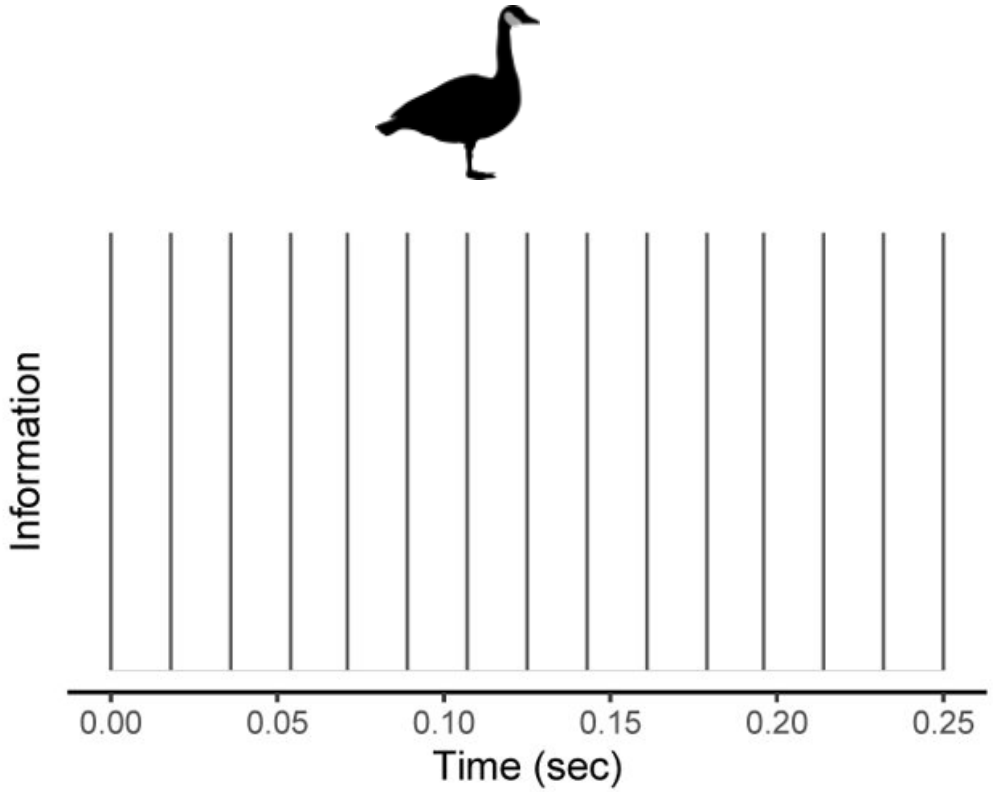
Human Vision

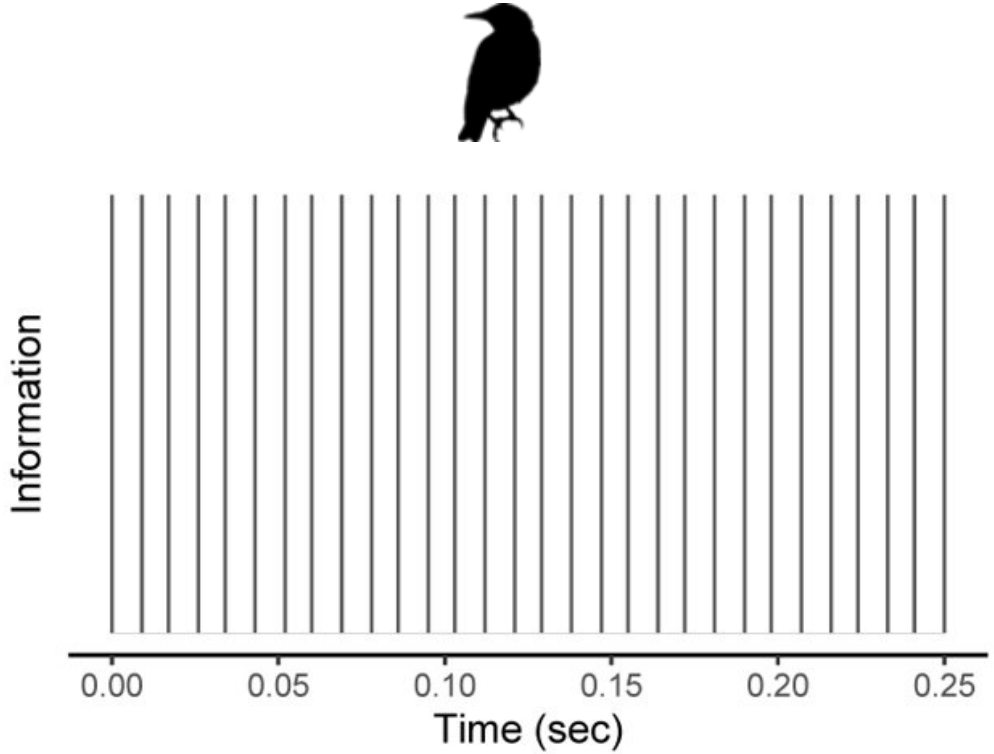


Bird Vision (Canada Goose)

Temporal Visual Resolution

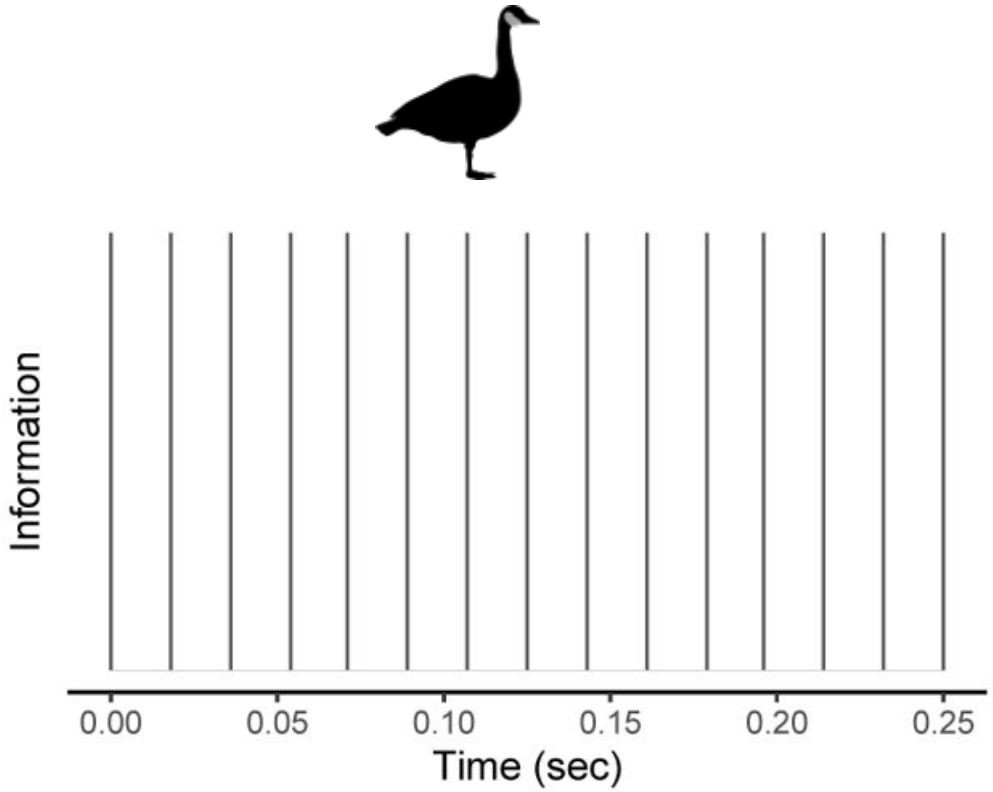
- How much visual information is obtained and processed over a given unit of time

