



The Mood of a Worm
Scott W. Emmons
Science **338**, 475 (2012);
DOI: 10.1126/science.1230251

This copy is for your personal, non-commercial use only.

If you wish to distribute this article to others, you can order high-quality copies for your colleagues, clients, or customers by [clicking here](#).

Permission to republish or repurpose articles or portions of articles can be obtained by following the guidelines [here](#).

The following resources related to this article are available online at www.sciencemag.org (this information is current as of October 25, 2012):

Updated information and services, including high-resolution figures, can be found in the online version of this article at:

<http://www.sciencemag.org/content/338/6106/475.full.html>

A list of selected additional articles on the Science Web sites **related to this article** can be found at:

<http://www.sciencemag.org/content/338/6106/475.full.html#related>

This article **cites 10 articles**, 5 of which can be accessed free:

<http://www.sciencemag.org/content/338/6106/475.full.html#ref-list-1>

time, emerging research is highlighting the danger of irreversible effects of current fisheries on overall ecosystems. These insights provide forceful arguments for a more precautionary approach to fisheries management, in which fishing is restricted to those places and amounts where it can be conducted safely and with minimal risk of jeopardizing the integrity of marine ecosystems.

References

1. C. Costello *et al.*, *Science* **338**, 517 (2012); 10.1126/science.1223389.
2. B. Worm *et al.*, *Science* **325**, 578 (2009).
3. V. R. Restrepo, G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, J. F. Witzig, *Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act* (NOAA Technical Memorandum NMFS-F/SPO 31, 1998).
4. A. E. Punt *et al.*, *ICES J. Mar. Sci.* **69**, 624 (2012).
5. E. K. Pikitch *et al.*, *Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs* (Lenfest Ocean Program, Washington, DC, 2012).
6. E. K. Pikitch *et al.*, *Science* **305**, 346 (2004).
7. J. A. Estes *et al.*, *Science* **333**, 301 (2011).
8. P. M. Cury *et al.*, *Science* **334**, 1703 (2011).
9. A. D. M. Smith *et al.*, *Science* **333**, 1147 (2011).
10. P. K. Dayton, *Science* **279**, 821 (1998).

10.1126/science.1229965

NEUROSCIENCE

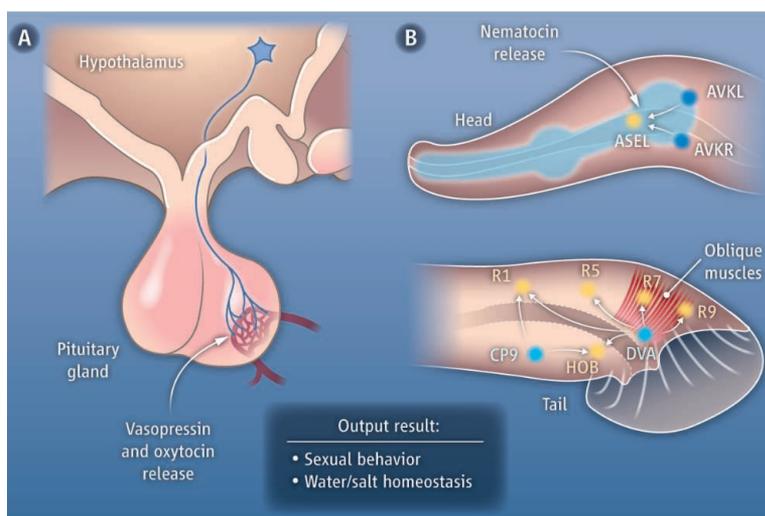
The Mood of a Worm

Scott W. Emmons

The human nervous system is a vastly complex network of functionally interconnected cells whose detailed structure is at present beyond reach. All our actions, calculations, feelings, memories, dreams—consciousness itself—emerge from its workings. To understand this colossal, enigmatic structure, experimentally amenable model animals with tractable nervous systems many orders of magnitude smaller are studied. A popular choice has been the worm *Caenorhabditis elegans*, a nematode 1 mm long with a nervous system containing fewer than 400 neurons. On pages 540 and 543 in this issue, Garrison *et al.* (1) and Beets *et al.*

(2), respectively, add to a growing body of evidence that even at the highest levels of coordinating fundamental and complex behaviors, the same neural mechanisms are at work in worms and humans.

