Hormones and Behavior

Complex effects of hormones

Input
Sensory Systems

Central
Nervous
System

Output
Effectors

BEHAVIOR

HORMONES

Principles of Animal Behavior, Third Edition  Figure 3.9
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Example 1

Testosterone and aggressive and reproductive behavior
Testosterone (T) and aggression feedback loop

High T increases probability of Winning a fight

Winning increases levels of T

Testosterone (T)
Based on placental circulation and random arrangement of embryos, some embryos get a double dose of testosterone produced by neighbors.
“2F” males have 1/2X the amount of T

“2M” males have 2X the amount of T
2M adult males provide less parental care... but are more aggressive about mating.
As adults, compared with 2F males, 2M males...

- received 2X the amount of T *in utero*.
- mounted females more rapidly.
- produced more offspring over time.
- spent more time searching for females.
- spent more energy searching for females.
- spent *less* effort relative to parental care.
Neurons in Hypothalamus (part of brain (CNS))

GnRH

pituitary

FSH, LH

testes

Castration gets rid of testosterone

testosterone
Reverse experiment re: mice in utero.

Now get rid of T → increase parental care.
... and even better, if you can replace the T in a castrate and restore function:

Can say that T is both necessary and sufficient for the behavior.
In this case, Guinea pigs

Guinea pig copulatory behavior

one can only imagine...
Hormones act on brain neurons as triggers, in other cases as maintenance factors → very different time constants.
Vasopressin and Oxytocin
Ancient hormones found in nearly all animalia

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Species</th>
<th>Peptide Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vasopressin</strong></td>
<td>Mammals</td>
<td>Cys-Tyr-Phe-Gin-Asn-Cys-Pro-Arg-Gly-NH₂</td>
</tr>
<tr>
<td><strong>Lysipressin</strong></td>
<td>Pigs, marsupials</td>
<td>Cys-Tyr-Phe-Gin-Asn-Cys-Pro-Arg-Gly-NH₂</td>
</tr>
<tr>
<td><strong>Phenypressin</strong></td>
<td>Marsupials</td>
<td>Cys-Tyr-Phe-Gin-Asn-Cys-Pro-Arg-Gly-NH₂</td>
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<tr>
<td><strong>Oxytocin</strong></td>
<td></td>
<td>Cys-Tyr-Ile-Gin-Asn-Cys-Pro-Leu-Gly-NH₂</td>
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<tr>
<td><strong>Mesotocin</strong></td>
<td></td>
<td>Cys-Tyr-Ile-Gin-Asn-Cys-Pro-Ile-Gly-NH₂</td>
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<tr>
<td><strong>Isotocin</strong></td>
<td></td>
<td>Cys-Tyr-Ile-Ser-Asn-Cys-Pro-Leu-Gly-NH₂</td>
</tr>
<tr>
<td><strong>Annepressin</strong></td>
<td>Annelid worms</td>
<td>Cys-Phe-Val-Arg-Asn-Cys-Pro-Thr-Gly-NH₂</td>
</tr>
<tr>
<td><strong>Conopressin</strong></td>
<td>Snails, cones, sea hare, leeches</td>
<td>Cys-Phe/Ile-Arg-Asn-Cys-Pro-Lys/Arg-Gly-NH₂</td>
</tr>
<tr>
<td><strong>Inotocin</strong></td>
<td>Some insects</td>
<td>Cys-Leu-Ile-Thr-Asn-Cys-Pro-Arg-Gly-NH₂</td>
</tr>
</tbody>
</table>
Oxytocin – many different functions.

Knockout mice (Oxt -) → behavioral deficit of social amnesia.

Every time a male interacts with the same female, the male sniffs as if a novel female.
The proximal cause of social amnesia, a “behavioral” deficit, is really a loss of olfactory memory due to non-production of oxytocin.

With a defective gene, sniffing persists as if a particular female is always novel.
The vasopressin receptor in the ventral pallium.

Prairie voles and Meadow voles differ in the amount of V1R in their brains...

...and also differ in parental care.
Prairie voles are monogamous.

Meadow voles are polygamous (polygynous = one male, multiple females)
1. How monogamy might have evolved?
2. How do you increase V1a receptors?

Monogamous prairie voles have a high concentration of vasopressin receptors in the ventral pallidum (VP) area of the brain.

Experimentally increasing the V1a receptors leads to increased prosocial behavior in male meadow voles.

Polygamous meadow voles have a lower concentration of vasopressin receptors in the ventral pallidum of the brain.
Once upon a time... Mutation in a *polygamous* ancestral Prairie Vole V1aR gene → perhaps ‘a’ allele binds V more strongly.