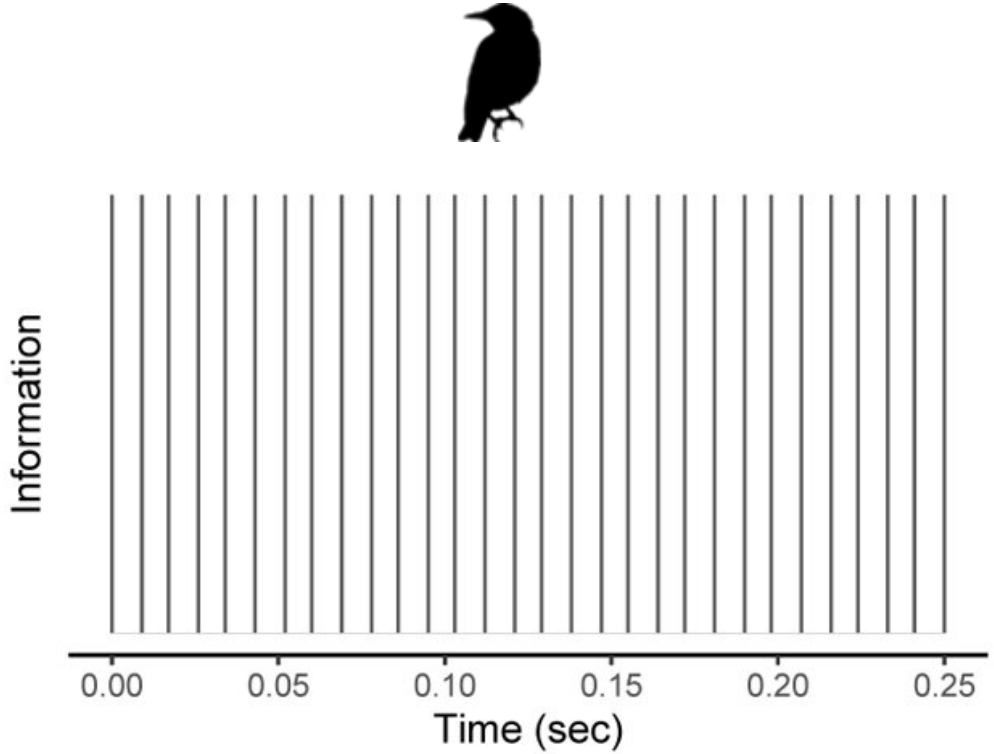




Temporal Visual Resolution

- How much visual information can be collected before a collision is imminent





Avian Family	% Damaging Strikes*	Number of Species in Family	Visual Fields (# Species)	Visual Acuity (# Species)	Achromatic Contrast Sensitivity (# Species)	Cone Sensitivities (# Species)	Temporal Resolution (# Species)
Columbidae (Pigeons/Doves)	7.1	353	2	2	1	1	1
Anatidae (Ducks/Geese/Swans)	46.4	174	39	7	3	1	0
Laridae/Sternidae (Gulls/Terns/Skimmers)	7.7	~ 100	9	0	0	2	0
Turdidae (Robins/Thrushes)	7.5	193	0	2	0	1	0
Corvidae (Crows/Ravens/Jays)	7.2	139	8	3	1	1	0
Accipitridae (Hawks/Eagles/Old World Vultures)	12.9	253	16	7	12	2	1
Cathartidae (New World Vultures)	48.7	7	1	2	0	0	0

*% Damaging Strikes is reported as the highest percentage of damaging strikes (1990 – 2023) for member of the family with 600+ strikes, per Dolbeer et al. 2024[6]

Objective

- What visual capabilities for vultures exist in the literature?
- Reproducible literature search
- Example Web of Science search string (visual acuity)

  “(TS = “visual acuity” OR TS = “spatial resolving power” OR TS = “cycles per degree”) AND (TS = vulture OR TS = Cathartid*)

Objective

- What visual capabilities for vultures exist in the literature?

- Reproducible literature search

- Example Web of Science search string (cone sensitivity)

  “(TS = "wavelength sensitivity" OR TS = "cone sensitivity" OR TS = "spectral sensitivity" OR TS = "color vision" OR TS = "colour vision" OR TS = "microspectrophotometry") AND (TS = vulture OR TS = Cathartid*)

Objective

- What visual capabilities for vultures exist in the literature?

- Reproducible literature search

- Web of Science **expanded** search string (cone sensitivity)

  “(TS = "wavelength sensitivity" OR TS = "cone sensitivity" OR TS = "spectral sensitivity" OR TS = "color vision" OR TS = "colour vision" OR TS = "microspectrophotometry") AND (TS = vulture OR TS = Cathartid* **OR TS = Accipitri* OR TS = raptor**)

Search Results

Visual Characteristic	Number of Results (Cathartids)	Number of Results (Accipitriformes)
Visual Fields	3	33
Visual Acuity	13	72
Achromatic Contrast Sensitivity	0	2
Cone Sensitivity	1	44
Temporal Visual Resolution	1	13

Dataset Structure (truncated)

Species	Metric	Citation	Value	Variance	Sample Size
BLVU	# of foveae (each eye)	Inzunza et al. 1991	1 fovea	NA	not reported
BLVU	Axial diameter	Ritland 1982	16.8 mm	NA	10
BLVU	Axial diameter	Lisney et al. 2013	18.07 mm	0.02 SD	5
BLVU	Corneal diameter	Ritland 1982	8.8 mm	NA	10
BLVU	Corneal diameter	Lisney et al. 2013	9.72 mm	0.36 SD	8
BLVU	Estimated visual acuity	Lisney et al. 2013	15.8 cycles/degree	1.2 SD	3
BLVU	Eye transverse diameter	Lisney et al. 2013	21.74 mm	0.33 SD	8
BLVU	Head length	Hall et al. 2009	51.9 mm	NA	4
BLVU	Inner diam. Sclerotic ring	Hall et al. 2009	10.77 mm	NA	4
BLVU	Orbit diameter	Hall et al. 2009	21.23 mm	NA	4
BLVU	Retinal surface area	Inzunza et al. 1991	400 mm^2	not reported	not reported
BLVU	Retinal surface area	Lisney et al. 2013	539.6 mm^2	27.4 SD	3
BLVU	RGC density, fovea	Inzunza et al. 1991	25,000/mm^2	not reported	not reported
BLVU	RGC density, streak	Inzunza et al. 1991	8000/mm^2	not reported	not reported
BLVU	RGC peak density, fovea	Lisney et al. 2013	23,796/mm^2	3707 SD	3
BLVU	RGC peak density, temporal area	Lisney et al. 2013	17361/mm^2	1791 SD	3
BLVU	Type of Retinal Visual Specializations	Inzunza et al. 1991	Nasal fovea, afoveate temporal area, nasal streak	NA	not reported

