Biological Electric Fields

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biological electrical fields

electrical field
magnetic field
visible and IR spectrum
detection (electroreception, magnetoreception)
vs. production (electrogenesis)
all organisms produce electrical fields

nerve signals

muscle contractions

membrane potentials
animal sensory apparatus

visible light
IR - viper pits, Haller’s organ
sound waves
chemical
gravity
electromagnetic fields ...
electroreception in animals

detection favored when other stimuli absent

imagine a deep sea environment ...
electroreception in animals

detection favored when other stimuli absent

Imagine a turbid tropical river ...
electrosensory perception

detect environmental objects

detect conspecifics, prey, predators

communicate

frequency jamming, overlap, shifting

passive vs. active techniques
Elasmobranchs - Sharks, Skates & Rays

Ampullae of Lorenzini
5-20 nV/cm
detect prey
rays feed in sediment
oceanic cables
sharks attacks electric field

C. plumbeus
Paddlefish (Polyodontidae)

USA freshwater systems (murky) detect metal, not plastic, objects. Attacked wires with 10 nV current. Rostrum w/ >40,000 ampullary sensors detect planktonic prey.
Paddlefish (Polyodontidae)
Monotremes - Platypus & Echidna

primitive, non-placental mammals

nocturnal feeder, thick sediment

attack buried batteries

bill w/ mucous-gland electroreceptors

300-2000 μV/cm
Electric Eels, Catfish

eel (*Electrophorus electricus*) technically a “knifefish”

murky freshwater

most feared fish in Amazon

scattered ampullae & tuberous receptors

13 μV/cm sensitivity

sensory -> communication -> defense -> offense
electrical field production - Electric Eels

produce up to 600 V (at 1 Amp)
4/5 of body = electrogenesis organs
3 organs: 1 communication, 2 more powerful
discharge: disorient, stun or kill
also: courtship, orientation
Eel Electric Organs

- Sach's Organ
- Main Organ
- Hunter's Organ

Electric organ:
- Resting
- Electrocyte
- Insulation

Electrolocation:
- Object
- Electric field by EODs
Electric Eels
electrogenesis - Electric Catfish

Africa, Nile; several genera in Fam. Melapteruridae produce up to 350 V for courtship, hunting.
electrogenesis - Electric Rays

c.a. 70 species (Or. Torpediniformes)
produce up to 8-220 V
paired organs stun or kill
electrogenesis - Weak Electric Fish

ca. 100 species knifefish
typically < 1 V
communication,
object detection
electrogenesis - Electric Mammal

Africa’s Giant Otter-Shrew (*Potamogale velox*)
aquatic; eats crabs, fish
fishermen report shocks
magnetoreception

earth’s magnetic field lines
magnetoreception

How? - mechanical vs. chemical vs. induction

polarity vs. intensity & inclination

biogenic magnetite ($\text{Fe}_3\text{O}_4$) = compass needle
magnetoreception - Birds

migratory birds, homing pigeons
disruption by magnets
magnetosensory linked to vision: “see” North
light-dependent sensor
magnetite-based sensor
magnetoreception - other animals

- sea turtles
- whales
- sharks
- salmon
- bees
- mole rats
- salamanders
magnetoreception - Bacteria

*Magnetospirillum* sp.
magnetoreception - Bacteria
magnetoreception - Bacteria
exposure to electromagnetic (EM) fields

- cancer rates - field correlations
  - childhood leukemia (CL) & electric utility workers
  - CL doubled - fields > 0.4 μT
  - CL increased 70% (< 200 m) transmission lines
- brain cancer, Lou Gehrig’s, Alzheimer’s, miscarriage
electrical fields as cures

- enhance bone deposition
- hip replacement
- bad breaks

*many* double-blind trials
cell phone radiation

some indications of cancer:

Swedish study: 240% brain tumor increase

British study: no effect

other studies: inconclusive

but ... improved reaction time & mental arithmetic
I. Introduction
   A. overview of relevant fields
      a. electrical, magnetic, visible and thermal-IR spectrum
      d. detection (electroreception, magnetoreception) vs. production (electrogenesis)
   B. function within animals
      1. nerve signals
      2. muscle firing
      3. action potential
         a. store charge differential, then release to generate current
         b. basis for some forms of electrogenesis
   4. all living organisms produce some level of electric field
      a. cell membrane potential
      b. voltage-gated sodium, etc., channels
   C. animal sensory apparatus
      1. visible light: eyes, ocelli, etc
         a. Teresa: high-energy muon light detector 2.5 km down saw much bioluminescence
      2. IR light: heat sensors in pit vipers, Haller’s organ in ticks
         o photons excite sensory cells, firing nervous signal
      3. sound: waves in air or water (excellent propagation)
         o waves affect sensory hairs, triggering nervous signal
      4. chemical: minute quantities in environment - tasted or smelled
      5. gravity: recognize up from down
      6. electromagnetic fields
   D. lecture overview
      1. sensing EM fields
      2. producing EM fields
      3. physiological reaction to EM fields