- Male vole copulates
- Vasopressin release
- Monogamy
- Happier male vole, spends more time with female.

V1aR gene expressed in neurons of the ventral pallium.

- New V1aR in pallial neurons = greater response from those neurons when vasopressin binds.

Greater neural response = increased activation of reward system of brain.

Happier male vole, spends more time with female.
So one individual vole has a mutation that leads to...

- a variation of the V1a receptor that binds hormone more strongly... or
- a transcription regulator that causes more V1aR to be present in neuron membranes... or
- a variant of the receptor with lower turn-over... or
- etc, etc

This vole leaves more offspring in the next generation, and so do those offspring, etc., fixing the gene rapidly in the population.
The V1aR gene inserted using an adeno-associated viral vector. Vectors contained either:

1. Prairie vole V1aR gene or modified V1aR gene from a genomic library
   a. Including a neuron-specific enolase promoter
2. Prairie vole V1aR gene and *Escherichia coli* lacZ
   a. Including a cytomegalovirus promoter

The gene is spliced at the neuron-specific enolase promoter to create a NSE-pvV1aR viral vector.

Properties of Adeno-associated viruses:

1. Contain a single strand of DNA
2. Infect non-dividing cells
3. Non-pathogenic
4. Site specific insertion of genetic material

The Adeno-associated viral vectors were syringe-injected into specific sites: The ventral pallium or the caudate putamen. Transduction occurs and the NSE promoter works to restrict expression of the gene to neurons in the brain.

Reference:
If you provide more receptors to the brain of a *non-monogamous* meadow vole, it will start behaving somewhat like the monogamous prairie vole.

Meadow voles with tweaked brains.
Monogamous male bachelor voles associate with females.

When a pair bond forms, bonded male voles are aggressive towards other females.

Their brains change in response to bonding with a particular female.
Association → bonding. Partner preference associated with neurotransmission at D2 dopamine synapses in the nucleus accumbens.
After a pair bond forms, D1 dopamine receptors (blue) are up-regulated. Associated with aggression to unfamiliar females.
D1 receptor antagonists block aggression toward unfamiliar females.

Are hormones involved in the behavior of invertebrates too?
Bees have pretty small brains and you might think all their behaviors are innate, programmed, and each bee is a behavioral duplicate of the next.

In fact, different bees in a hive have different behaviors, and this is under hormonal control.
Bee brains (which control bee behavior!) vary in terms of gene expression. So even though the genotype is the same across individuals, gene expression is not.

<table>
<thead>
<tr>
<th>Equivalent Drosophila gene</th>
<th>Expression ratio (F/N)</th>
<th>Typical colonies</th>
<th>Single-cohort colonies</th>
<th>Putative function</th>
</tr>
</thead>
<tbody>
<tr>
<td>fax</td>
<td>0.63</td>
<td>YN</td>
<td>OF</td>
<td>Axonogenesis</td>
</tr>
<tr>
<td>fax</td>
<td>0.65</td>
<td>YN</td>
<td>OF</td>
<td>Cell adhesion</td>
</tr>
<tr>
<td>BM-40-SPARC</td>
<td>0.52</td>
<td>YN</td>
<td>OF</td>
<td>Glycogen phosphorlase</td>
</tr>
<tr>
<td>GlyP</td>
<td>0.65</td>
<td>YN</td>
<td>YF</td>
<td>Oxidoreductase</td>
</tr>
<tr>
<td>GlyP</td>
<td>0.72</td>
<td>YN</td>
<td>ON</td>
<td>Rho small monomeric GTPase</td>
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<tr>
<td>CG7322</td>
<td>0.70</td>
<td>YN</td>
<td>YF</td>
<td>MAP kinase</td>
</tr>
<tr>
<td>Rab10</td>
<td>0.77</td>
<td>YN</td>
<td>ON</td>
<td>Methionine sulfoxide reductase</td>
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<tr>
<td>CG32703</td>
<td>2.45</td>
<td>YN</td>
<td>ON</td>
<td>Trehalose-6-phosphate synthase</td>
</tr>
<tr>
<td>Eip71CD</td>
<td>1.86</td>
<td>YN</td>
<td>ON</td>
<td>Translation regulator</td>
</tr>
<tr>
<td>Tps1</td>
<td>1.74</td>
<td>YN</td>
<td>ON</td>
<td>Carbonic anhydrase</td>
</tr>
<tr>
<td>Tps1</td>
<td>1.55</td>
<td>YN</td>
<td>ON</td>
<td>Inositol-3-phosphate synthase</td>
</tr>
<tr>
<td>CG11334</td>
<td>1.80</td>
<td>YN</td>
<td>ON</td>
<td>Triacylglycerol lipase</td>
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<tr>
<td>CAH1</td>
<td>2.35</td>
<td>YN</td>
<td>ON</td>
<td>Transcription factor</td>
</tr>
<tr>
<td>Inos</td>
<td>1.98</td>
<td>YN</td>
<td>ON</td>
<td>Pre-mRNA splicing factor</td>
</tr>
<tr>
<td>CG5966</td>
<td>1.34</td>
<td>YN</td>
<td>ON</td>
<td></td>
</tr>
<tr>
<td>HLH3B</td>
<td>1.43</td>
<td>YN</td>
<td>ON</td>
<td></td>
</tr>
<tr>
<td>U2af50</td>
<td>1.18</td>
<td>YN</td>
<td>ON</td>
<td></td>
</tr>
</tbody>
</table>
Juvenile hormone and octopamine are involved in transitioning young hive cleaner bees into forager bees.
Bees do different things at different developmental stages.
Surgically remove corpora allata → no JH made → delayed transition to forager bees.