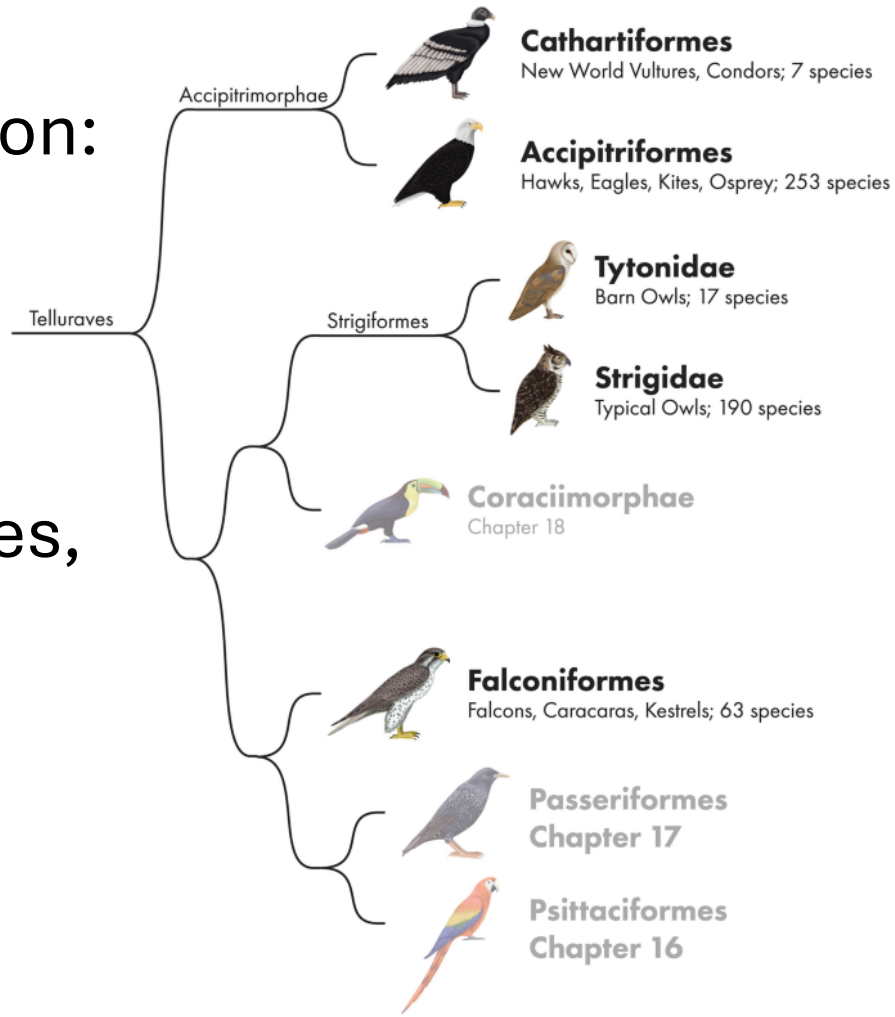
Visual Characteristics of Interest

Common Name	IUCN Status	Region	Visual Field	Visual Acuity	Achromatic Contrast Sensitivity	Cone Sensitivity	Temporal Visual Resolution
Black Vulture	Least Concern	Americas	X	X			
Turkey Vulture	Least Concern	Americas	X	X			
Lesser Yellow-headed Vulutre	Least Concern	Americas					
Greater Yellow-headed Vulture	Least Concern	South America					
King Vulture	Least Concern	Americas					
California Condor	Critically Endang	North America					
Andean Condor	Vulnerable	South America					
Palm-nut Vulture	Least Concern	Africa	X				
Bearded Vulture	Near Threatened	Afro-Eurasia					
Egyptian Vulture	Endangered	Afro-Eurasia	X	X	X		
Hooded Vulture	Critically Endang	Africa	X				
Indian Vulture	Critically Endang	Asia		X			
Slender-billed Vulture	Critically Endang	Asia					
White-rumped Vulture	Critically Endang	Asia					
Griffon Vulture	Least Concern	Afro-Eurasia	X	X	X		
Rüppell's Vulture	Critically Endang	Africa					
Himalayan Vulture	Near Threatened	Asia					
White-backed Vulture	Critically Endang	Africa	X				
Cape Vulture	Vulnerable	Africa					
Red-headed Vulture	Critically Endang	Asia					
White-headed Vulture	Critically Endang	Africa	X				
Cinerous Vulture	Near Threatened	Eurasia			X		
Lappet-faced Vulture	Endangered	Africa/Asia					

Phylogeny of New World Vultures

- In order to hypothesize about vulture vision:

- Examine the visual characteristics of close relatives in order *Accipitriformes*
- Special interest toward Old World Vultures, which share a niche



Phylogenetic relationships of the raptors (highlighted) – from Moore & Montiani-Ferreira 2022[7]

Species	# Strikes	% Damaging Strikes*	Visual Fields	Visual Acuity	Achromatic Contrast Sensitivity	Cone Sensitivities	Temporal Resolution
Turkey Vulture	1163	48.7	Yes	Yes	No	No	No
Black Vulture	353	62.6	No	Yes	No	No	No
Red-tailed Hawk	4048	12.9	Yes	No	No	No	No
Swainson's Hawk	240	15.0	No	No	No	No	No
Broad-winged Hawk	60	33.3	No	No	No	No	No
Ferruginous Hawk	70	7.1	No	No	No	No	No
Bald Eagle	492	36.4	Yes	Yes	Yes	Yes	No
Golden Eagle	37	32.4	Yes	Yes	Yes	Yes	No
Osprey	628	21.3	No	No	No	No	No
Egyptian Vulture	NA	NA	No	Yes	Yes	No	No
Indian Vulture	NA	NA	No	Yes	No	No	No
Griffon Vulture	NA	NA	Yes	Yes	Yes	No	No
White-backed Vulture	NA	NA	Yes	No	No	No	No
White-headed Vulture	NA	NA	Yes	No	No	No	No
Cinerous Vulture	NA	NA	No	No	Yes	No	No

*% Damaging Strikes is reported as the percentage of damaging strikes (1990 – 2023) for each species, per Dolbeer et al. 2024

Visual Fields in Vultures

- Turkey Vulture has ~ 315˚vision at horizontal
- 45˚blind spots
- Small overhead blind spot

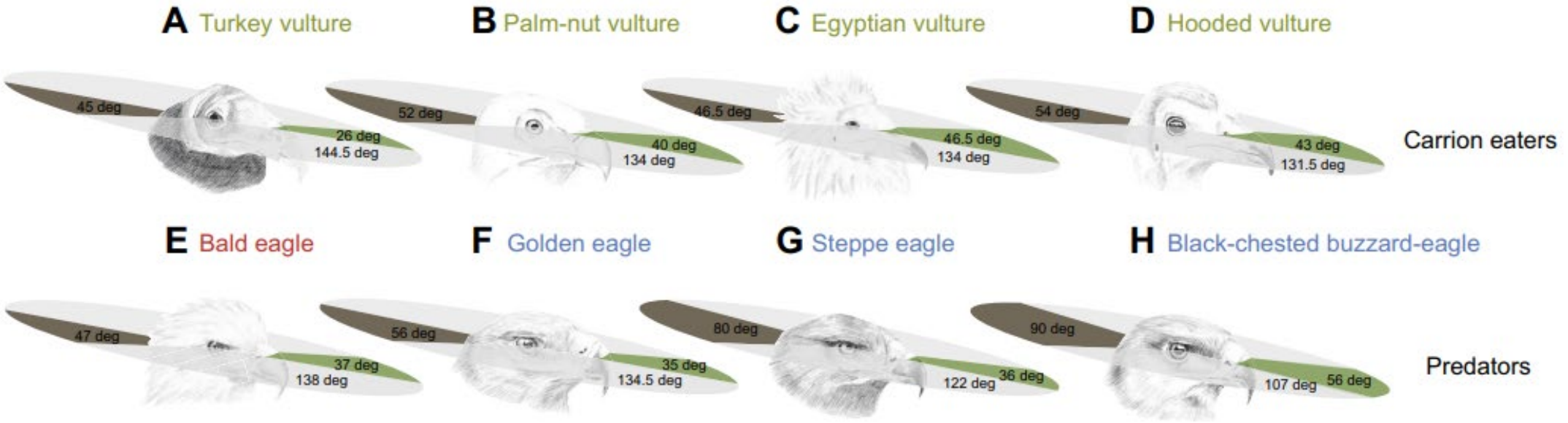


Image from Potier et al. 2018[8]

