Brains and senses

The sensory experience of birds extends beyond those of humans
Owls can track prey in complete darkness using infrasounds
Birds can navigate by following Earth’s magnetism

Outline:
- Avian Intelligence
- Brain Structure
- Vision
- Hearing
- Taste and Smell

Intelligence

- Are birds intelligent animals?
- Recent research reveals that birds have well-developed brains
- Birds are capable of outperforming mammals in advanced learning experiments

The Krushinsky problem

- Comparative experiment of dogs, cats, rabbits, chickens, pigeons, crows.

The Krushinsky problem

- Cats, rabbits, chickens, and pigeons do poorly on the test, but crows and dogs solve the problem immediately

Problem Solving

- Carrion crows will hop into cross walks when it is safe to cross and place walnuts on the road
- Cars break the walnuts open and the crows return during the next light to retrieve the reward

Other tests of intelligence

- Simpler food-reward tests
  - Stimulus-food vs stimulus-no food
    - Birds – no problem
    - Cats, Squirrel Monkeys – problems
  - Counting Crows (actually ravens and parakeets)
    - Identify food boxes with number of objects in front of them
- Imitation experiments (insight learning)
  - Blue Jays can learn tasteful vs distasteful butterflies from naive neighbors
  - English titmice learned to open milk bottles which spread throughout population
- Novel Behavior
  - Tool use
    - Throwing stones at ostrich eggs
    - Stick-probing by Galapagos Woodpecker Finches
Tool Use in Birds

Egyptian Vulture

Woodpecker Finch

Green Heron

New Caledonian Crows

- Known for their ability to not only use tools, but also make tools

The avian nervous system

- Functions:
  - obtain information about the internal & external environment
  - analyze & respond to that information
  - store information as memory & learning
  - coordinate outgoing motor impulses to skeletal muscles & the viscera (smooth muscle, cardiac muscle, & glands)

- Parts
  - brain and spinal cord
  - cranial and spinal nerves
  - autonomic nerves and ganglia
  - tissues associate w/ sense organs

Central Nervous System

- Brain and Spinal Cord
  - Olfactory bulb
  - Cerebrum
  - Cerebellum
  - Medulla
  - Spinal cord
  - Optic lobe

Central Nervous System

- Forebrain – complex behavioral instincts, sensory integration, and learned intelligence
  - Olfactory bulb
  - Cerebral hemispheres

- Midbrain – regulates vision, balance, hormones
  - Optic lobes
  - Cerebellum

- Hindbrain (medulla) – links brain to spinal cord, controls heart rate, respiration, and blood pressure
  - Spinal cord

Recently, a consortium of neuroscientists (Jarvis et al. 2005) has proposed a renaming of the structures of the bird brain to correctly portray birds as more comparable to mammals in their cognitive ability.
Central Nervous System

The revised nomenclature replaces the system developed in the 19th century by Ludwig Edinger, the father of comparative neuroanatomy. Edinger used prefixes such as palaeo- (“oldest”) and archi- (“archaic”) to designate structures in the avian brain and neo- (“new”) to designate supposedly new structures, particularly in the mammalian brain.

Based on this nomenclature the avian cerebrum is composed of basal ganglia, a structure involved only in instinctive behavior.

Modern View of Avian Brain

Jarvis et al. (2005) demonstrated that so-called “primitive” regions of avian brains are actually sophisticated processing regions homologous to those in mammals.

The neocortex and related areas are derived from a region in the embryonic cerebrum called the pallium (= mantle or covering).

Edinger's nomenclature indicated that most of the cerebrum was part of Basal Ganglia (now known not to be true).

The new nomenclature explains evolution of complex avian behaviors.

Spatial Learning and Memory

- In fall, chickadees gather and store seeds
- Use memory to re-call seed locations months later in winter
- The hippocampus, structure responsible for spatial organization and memory, expands in volume by 30% by adding new nerve cells.
- In Spring, hippocampus shrinks back to normal size
- Songbirds are first vertebrates observed where brain growth occurs in adults

Episodic Memory

- Birds can remember not only where, but WHEN they hid food items
- Scrub jays stored wax worms or peanuts
- Birds returned to wax worms first but avoided worms as time since caching increased
- First demonstration of episodic, or event based, memory in animals other than humans.

Senses

Vision
Hearing
Taste and Smell
Vision

- Dominant sense in birds
- Eyes very large relative to head
  - Human eyes = 1% mass of head
  - Starling eyes = 15% mass of head
- Large eyes provide larger, sharper images
- Passerines and raptors thought to have keenest sight of all birds
- Bird eyes are set in the side of the head and therefore, they see better to the sides than to the front.

Accommodation (focusing ability)

- Faster than mammals
- Lens softer, more flexible than in mammals
- Striated muscle in birds vs. smooth in mammals
- Rapid focus aids flying and feeding on small objects nearby and quickly scanning distance for danger.