C. elegans neurons do not conform to a long-held principle of neuroscience that neurons are polar, with a clear input side consisting of the cell body with branching extensions called dendrites and a dedicated output process called an axon. Many *C. elegans* neurons are unbranched. Sites of input and output are often intermingled along processes, preventing a clear distinction between dendrite and axon. Moreover, some *C. elegans* neurons



Sex and salt. (A) Neurons in the hypothalamus of the human brain secrete the hormones oxytocin to regulate sexual and reproductive behaviors, and vasopressin to control water balance. (B) Secretion of nematocin from neurons in the head and tail of the worm *C. elegans* regulates related behaviors—sexual behavior and salt chemotaxis. Names of neurons and muscles in the worm are indicated.

don't “fire” (discharge a short-lived electrical impulse, or action potential), but are analog devices with graded electrical responses. But the relevance of *C. elegans* was supported by genome sequencing. The *C. elegans* genome contains nearly the same suite of genes—encoding neurotransmitters, neurotransmitter receptors, ion channels, components of the synapse, transcription factors, and so forth—that underlie nervous systems of other animals, including humans (3). In addition, in some parts of the male nervous system, *C. elegans* neurons are highly branched and form a neural network with connectivity patterns also found in the human brain (4).

Garrison *et al.* and Beets *et al.* show that *C. elegans*, like other animals, expresses a neuropeptide related to oxytocin and vasopressin, key peptide hormones released by

The behavioral effects of two hormones on the human brain are similar to those of a neuropeptide on sensory neurons in the worm.

the neuroendocrine system of the human brain (see the figure). *C. elegans* uses this peptide to regulate behaviors similar to those modulated by oxytocin and vasopressin. Neuropeptides and other types of hormones are one of the three ways in which cells of the nervous system communicate with one another and with other tissues, the others being chemical synapses (electrical synapses). Oxytocin and vasopressin, similar short peptides of nine amino acids, are secreted by neurons in the hypothalamus and released into the blood stream and central nervous system. Although both have widespread effects, oxytocin regulates primarily sexual

and reproductive behavior, whereas vasopressin is involved in homeostatic regulation of water balance, with effects on the kidneys, vascular system, feelings of thirst, and drinking behavior.

Garrison *et al.* demonstrate that similar to oxytocin, the *C. elegans* peptide, named nematocin, is required for normal sexual behaviors by the male. Mutant males lacking nematocin explored their environment in search of mates less frequently than wild-type males. When mutant males encountered a mating partner, they initiated copulation more slowly and executed poorly. This diffuse set of defects led the authors to speculate that nematocin primes a variety of neural circuits to stimulate an overall appetitive behavioral drive. Beets *et al.* show that nematocin allows worms to modify their behav-

ior in light of recent experience. Normally, worms are attracted to salt. But if they experience salt in the absence of food, they quickly learn to avoid it. The authors observed that nematocin-deficient worms cannot do this. Function in salt attraction is reminiscent of vasopressin's role in water balance. A role for nematocin in memory of experience in the worm is similar to the roles of both oxytocin and vasopressin in establishing memory in parental, pair-bonding, and social settings in mammals (5, 6).

An advantage of *C. elegans* is that every cell is known and the same in every animal. Garrison *et al.* and Beets *et al.* identify the relevant cells that secrete nematocin and the cells that bear nematocin receptors. In both studies, the receptors are in sensory neurons whereas secretion of the peptide is from a cell targeted by sensory neurons, suggesting a role in feedback. The sensory neurons expressing nematocin receptors were previously shown to act in the relevant pathways, male sexual behavior and salt chemotaxis. Expression of both peptide and receptor in additional cells indicates further functions yet to be identified.

Neuropeptides that function in other *C. elegans* circuits modify the responses

of neurons such that functional circuitry is changed within fixed structural circuitry (7). The reason for multiple modes of communication within the nervous system may have to do with the time scales over which they operate. Gap junction- and chemical synapse-mediated communication occur over milliseconds to seconds, allowing for quick reactions. Neuropeptides and other types of hormones, by contrast, allow new points of communication between cells not in physical contact, and their effects can also persist over much longer periods. Thus, they establish behavioral states, enabling the nervous system to adjust its output to correspond to more slowly changing environmental and physiological circumstances, or intrinsic conditions such as sex or developmental time.