Visual Acuity in Vultures

New World Vultures[9]

- Black Vulture: 15.8 cycles/degree
- Turkey Vulture: 15.4 CPD

Old World Vultures[10]

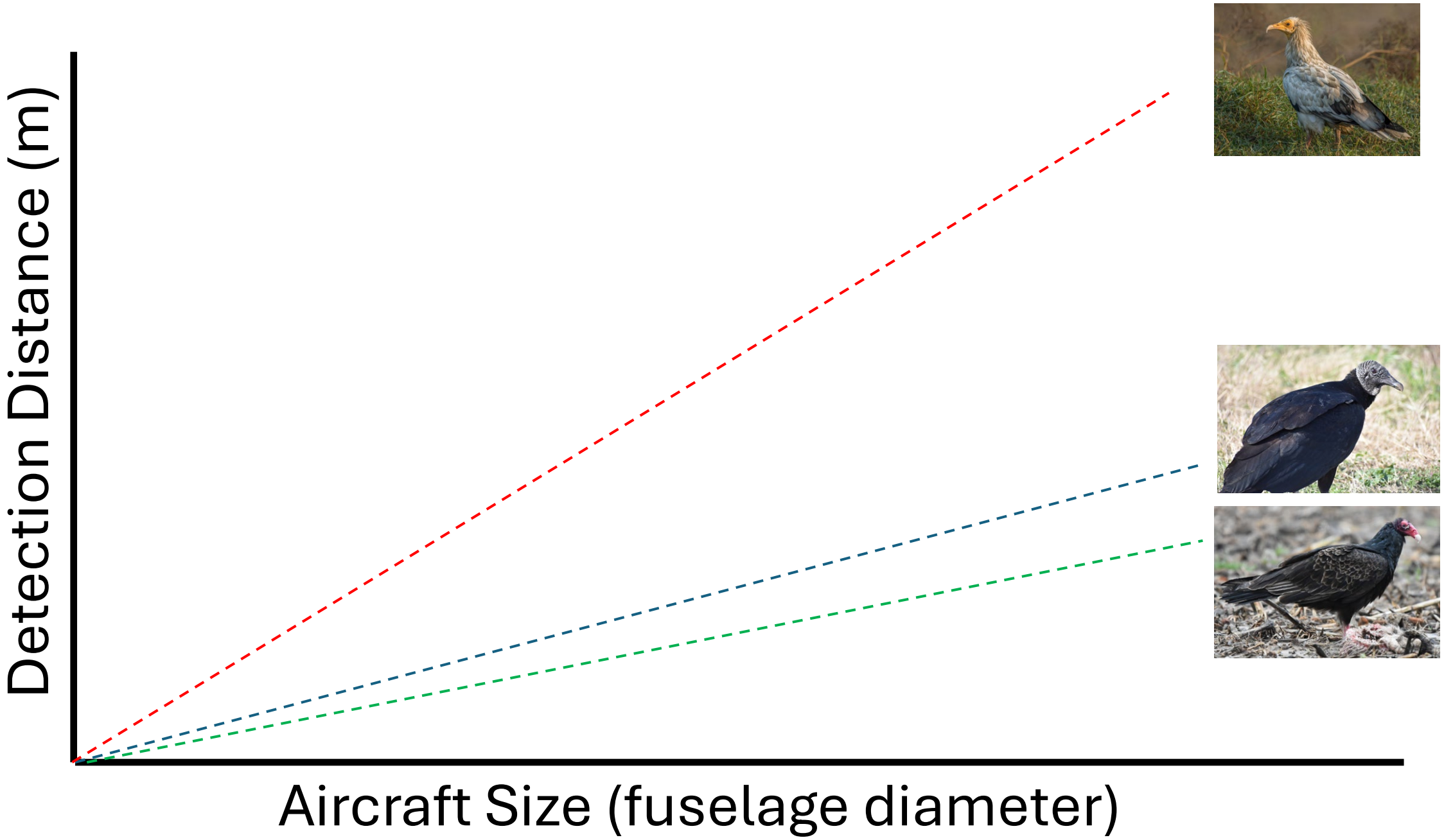
- Griffon Vulture: 104 CPD
- Egyptian Vulture: 108 – 135 CPD
- Indian Vulture: 135 CPD