Methoprene (JH analog) injection to allatectomized (!) bees restored timing (normal transition)
Octopamine levels in bee brain higher when bees become foragers.

Inject octopamine → more foraging flight behavior.
Octopomine is similar to the vertebrate hormone noradrenaline.

Noradrenaline (vertebrates)

Octopamine (invertebrates)

Both noradrenaline and octopamine:
Are stress hormones
Prepare animal for energy-demanding situations (“fight or flight”)
Stimulate sugar production
Regulate arousal in the nervous system
Another chemical regulator, ethyl oleate, modulates the overall rate at which bees transition to foragers.
How bee behavior changes over time

Old hive: Higher % forager (old) bees. Old bees die off, less EO, increase transition to foragers.

Ethyl oleate slows transition of nurse bees to worker bees.

- Sterile female worker bees
- Initially: Feed to nurse bees
- Later: Synthesize ethyl oleate
- Nurse bees
- Forager bees
Experimental addition of old (forager) bees → slows transition to make new foragers → old bees die off → too few foragers

Add young bees – amount of EO per bee goes down → fast transition to make lots of foragers.

Bottom line: “Nurture” (development) can affect non-learned/genetically programmed behaviors.
Two different physiological and behavioral male morphs in the midshipman fish (*Porichthys notatus*).

Type I males – Delayed maturity: incr growth, larger vocal apparatus. Put more energy into stable long-term relationship.

Type II males – Put more developmental energy into gonads. Smaller as adults, don’t give advertisement call.
Note error in text pg 96 – “...type II males, have a very high gonad-to-body size...” Should be “...type II males have a small gonad-to-body size...” as per this table.

**TABLE 3.2. Traits of type I and type II males.** A summary of the differences between type I and type II plainfin midshipman, and a comparison with plainfin midshipman females.

<table>
<thead>
<tr>
<th>SEXUALLY POLYMORPHIC TRAITS</th>
<th>TYPE I MALE</th>
<th>TYPE II MALE</th>
<th>FEMALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nest building</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Egg guarding</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Body size</td>
<td></td>
<td>large</td>
<td>small intermediate</td>
</tr>
<tr>
<td>Gonad-size/body-size ratio</td>
<td>small</td>
<td>large</td>
<td>large (gravid),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>small (spent)*</td>
</tr>
<tr>
<td>Ventral coloration</td>
<td>olive-gray</td>
<td>mottled yellow</td>
<td>bronze (gravid),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mottled (spent)*</td>
</tr>
<tr>
<td>Circulating steroids</td>
<td>testosterone, 11-Ketotestosterone</td>
<td>testosterone</td>
<td>testosterone, estradiol</td>
</tr>
<tr>
<td>Vocal behavior</td>
<td>hums, grunt trains</td>
<td>isolated grunts</td>
<td>isolated grunts</td>
</tr>
<tr>
<td>Vocal muscle</td>
<td>large</td>
<td>small</td>
<td>small</td>
</tr>
<tr>
<td>Vocal neurons</td>
<td>large</td>
<td>small</td>
<td>small</td>
</tr>
<tr>
<td>Vocal discharge frequency</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

*Gravid connotes pregnant; spent connotes postpregnant.
Sonic muscles larger in type I males.

Good dad
Larger sonic muscles

Deadbeat
Smaller sonic muscles

Deadbeats: Smaller muscles, but they still could call... except they don’t call. Why not?
Both type I and type II:

Command neurons → pacemaker neurons (CPG) → sonic motor nucleus → sonic muscles

So same neural “hardware”, so they *could* call... except they don’t!
POA command neurons have receptors for the hormone arginine vasotocin (AVT).