Nervous system function may be understood as the emergent collective property of a network rather than as the sum of individual circuits. This requires identifying all the interactions between the elements. Because gap junction communication and chemical synaptic communication occur at recognizable cellular sites, the potential functional network they create may be ascertained by describing the physical structure of the system. This has

been done for *C. elegans* and is the goal of the field of connectomics (4, 8–10). Interactions due to widely diffusing neuropeptides and other hormones can only be discovered by experimentation, which necessitates the use of tractable model systems. Just as today's major roads and highways may once have been ancient trails, biological systems can retain essential features derived from their origins. Although it is a mistake to consider small invertebrates as primitive, their systems may be closer to the ancestral condition than those of their larger cousins. Insights into what that ancestral condition was can help us understand function today.

References

1. J. L. Garrison *et al.*, *Science* **338**, 540 (2012).
2. I. Beets *et al.*, *Science* **338**, 543 (2012).
3. C. I. Bargmann, *Science* **282**, 2028 (1998).
4. T. A. Jarrell *et al.*, *Science* **337**, 437 (2012).
5. A. Meyer-Lindenberg, G. Domes, P. Kirsch, M. Heinrichs, *Nat. Rev. Neurosci.* **12**, 524 (2011).
6. C. McCall, T. Singer, *Nat. Neurosci.* **15**, 681 (2012).
7. C. I. Bargmann, *Bioessays* **34**, 458 (2012).
8. O. Sporns *et al.*, *PLoS Comput. Biol.* **1**, e42 (2005).
9. J. G. White *et al.*, *Philos. Trans. R. Soc. B Biol. Sci.* **314**, 1 (1986).
10. L. R. Varshney, B. L. Chen, E. Paniagua, D. H. Hall, D. B. Chklovskii, *PLoS Comput. Biol.* **7**, e1001066 (2011).

10.1126/science.1230251

ASTRONOMY

Measuring Solar Magnetism

Alfred G. de Wijn

The importance of magnetic fields in astrophysical processes has long been recognized. A thriving field of research is centered on the life cycle (the creation, evolution, and destruction) of magnetic fields in astrophysical plasmas, and prominently in solar physics. The discovery by Hale in 1908 that sunspots are associated with strong magnetic fields (1) spurred advances in spectroscopy, polarimetry, instrument development, and research into solar magnetism. Magnetism is now known to be the key to most unsolved problems in solar physics, including the 11-year activity cycle, chromospheric and coronal heating, flares, coronal mass ejections, and space weather. Even though more than a century has passed since the discovery of magnetism in the solar atmosphere, these measurements remain difficult.

High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO 80307–3000, USA. E-mail: dwijn@ucar.edu

Magnetic field diagnostics are most mature for the solar photosphere, the deepest layer that can be directly observed with optical telescopes. During the past decade, measurements of the photospheric magnetic field have become routine with the development of the SpectroPolarimeter instrument of the Hinode Solar Optical Telescope (2, 3) and the Helioseismic and Magnetic Imager (4) on the Solar Dynamics Observatory (5). Diagnostics of the magnetic field in the chromosphere and corona above the photosphere are in their infancy but are becoming more common.

There are, broadly speaking, two classes of magnetic field diagnostics: qualitative and quantitative. Of the former, the best known is proxy magnetometry, which involves the identification of locations of magnetic field through features associated with the field, such as sunspots (see the figure, panel A). Despite its limited diagnostic power, proxy magnetometry has contributed substantially to our understanding of solar magnetism; records of sunspot observations going back

How do you go about accurately measuring the magnetic field in the solar atmosphere?

300 years show the cyclical magnetic activity of the Sun (6).

Most quantitative measurements to date have relied on the Zeeman effect (7), whereby a magnetic field separates the single spectroscopic line of the degenerate atomic energy levels into three (or more) components. The separation of the components depends on the effective Landé factor of the line and the field strength. The former can be calculated from atomic models or measured by atomic spectroscopy, so that if the extent of the line separation can be measured, then the field strength can be determined. For regions of strong magnetic field in the photosphere, such as sunspots, the separation can be larger than the line width (see the figure, panel B). For weaker fields, the splitting is small and effectively only broadens the line. In this case, it is difficult or impossible to determine the separation from the intensity measurement alone. Fortunately, the two shifted components are circularly and oppositely polarized (see the