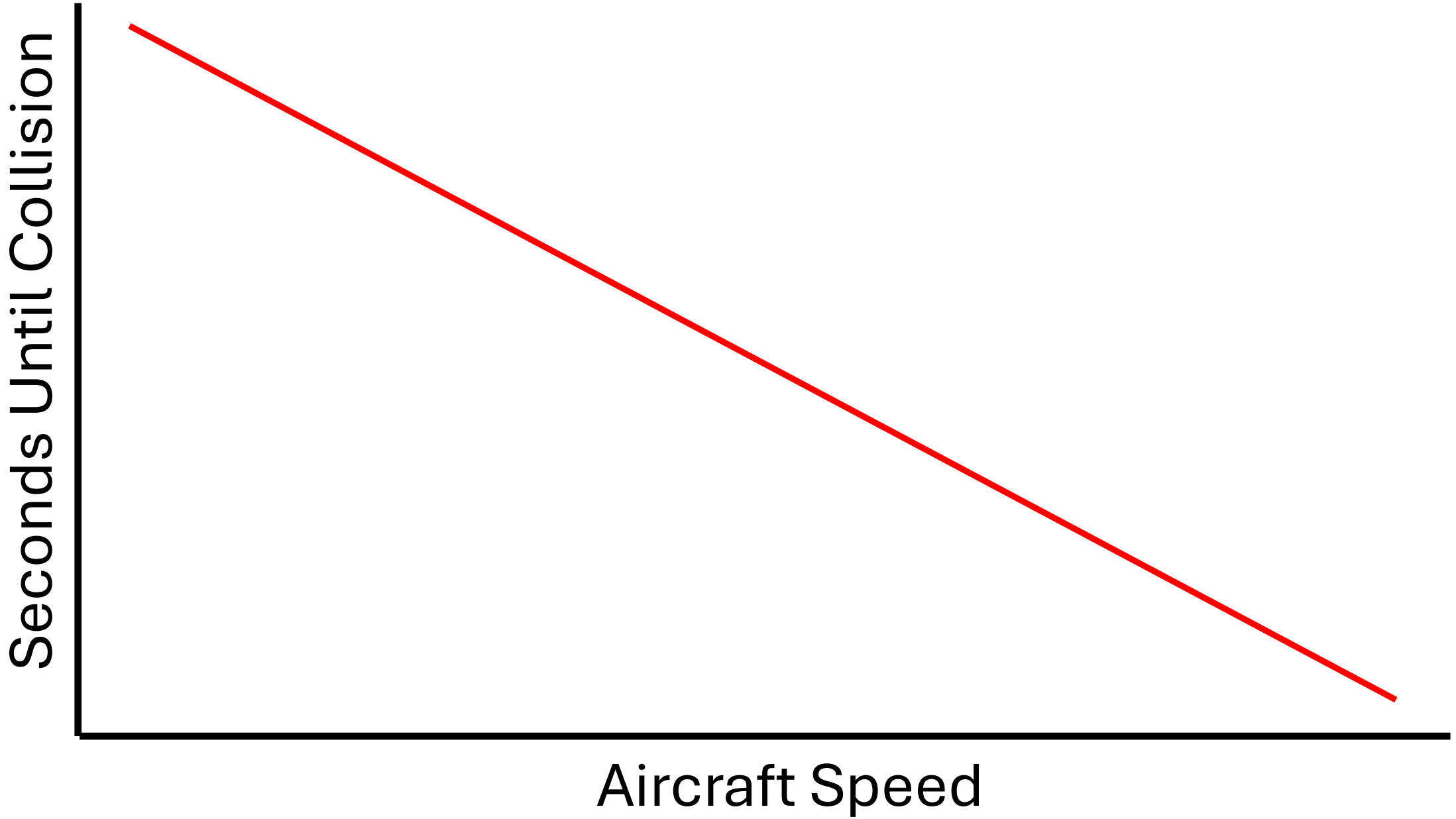
Griffon Vulture

Egyptian Vulture

Indian Vulture

Griffon Vulture © Santiago Caballero Carrea; Egyptian Vulture © Anand Singh; Indian Vulture © Shekar Vishvanath
All from Macaulay Library


Detection Distance (m)
Aircraft Size (fuselage diameter)


Seconds Until Collision
Aircraft Speed

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Airbus A320 – fuselage diameter 3.95 m

3.59 kilometers

3.48 kilometers

23.5 kilometers

30.4 kilometers

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Airbus A320 – fuselage diameter 3.95 m

Assuming a takeoff speed of 140 knots:

3.59 kilometers

49.7 seconds to collision

3.48 kilometers

48.2 seconds to collision

23.5 kilometers

5.4 minutes to collision

30.4 kilometers

7.0 minutes to collision

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Boeing 737-800 - fuselage diameter 3.76 m

Assuming a takeoff speed of 130 knots:

3.42 kilometers

51.3 seconds to collision

3.31 kilometers

49.7 seconds to collision

22.4 kilometers

5.6 minutes to collision

28.9 kilometers

7.2 minutes to collision

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Lockheed Martin F-16 - fuselage diameter ~ 1.0 m

Assuming a takeoff speed of 130 knots:

0.91 kilometers

13.7 seconds to collision

0.88 kilometers

13.2 seconds to collision

5.95 kilometers

1.5 minutes to collision

7.69 kilometers

1.9 minutes to collision

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Photo from U.S. Naval Air Systems Command, photo by Shannon Renfroe

Boeing F/A-18E - fuselage diameter ~ 1.0 m

0.91 kilometers

11.7 seconds to collision

0.88 kilometers

11.3 seconds to collision

5.95 kilometers

1.3 minutes to collision

7.69 kilometers

1.6 minutes to collision

Assuming a takeoff speed of 150 knots:

Seeing Distant Aircraft

- In sunny, daylight conditions, these vultures could see:

Robinson R44 - body diameter of 2.2 m

Assuming a cruising speed of 100 knots:

2.00 kilometers

38.9 seconds to collision

1.94 kilometers

37.8 seconds to collision

13.1 kilometers

4.2 minutes to collision

16.9 kilometers

5.5 minutes to collision

Seeing Distant Aircraft – What's Going Wrong?

- These are *ideal* circumstances – actual visual acuity will be constrained by:
  - Light levels
  - Haze/Fog/Clouds
  - Contrast sensitivity

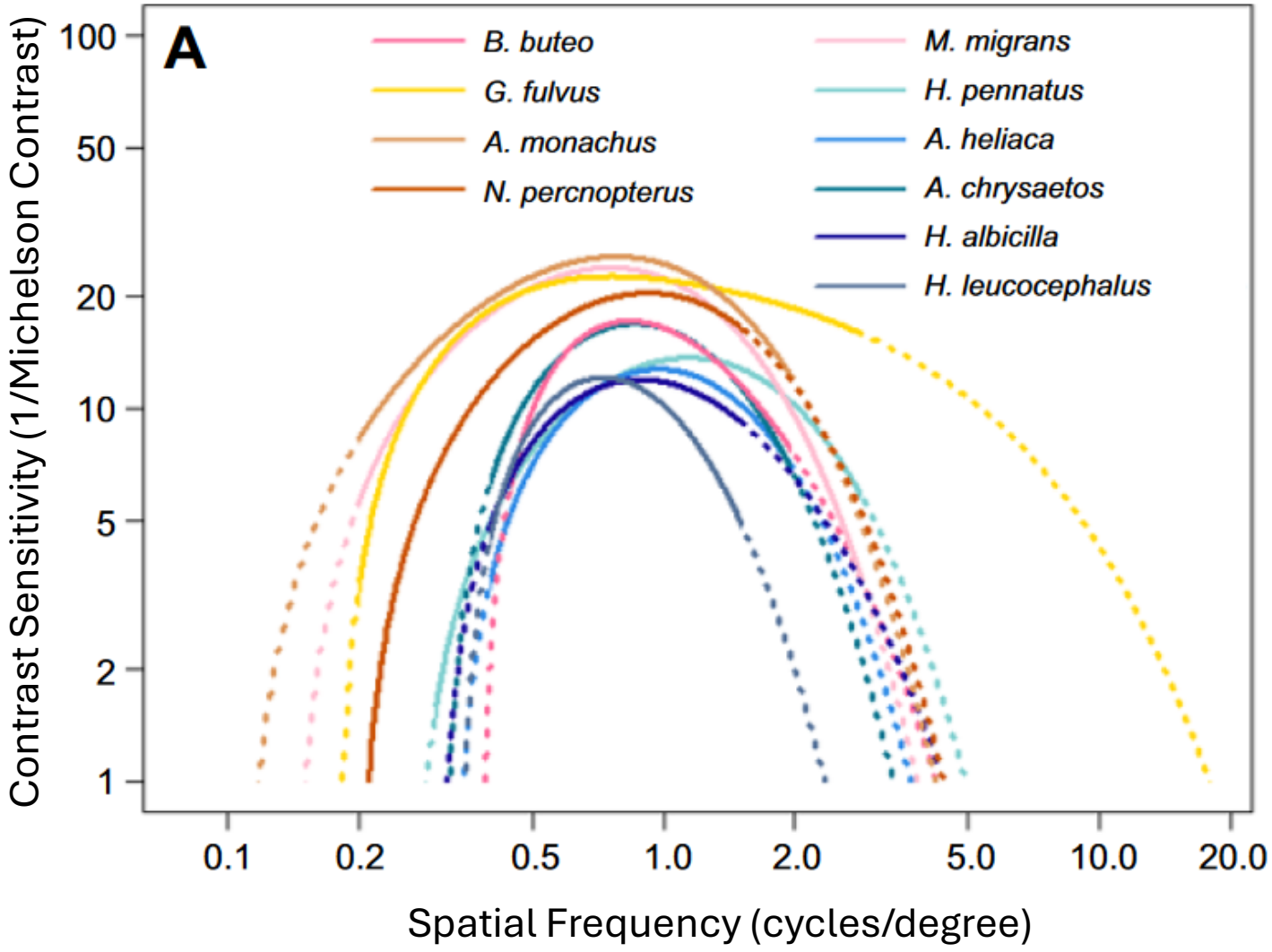
- Detection is impacted by
  - Direction of gaze and visual field
  - External stimuli

- Avoidance response requires bird to feel threatened

Achromatic Contrast Sensitivity in *Accipitriformes*

Contrast sensitivity curves for selected hawks, eagles, and Old World Vultures. Image from Blary et al. 2024[11]

