Cogs 143 * Animal Cognition

Lecture 4: CETACEAN BRAINS

On Comparing Brains…

- **EQ** = **Encephalization Quotient** (see Jerison, 1973; Jerison, 1980; Jerison & Barlow, 1985)
  = Ratio of actual brain mass to expected brain mass of comparison animal, corrected for body size
  - "Expected brain mass" is calculated as = 0.12 X (Body mass in grams)$^{2/3}$
- Others use ratio of cortex to rest of brain, brain to cord, sensory-motor areas to association cortex, etc
  - Most of these put humans at the top, but all have some counter-intuitive results
    - e.g. Tree shrew brain is 10% of its body weight; Orca E.Q. less than Amazon River Dolphin
- All are designed to assess amount of "excess" brain, beyond that needed to run basic functions
  - *Somehow* this should be related to "intelligence"…?
- Huge body size of cetaceans tends to throw off such metrics
  - e.g. Sperm whale (body up to 40 tons) has the largest mammalian brain (7-9000 g) but EQ=.07
- PLUS, absolute brain size matters! Larger brains, more cells, more connections, more processing capacity
- Comparing cetacean brains further complicated by 50million yrs of evolution from land mammals
  - Difficult to identify homologues, esp in later developing areas like cerebral cortex

Overall Brain Size and Shape

- Shape globular, gross size HUGE, including expansion of Cerebral Cortex
- Size: *Tursiops*: Body 170Kg Brain 1500g EQ 4.4 - *Orcinus*: Body 10,000kg Brain 6000g EQ 2.7
  - *Gorilla:* Body 170kg Brain 500g EQ 1.8 - *Homo*: Body 85kg Brain 1000g, EQ 7.5
  - Riverine dolphins 200-400 g EQ ranges 1.8-3.5

Brain Development

- Unlike **altricial** Primates (esp Humans) cetaceans are **precocial** (well developed) at birth
  - Dolphin: 12 mo gestation (vs. 9 mo Hum, 8 mo apes) - Brain 40% adult at birth (vs. 25% in Hum)
- Due to impedance match of seawater and amniotic fluids, fetus receives continuous auditory input
  - Possibly contributes to extensive development of acoustic processing by brain

Cerebellum

- Enormous, largest (absolute *and* relative size) of *any* mammal (Tursiops:**15%** brain; Primates:8-11%)
- Areas involved in movement of limbs, posture, head (e.g. for visually tracking) much reduced
- Areas controlling face (probably involved in echolocation) and trunk/tail are enlarged,

Auditory System - Main source of info on shape, size, content, distance of stimuli

- **Most developed system** thruout brain. Moreso in Odontocetes than Mysticetes
  -Auditory Nerve 2.5X fibers vs. hum. - Many **huge, myelinated** fibers inc transmission speed
    - Helps make up for great distances signals must travel, & enables high-speed processing
  - Lateral Lemniscus (Medulla to Mid) 250X size humans, Inferior Colliculus 12X, Thalamus MGN 7X
  - NOTE: Like Primates, majority of synapses on auditory pathway are **binaural** (info from both ears)
- **Dual Processing System**: (See discussion in Ridgway Reading)
  - Brainstem = for ultrasonic, ultra-brief, fast-rising, closely-spaced tones (Echoloc!)
  - Cortex for "higher order" processing of Echolocation (meaning??),also adapted for Social Sounds

Other Senses

- **Vision** - well developed eyes, but no fovea, altho dense, giant myelinated ganglia from central area
  - No color, only one type of Cone receptor (for detail, contrast), Rods (for motion) predominant
  - Complete crossover, includes well developed Superior Colliculus => motion in panoramic view
  - Virtually no binocular vision, so no binocular disparity for depth perception
- **Touch** – Most receptors/highest sensitivity in face (esp eyes, lower jaw), blowhole, genital area
  - Trigeminal Nerve from face second in size only to Auditory Nerve
  - Specialized **Tacto-Acoustic** cortex responds to touch (tap, water drip) AND sound (buzz)
- **Vestibular** - Tracts much reduced (~1/3) compared to other mammals;
  - Enable frequent, rapid body rotations; Grace, balance handled by other systems (e.g. Cerebellum)?
  - ?? Bodies neutrally buoyant - Arguably avoid motion sickness in "virtually-weightless" env?
- **Anosmic** = No sense of smell in Odontocetes, but do have Taste receptors & tracts (taste hormones in water?)