II. Electro-reception by animals
   A. how & why it works
      1. all organisms (plants, animals, etc.) produce electric fields
      2. detection of fields favored in environments without other stimuli
      3. Deep-sea and tropical river environments
         a. DARK (deep, or turbid): no light detection -- chemical & other senses take over
         b. WET: excellent transmitter of sound, but also of electric currents
      4. strong in predators and prey alike, but not grazers
         a. electrosensory organs likely modified for defensive, then offensive uses
      5. also can detect abiotic objects, not just living organisms
      6. commonly used for communication
         a. transmit/detect gender, size, identity, reproductive status, etc.
         b. species in same location avoid frequency overlap
         c. can shift frequency slightly to avoid “jamming” of conspecifics
      7. passive vs. active electro-sensory techniques:
         a. active: generate electric field and sense distortions in field (common in weak e-fish)
            • can discriminate objects based on resistance and capacitance values
         b. passive: sense electric fields of other organisms; common in elasmobranchs
   B. Elasmobranchs - sharks, skates and rays
      1. organ - Ampullae of Lorenzini, concentrated around head
2. sensitivity - down to < 5-20 nV/cm (that’s billionths of a volt!)
   a. can detect local fields produced by prey (& predators)
   b. sensitive enough to function in geomagnetic navigation
   c. long canals of some ampullae can sense alignment w/ magnetic field
3. hammerheads may have large head to accommodate more sensory pores
4. most electrically sensitive animals known on earth
5. sub-oceanic cables suffered early problems from shark “attacks”

C. Paddlefish ()
1. large freshwater fish, in major river (and lake) systems of USA; esp. murky rivers
2. can detect metal, but not plastic objects; attack wires with AC current of only 10 nV
3. rostrum (“bill”) with ampullary sensors (>50,000)
4. developed to detect weak fields of moving zooplankton prey (e.g., Daphnia)

D. Other fish
1. many fish believed to e-sense, through lateral lines
2. especially developed in deep-water species
3. some can detect variations of 0.03 μV/cm: equivalent to a flashlight at several 1000 m (!)
4. fish often appear rigid (may reduce complexity of own field), and approach objects tail-first

E. Monotremes (Platypus and Echidna)
1. only mammals known with e-sense (v. primitive group)
2. duck-billed platypus feeds in aquatic sediments, usu. at night
3. was known they would attack batteries buried in sediment
4. organ - bill/beak with many “mucous gland” electoreceptors
5. sensitivity - 300-2000 μV/cm
6. can locate prey, perhaps by differential response of receptors across bill

F. Famous Electric eels, catfish etc.
1. technically, electric eel (Electrophorus electricus) is a knifefish: up to 9 feet, 60 pounds (!)
2. live in murky fresh water systems (New World tropics)
3. among most feared fish, since they can kill humans
4. sensory organs
   a. scattered ampullae or tuberous receptors
   b. some are low-pass filters (not sensitive > 20 Hz)
   c. some are high-pass (not sensitive < 30 Hz)
5. sensitivity - down to 13 μV/cm
6. developed from sensory to offensive capability

III. Electric field production by animals (electrogenesis)
A. Electric eel
1. can produce up to 600 V (@ 1 amp)
2. 4/5 of body packed with electricity-producing organs
   a. made of electrocytes, disk-like cells stacked like a battery (5000-6000)
   b. each electrocyte produces about 0.15 V
   c. modified muscle cells that no longer contracts
   d. pump positive sodium & potassium ions out (by ATP)
   e. shock initiates: sodium channel opens, reversing charge; propagates as electric current
   f. nerves specially designed to initiate shock in all electrocytes simultaneously
   g. typically, multiple (>300) pulses emitted almost instantaneously
3. 3 electric organs, one used for electrolocation and communication (10 V)
4. low level discharges can disorient prey, confuse predators

B. Electric catfish (several genera, Fam. Melapteruridae)
1. can produce up to 350 V
2. electrogenic organs for courtship, hunting; receptors widespread in catfish
3. range: Africa, and Nile river

C. Electric rays, 69 spp. (Or. Torpediniformes)
1. can produce 8-220 V
2. pair of organs stun or kill prey

D. Weakly electric fish
1. includes other knifefish species (> 100, varyingly electric)
2. produce weak (< 1 V) currents, for communication and object detection

E. Possible electrogenic mammal: Giant Otter-Shrew (*Potamogale velox*)
1. western-central Africa, resembling cat-sized otter
2. feeds on crabs, fish & amphibians in rain forest streams
3. eyes not used for prey-detection
4. anecdotal (*unconfirmed*) reports by fisherman of shocks received from netted animals