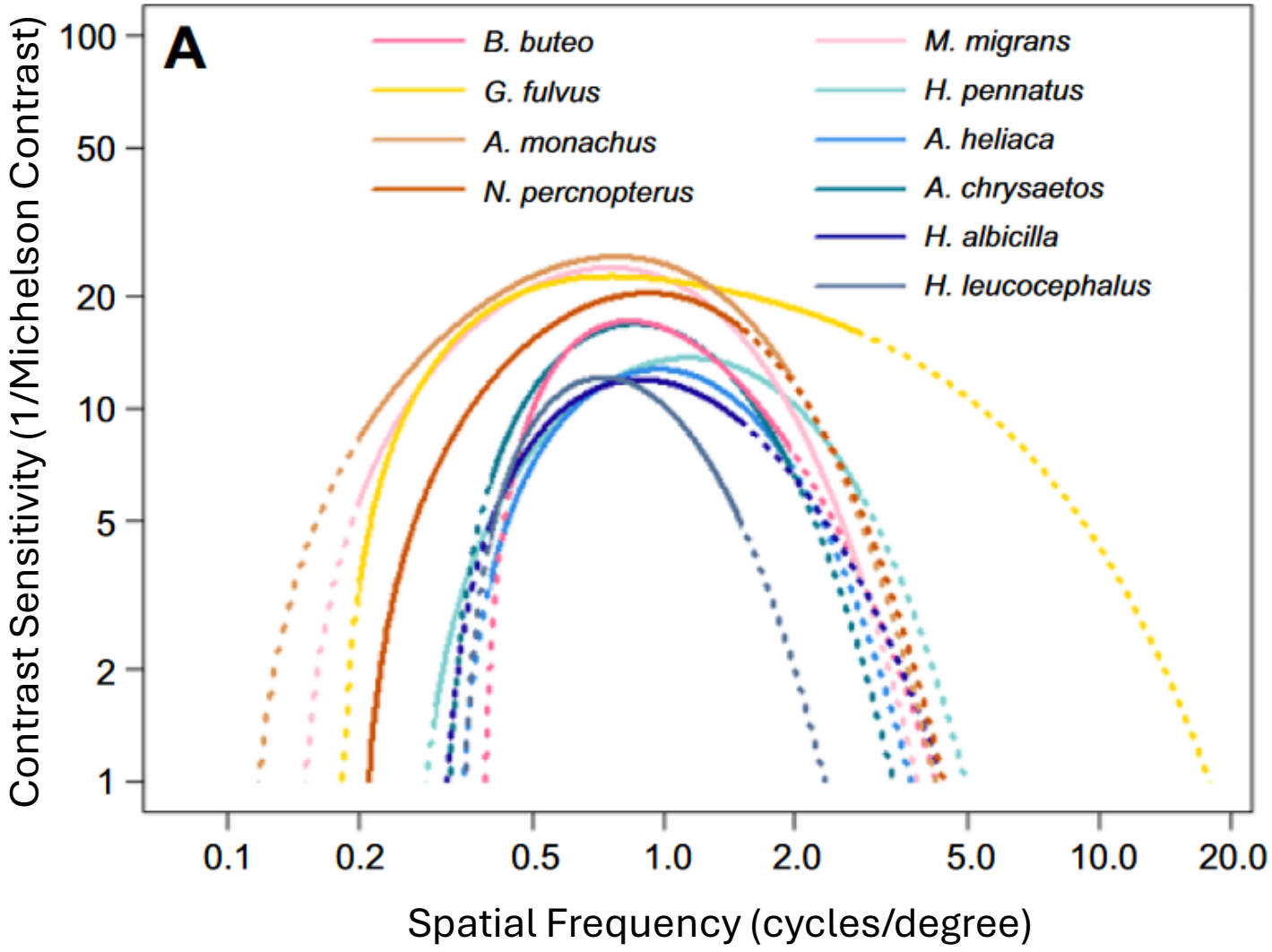
Vulture relatives have contrast sensitivities between 10 – 26 at a peak spatial frequency between 0.7 – 1.2 cycles/degree.



Achromatic Contrast Sensitivity in *Accipitriformes*

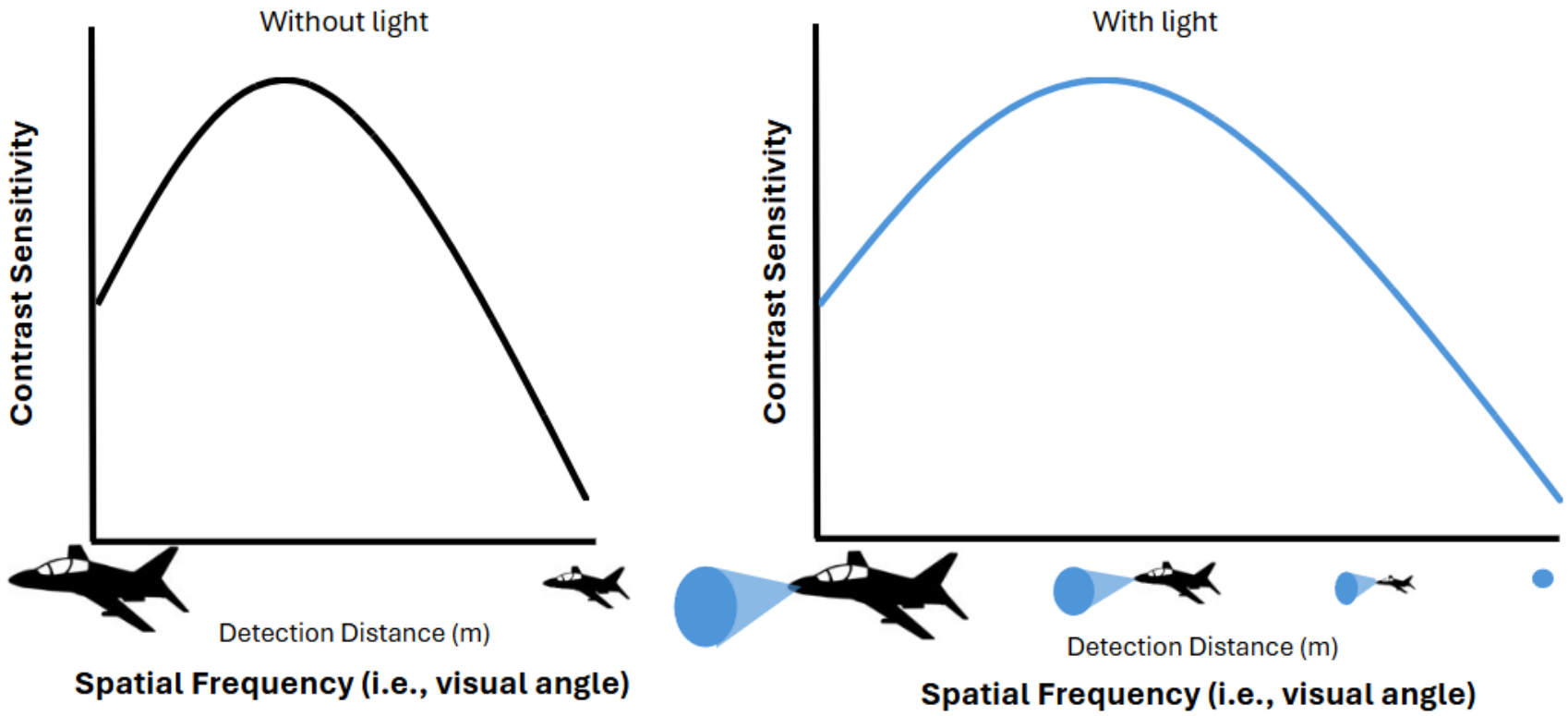
Contrast sensitivity curves for selected hawks, eagles, and Old World Vultures. Image from Blary et al. 2024[11]

Airbus A320 is best resolved against visual background between 165 - 282 m away.