AVT inhibits command neurons.
Deadbeat type II males have 6x more AVT-ir (immunoreactive) neurons per gram body weight than type I males!

So deadbeat male command neurons completely shut down.
Environment $\rightarrow$ development $\rightarrow$ + / - AVT receptors

Natural populations of midshipmen – more dense or less dense.

Lab raise fish in low density or high density.

---

**Low Density juveniles**
- Fewer AVT-ir neurons & type I morph

**High Density juveniles**
- More AVT-ir neurons & type II morph

Deadbeat dads favored in high density environment
Hormones and long term oscillators
Birds have seasonal sensitivity to light level.

When daytime coincides with a period of light sensitivity, reproductive development is triggered.

An oscillator is reset every day at dawn.

Light sensitivity occurs 16 – 20 hours later. Will it be light out 16-20 hours after dawn?
Oscillator resets at dawn. Same ramp/slope summer/winter but only in summer (long days) is the mechanism tripped – crosses dashed red line.
What the oscillator controls...

environmental synchronization (light level & duration)

Change in behavior:
Territoriality
Aggression
Mating
Parental care

oscillator

Change in hormone levels
Counting mechanisms

Artificial day length manipulation can change when a mouse loses its tendency for infanticide.

Is the hormonal control based on...

(1) the number of light/dark cycles post copulation, or

(1) the “real” amount of time that has passed?
Day length manipulations: make 22, 24, or 27 hour days.

Infanticide stops on day 22 for slow days and day 22 for fast days ⇒ counting.

Infanticide stops here for long days.
Interpretation of previous slide:

Probably a stable chemical is produced, one burst per day/night (L/D) cycle.

The rate of accumulation corresponds to the number of L/D cycles, not on the absolute amount of time that has passed (next slide).
The behavior match is with number of light/dark cycles since mating, not the “real” days since mating.

Match with hours: NOT

Match with #cycles: YES

(B)

Males committing infanticide (percent)

<table>
<thead>
<tr>
<th>“Real” days since mating</th>
<th>1</th>
<th>16.3</th>
<th>20</th>
<th>24.8</th>
</tr>
</thead>
</table>

“Fast-day” males

“Slow-day” males

Light–dark cycles since mating

| 1 | 18 | 22 |

“Fast-day” males

“Slow-day” males
Hormones can affect behavior and/or morphology – both of which contribute to social status.

**Example:** Signals of social rank in Harris’s sparrow (*Zonotrichia querula*).

Harris’s sparrows set up summer breeding territories near the Arctic circle.

During the winter, they form mixed-sex and mixed-age feeding flocks. Resource competition generates a social hierarchy that changes frequently.

How are agonistic encounters minimized in feeding flocks?
Winter: Sparrows form mixed-sex and mixed-age feeding flocks.

Resource competition generates a social hierarchy that changes frequently.

Summer: Sparrows set up breeding territories near the Arctic circle.
Winter: Social signals minimize agonistic encounters.
Coloration in the head and chest is highly variable among males.

Fall: Testosterone levels determine what plumage looks like in Winter.

At Fall molt, winter plumage is set.

T levels drop in Winter; not needed to maintain plumage

Winter plumage will determine social status.
Darker throat plumage → more dominant → OK, I won’t fight with you because you are more dominant than me. You don’t fight me because my color shows I am subordinate.

So - social signal respected, aggression avoided.
Experiment: Artificially change throat coloration.

Light throat subordinate males painted darker:

Changing the subordinate bird’s plumage signal didn’t change its behavior. Still “knows” it is subordinate and behaves as such but…

…truly dark (dominant) males attacked dominant-looking subordinate males 4x more than normal subordinate males.
Experiment: Artificially change throat coloration.

Dominant males bleached lighter:

Bleached birds had a hard time trying to maintain dominance in the absence of the accepted signal.

Bleached dominant males get into more fights with normal dominant males.
Conclusion: Neither experimental group did well compared to controls.

If subordinate darkened males were also treated with T, they exhibited both aggressive behavior and the appropriate social signal.

These males increased in social status.

So hormones affect both behavior and morphology.
Remember that Harris’s sparrows establish dominance hierarchies in winter feeding flocks... when testosterone concentrations are very low.

In species that exhibit aggression during the *nonbreeding* season, what regulates these agonistic behaviors?

1. Synthesis of steroids within the brain itself (called neurosteroids).
2. Conversion of adrenal steroids (e.g., dehydroepiandrosterone, DHEA) into testosterone and/or estradiol in the brain.
3. Change in the signaling cascades that regulate sensitivity to steroid hormones.
4. Other hormones.