Structure of Avian Eye

- Light entering the eye is refracted by the cornea & lens and strikes the retina where the sensory cells (the cells that convert light into nervous impulses) are located
- In birds, cornea and lens change curvature while focusing.

Nictitating Membrane

- Clear third eyelid in birds and other verts except mammals
- Protects cornea
- Cleans and lubricates cornea without closing other eyelids by flicking horizontally across the eye
- Transparent in diurnal birds.

Retina

- Avian retina is avascular (contains no blood vessels)
  - Prevents shadows and light scattering
  - Mammal retinas have blood vessels
  - Possible because of unique structure = Pecten
- Pecten is highly vascular structure projecting from retina
  - Nutrients and oxygen diffuse from pecten to retinal cells (rods and cones).
The avian retina has three types of photoreceptors that ‘translate’ light into nervous impulses:
- rods - black & white vision
- cones - color vision
- double cones - color vision

Photoreceptors (rods and cones) transmit signals to retinal neurons.

Nocturnal birds, like owls, have retinas consisting entirely of rods, while the retinas of diurnal birds contain both rods & cones.

Retina – Area and Fovea
- Area – horizontal streak across retina with higher concentrations of sensory cells
- Fovea – Concave depression of high cone density
  - Located in center of retina
  - Near optic nerve
- Cone density can exceed 65,000 / mm² in diurnal birds
- 38,000 / mm² in humans.

Arctic Tern

Vision
- Placement and number of fovea influences vision:
  - Almost all birds have a central fovea - most acute vision to side
  - most also have temporal fovea which enhance binocular vision

Visual Field
- Eyes laterally placed
- Visual field expanded by eye movement in socket
- Except owls, all birds have some mix of monocular and binocular vision

Visual Field
- Monocular vision: To sides. Acute field from central fovea.
- Binocular vision:
  - Birds with only central fovea can get small binocular field by converging eyes; not acute.
  - Temporal fovea allows acute binocular vision
Vision - Color

- Cones responsible for color vision
- Many cones contain oil droplets
  - Consist of lipids and carotenoid pigments
- Pigments convert the electromagnetic energy of light into neural energy
- These oil droplets:
  - Absorb light below their characteristic wavelength
  - Provide a protective shield against UV light
  - Probably act as lenses that focus light onto the photoreceptor & improve the reception of visual pigments.

Vision - Ultraviolet

- Transparent oil droplets permit perception of very short spectral wavelengths (ultraviolet or near ultraviolet)
- Serves a signaling function in some species (bird plumage tends to have shorter wavelength reflectance than many other natural objects)
- Is likely used as a cue in discriminating foods (e.g., plants, seeds, berries) or other natural objects.

Vision – Magnetic field

- Migrating birds navigate without a compass, map, or GPS unit
- But they may be able to “see” Earth’s magnetic field
- Recent research suggests that migrating birds receive visual feedback about their direction from magnetic field
- This occurs in the retina and brain.

Hearing

- The avian ear, like that of mammals, has three sections: outer ear, middle ear, & inner ear:
  - The outer ear of birds have no pinnae
  - Middle ear contains one ear bone (columnella = stapes) connecting the tympanic membrane to the pressure sensitive fluid of the inner ear
  - Inner ear includes 3 semicircular canals and is location where sound is converted to nervous impulses and sent to brain.
**Hearing**

For most birds, hearing is best at frequencies of 1 - 4 kHz, but some birds are able to detect much higher frequencies (up to 10 - 12 kHz).

The ability of birds to discriminate differences in the frequency of sounds & to detect gaps between sounds is generally similar to humans.

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**Echolocation**

The Oilbird (*Steatornis caripensis*), a nocturnal bird of South America that lives in caves.

Oilbirds use echolocation to find their way within the caves where they roost.

They emit sounds within the range of human hearing: bursts of astonishingly rapid clicks (as many as 250 per second).

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**Smell - Olfaction**

- Based in surface epithelium of olfactory cavities
- Traditionally thought that birds have limited sense of smell (because of their small olfactory lobes)
- But, most birds probably can smell & use odors in daily activities & some birds appear to have a very well developed sense of smell, including Turkey Vultures, Kiwis, & many seabirds (puffins, albatrosses, petrels, & shearwaters). Large amounts of surface area are lined with olfactory epithelium.

**Taste**

- Birds have few taste buds compared to mammals
- Located on back of the tongue and floor of pharynx
- Comparison:
  - Chicken = 24
  - E. Starling = 200
  - Mallard = 375
  - Lizards = ~500
  - Humans = 9,000
  - Catfish = 100,000
- Some are better
  - Dunlins can taste where worms were and weren't in sand
  - Hummingbirds can distinguish b/w different sugar solutions
- Generally high tolerance to acidic and alkaline solutions.

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End Brains & Senses