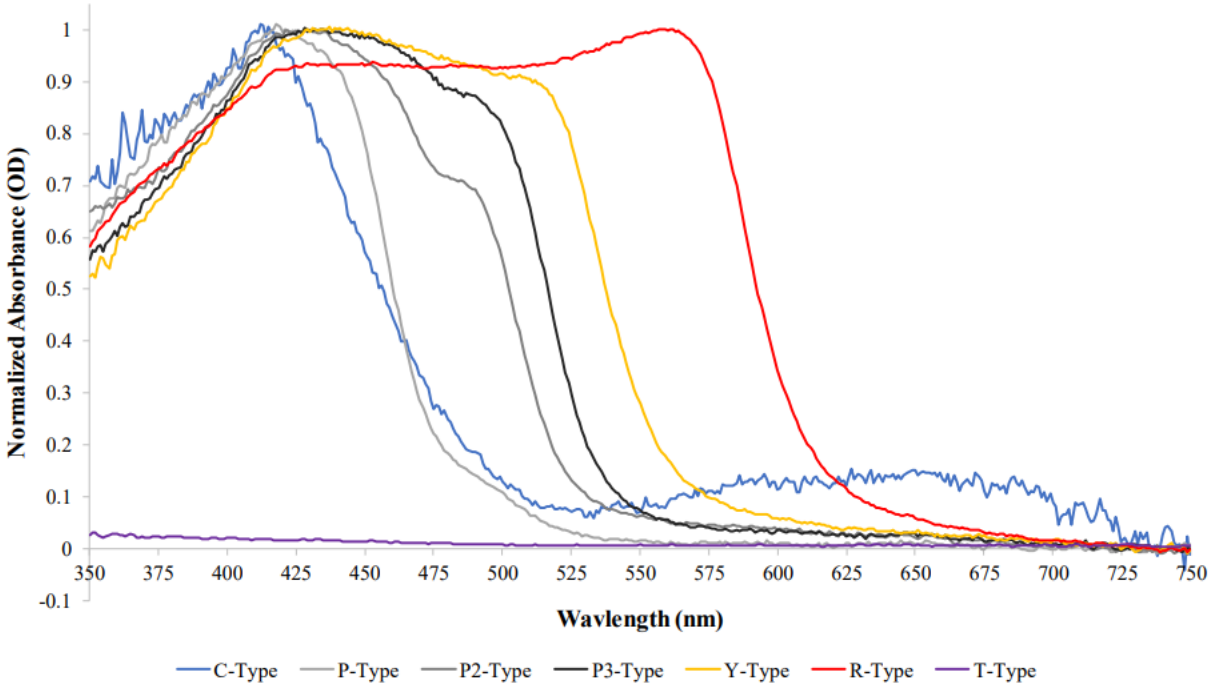


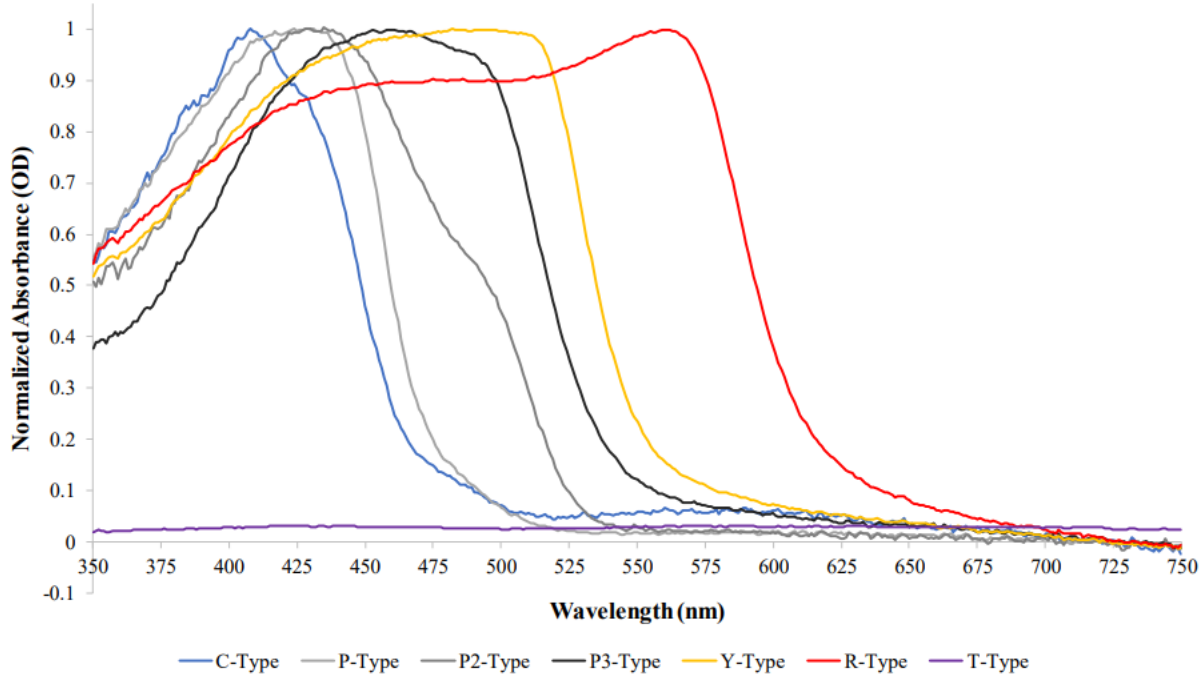
Achromatic Contrast Sensitivity in *Accipitriformes*

- Salient lighting can extend the limits of the contrast sensitivity curve, allowing detection at longer distances.



Cone Sensitivities in *Accipitriformes*





Oil droplet absorbance of Bald Eagle (left) and Golden Eagle (right). Peak sensitivities of C-type oil droplet indicate violet-sensitivity.

Images from Fernández-Juricic et al. 2020[12]

Cone Sensitivities in *Accipitriformes*

- Genetic sequencing

Anseriformes	Anatidae	*Branta bernicla*	Brant goose	**FISCIFSVFIV**	VS
Anseriformes	Anatidae	*Cairina moschata*	Muscovy duck	**FVSCXFSVFIV**	VS
Anseriformes	Anatidae	*Mergus merganser*	Goosander	**FISCIFSVFIV**	VS
Procellariiformes	Procellariidae	*Pterodroma macroptera* 2	Great-winged petrel	**FISCIFSVFTV**	VS
Podicipediformes	Podicipedidae	*Podiceps cristatus*	Great crested grebe	**FICCIFSVFTV**	VS
Phaethontiformes	Phaethontidae	*Phaethon rubricauda* 3	Red-tailed tropicbird	**FMACIFSVFTV**	VS
Phaethontiformes	Phaethontidae	*Phaethon lepturus fulvus*	White-tailed tropicbird	**FMACIFSVFTV**	VS
Pelecaniformes	Threskiornithidae	*Plegadis falcinellus*	Glossy ibis	**FISCIFSVFTV**	VS
Pelecaniformes	Threskiornithidae	*Platalea ajaja*	Roseate spoonbill	**FISCIFSVFTV**	VS
Accipitriformes	Cathartidae	*Cathartes aura ruficollis*	Turkey vulture	**FISCIFSVFTV**	VS
Accipitriformes	Accipitridae	*Aviceda subcristata*	Pacific baza	**FICCIFSVFIV**	VS
Accipitriformes	Accipitridae	*Ictinia mississippiensis*	Mississippi kite	**FICCIFSVFTV**	VS

From Ödeen & Håstad 2013[13]

- Physiological testing still needed for actual peak sensitivity

General Outcomes

- We know very little about the vision of New World vultures
- Black & Turkey Vultures should be able to see an aircraft (under perfect conditions) at 0.9 – 3.6 km
- From close relatives, we expect:
  - Vultures will be violet sensitive
  - Have relatively high achromatic contrast (for birds)

Tuning Onboard Lighting to Vulture Eyes

What do we need to know to make a difference in collision mitigation?