IV. Magneto-reception by animals
A. How it works
1. earth’s magnetic field connect poles, curve down towards earth near poles
2. how sensed:
   a. mechanical: field exerts torque on ferromagnetic material (bacteria, birds)
   b. induction: movement through magnetic field creates electrical field (elasmobranchs)
   c. chemical: transition b/w spin states influenced by magnetic field (birds, salamanders)
3. magnetic compass vs. magnetic map
   a. compass: fields arrayed in lines, detecting polarity = orientation
   b. map: field intensity and inclination = location
4. biogenic magnetite & chemical reactions modulated by magnetic fields
   a. magnetite (Fe₃O₄) crystal swings like a bar; may activate position sensors
   b. 3D arrays sensitive to three-axis variation
5. seawater ions moving (current) across field produce electrical field perpendicular to current
   a. thus equatorial current flowing E-W produces surface-to-bottom field
   b. knowledge derives from James Maxwell’s work (mid-1800s)
   c. provides basis for marine navigation: animals move through earth’s field (& pivot head)

A. birds
1. first seen in migratory species - Robins, Bobolink, Warblers, homing Pigeons, et al.
   * also found in non-migrants, including chickens
2. evidence for magnetoreception:
   a. wearing a magnet interferes with homing (field)
   b. strong magnetic pulses randomized or deflected preferred orientation (captivity)
   c. cannot orient N-S without blue/green light
3. mechanism 1: vision-based chemical compass, uses POLARITY
   a. magnetic field interacts with radical-pairs in the eye, showing N-S axis
   b. dawn & dusk light used to calibrate - which way is North
   c. evidence for extra-ocular photosensors near pineal gland (top of head)
   d. sensory apparatus linked (2007) to vision nerves; may “see” North
4. mechanism 2: magnetite-based mechanical compass, uses INCLINATION
   a. magnetite-bearing cells found in beak of many birds, including chickens
   b. “bar” functions like compass, activates stretch receptors
   c. detect inclination of magnetic field to distinguish “poleward”

B. sea turtles
1. use currents, water “taste” and magnetic lines of force to navigate
2. attaching magnets to head disturbs navigation
3. absence of light suggest magnetite-based compass system

C. whales, sharks, salmon etc.
1. whale mass strandings occur where magnetic contours cross coast
2. strandings increase when solar activity is high (disrupts magnetic fields)
3. deep sea floor magnetic striping may be navigational aid
4. sharks can use Ampullae of Lorenzini to detect induction electrical field

D. Bees
1. found mineralization of super-paramagnetic magnetite in granules (1.25 g/cm³) in abdomens
2. comb-building and orientation affected by geomagnetic field

E. Mole Rats
1. live in subterranean tunnels, never surface
2. communicate by drumming on tunnel floor, waves propagate through soil
3. orientation by sensing magnetic lines of force
4. demonstrated by lab experiments with manipulated magnetic fields

F. Salamanders (red-spotted newt)
1. possess both polarity and inclination compasses
2. inclination may be used during migration, polarity for homing movements
3. as in migrant birds, light & its polarity also participate in magnetic system

G. Bacteria (Magnetospirillum sp.)
1. magnetosome (chain of nanomagnets) of iron-based molecules
2. chain strung along a filamentous structure similar to cytoskeleton
3. ecology: live in deep, anoxic mud; magn. used to orient up-down, seek ideal conditions

V. Effects of exposure to EM radiation
A. cancer rates
1. weak associations in real world:
   a. b/w childhood leukemia & chronic lymphocytic leukemia and electric utility workers, machinists, and welders
   b. 2001 Ahlbom et al.: childhood leukemia (CL) doubled for fields > 0.4 μT
   c. 2005 Draper et al.: 70% increase in CL if living < 200 m of overhead transmission lines (possibly b/c field attracts aerosol pollutants)
   d. 2002 CA dept of Health: EMFs increased CL, adult brain cancer, Lou Gehrig’s disease, and miscarriage
   e. occupational exposure to low freq. (50-60 Hz) increased Alzheimer’s disease risk
      * further tests show overnight exposure increases expression of mutant precursor protein
2. strong effects not demonstrated in lab tests
   a. variety of complicating effects implicated in field studies
   b. no mechanism cited in correlative studies

C. gene transcription demonstrated to be affected
1. animal models showed enhanced gene expression when ELF-EMF combined with heat stress
2. breast cancer shown not to be affected (by 60 Hz = Low Frequency EMF)
3. other cancer gene markers (c-myc) increased expression when exposed to ELF-EMF

D. bone regeneration
1. pulsed EMFs, simulating in-body levels, promotes bone deposition (healing)
2. supported by double-blind trials
3. applied in many cases, including loosened hip replacements, bad breaks, etc.

D. disrupt migration: birds, whales, etc.
E. human response times
1. cell phone radiation increased reaction time, and mental arithmetic ... so use your phone!