Limbic System - Overall well developed, but w/certain structures enlarged, others reduced vs. Primates

- No Olfactory Bulb or O Tract in Odontocetes (reduced in Mysticetes) - No longer "Rhinencephalon"!
  - Above seen in fetus of some Ondontocete species, but degenerates by birth
  - Lost when nares migrated to top of head??

Limbic System -Continued

- **Hippocampus reduced** -Excellent memory & as in primates, many reciprocal connections w/ cortex
  - Reduction poss related to reduced role of hippocampus in spatial mapping??
- **Amygdala enlarged**, and heavily connected with **Auditory** system
  - As in other mammals, presumed role in emotional expression & interpretation (?Theory of Mind?)

Cortex shows **most convoluted** surface of any mammal, although cortex layer is **thinner** than Primates

- **Cytoarchitecture** (cell structure/configuration) is markedly different from most mammals
  - e.g. No obvious granularity in **Layer IV** (normally the receiving layer from Thalamus)
  - e.g. Less columnar differentiation (in Primates, marks distinct info-processing modules)
- Adult form most likely a **secondary adaptation**, not expanded "initial" pattern (See Ridgway)
  - Some argue highly expanded but "primitive" (= giant hedgehog! – like primitive insectivores)
  - BUT Fetal brains show granularity & other more-typical structuring, that is then lost in adult

- Some mappings of sensory & motor fields done for some species (difficult to map to homologues!)
  - **A1** = Not in Sylvian Fissure, but above, on dorsal-lateral surface, along "Ectosylvian Gyrus"
  - **A2**=Huge rostral-caudal strip, dorsal to above, filling the wide "Suprasylvian Gyrus"
  - **S1** = Rostral to A1; - **Motor** = Medial to S1, parallel map; Separated by "Cruiciate Sulcus"
  - **S-A**: Specialized frontal area, adjacent to S1, for processing "**Tacto-Acoustic**" info
  - i.e. Responds to either acoustic OR tactile input, suggesting these, in some sense, equivalent
  - **V1** = Narrow dorsal strip, parallel and medial to A1 but shorter, along adjacent "Lateral Gyrus"
- PLUS – **Huge** amount of remaining, un-mapped "**Association Cortex**" for "higher" processing
  - Especially adjacent/lateral to Auditory cortex
- **Paralimbic** covers extensive medial wall of both hemispheres, "remarkable development"
  - Signif connections w/lower limbic system as well as other cortices ??=Human Prefrontal?!

- **Von Economo Neurons** – so far, identified in a few species
  - As in Humans & Apes, found in ACC & FI; Unlike in us, also in Frontal Pole
  - Found in Sperm Whales, Orcas, and Bottlenose dolphins (probably more!).
  - Among the Mysticetes, also found in Humpback Whales but not in Fin Whales
- Mirror Cells
  - No evidence (identified functionally and difficult to get behavioral/brain data in cetaceans)
  - Predict some such circuits, since adept vocal and motor mimics

- **Asymmetrical** - Right hemisphere larger
  - Dominant?? Some cognitive data: right dominant for global/spatial/emotional
  - Acoustic mechanisms asymmetrical (larger on right); Right side of skull also larger
  - **Lateralization??** Some indications, e.g. Examine strangers more with left eye
- **Corpus Callosum** - **Smallest** among mammals, despite huge size of cortex (¼ thickness of Humans)
  - Supports significant independence of two cortical hemispheres (see Sleep)
- **Sleep** - Researchers classify EEGs as: Stage 1 (= Primate Stage 1), Stage 2 (=2+3), Stage 3 (=4)
  - Stage 1 and 2 can be detected from one or both hemispheres at once
  - But Stage 3 only detected in one hemisphere at a time, other must stay awake enough to breathe!
  - -Thus, when "sleep" only one eye (opposite of sleeping hemisphere) is closed
  - Blood supply to 2 hemi's fairly independent, so cool one during deep sleep, other stays warm
  - Some larger whales snooze at surface, but nearly all Odontocetes remain in constant motion
- No REM! Unlike all other mammals (except primitive Echidna)
  - Perhaps replaced by above warming strategy? But what of other putative functions of REM??

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