1. Blind spots (visual fields)
2. Maximum detection distances (visual acuity)
3. Is aircraft detectable against visual background? (contrast/wavelength sensitivity)
4. Maximum allowable time-to-collision (temporal resolution)

Moving forward with New World Vultures

- Measuring:
  - Visual Fields
  - Achromatic Contrast Sensitivity
  - Cone Sensitivity
  - Temporal Resolution
- Behavioral tests:
  - Lighting Choice Test
  - Simulated Vehicle Approaches

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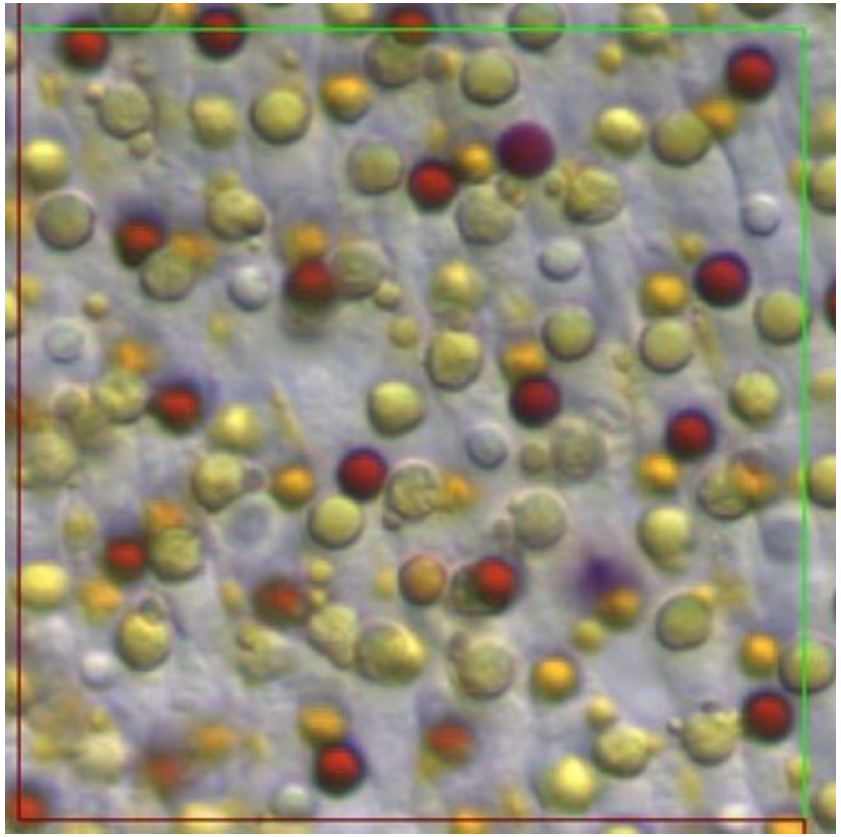
Appendix

Supplemental Materials

Cone Sensitivities

- Birds have 4 color photoreceptors (cones)
  - Red, Green, Blue, Violet/Ultraviolet

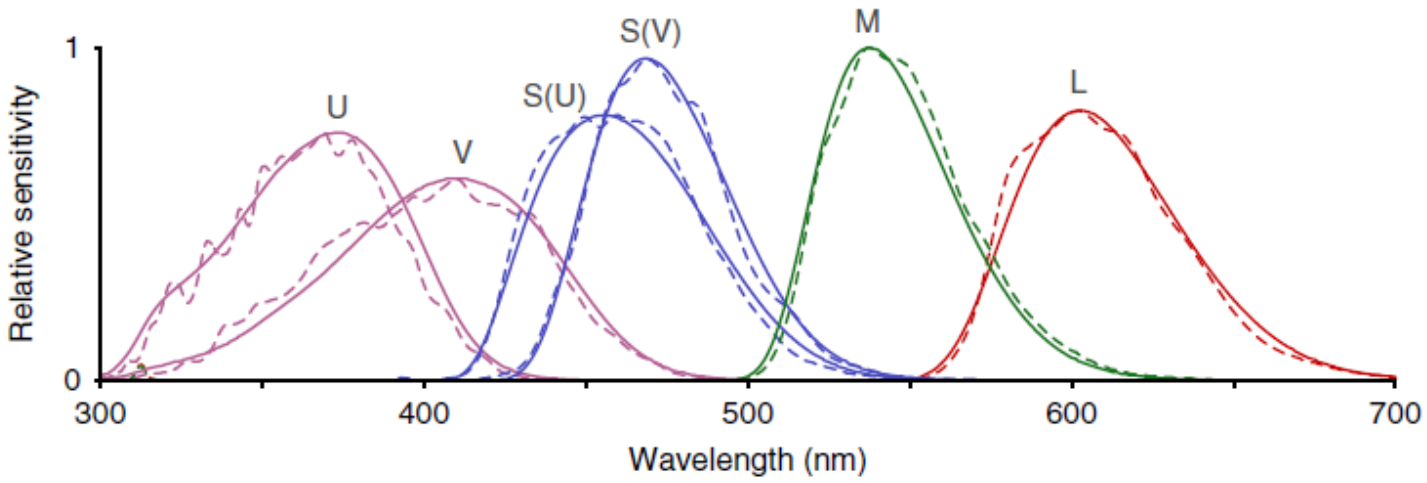
- Oil droplets



Cone Sensitivities

- Birds have 4 color photoreceptors (cones)
  - Red, Green, Blue, Violet/Ultraviolet

- These sensitivities determine which colors are most visible to the avian eye



Example cone sensitivities of a hypothetical avian eye. Placements of short-wavelength cone sensitivities depend on violet/ultraviolet sensitivity.

Image from Tedore & Nilsson 2019[14]

All Search Strings

1. TS = "visual field$" OR TS = ophthalmoscopic reflex
2. TS = "visual acuity" OR TS = "spatial resolving power" OR TS = "cycles per degree“
3. TS = "wavelength sensitivity" OR TS = "cone sensitivity" OR TS = "spectral sensitivity" OR TS = "color vision" OR TS = "colour vision" OR TS = "microspectrophotometry“
4. TS = "achromatic contrast sensitivity" OR TS = "spatial contrast sensitivity“
5. TS = temporal visual resolution OR TS = "flicker fusion frequency“
6. TS = eye size OR TS = "corneal diameter" OR TS = "axial diameter" OR TS = retina* OR TS = "retinal ganglion cell" OR TS = "photoreceptor" OR TS = "bipolar cell" OR TS = optic* OR TS = ophthal*

AND TS = vulture OR TS = Cathartid* **/** TS = vulture OR TS = Cathartid* OR TS = Accipitri* OR TS = raptor

Visual Acuity to Detection Distance Formula

Detection distance = $\frac{r}{tan\frac{\alpha}{2}}$

Where r is the radius of approaching object

And $\alpha = \frac{1}{visual\ acuity}$