

doi: 10.4088/JCP.12m08083). Thus, the meditation proved efficient in the activation of the ventrolateral pre-frontal cortex and in increasing the connectivity between amygdala and pre-frontal cortex. Both these neurological changes are believed to be beneficial for the reduction of GAD symptoms.

Such findings demonstrating that soft healing approaches like meditation can be backed up by hard evidence might help to reconcile the warring factions of mainstream and alternative medicine.

Good vibrations

Like meditation, music can also contribute to health and well-being for many people, and the scientific study of its effects on the brain is only just beginning. Mona Lisa Chanda and Daniel Levitin from McGill University at Montreal, Canada, have recently reviewed what is known about the neurochemical basis for musical feelgood factors so far (*Trends Cogn. Sci.* (2013) 17, 179–192).

Specifically, they report that music has been found to influence the reward system (mediated by dopamine and opioids), stress and arousal (cortisol and other hormones), immunity (serotonin and other substances), and social connectedness (oxytocin).

There have been a few studies of the effects of music on the reward system, suggesting that it can induce the body to release opioids. One study found that the self-reported musical pleasures could be blocked with the opiate antagonist naloxone. However, Chanda and Levitin admonish that the studies existing so far are insufficient in their design (e.g. lack of controls) and call for more research in this direction. A newer study published in April 2013 showed that activity in the nucleus accumbens monitored while participants listened to a piece for the first time was the best predictor for the value they would assign to it in an auction scenario (*Science* (2013) 340, 216–219).

Many people use relaxing music to fight stress, and there have also been some studies of its usefulness in post-operative situations. Some studies found beneficial effects while others gave inconclusive results. Systematic problems include the use of self-selected music, where the

expectations and emotions linked to particular pieces may be mixed up with the effect of music as such, and the difficulty in establishing appropriate control experiments.

Several studies have found that recreational music making, more than passive listening to music, can influence the immune system and ward off its deterioration with age and stress. Specifically, several studies have looked into the benefits of group drumming circles, although the reviewers again find that not all non-musical aspects of the activity were covered by control experiments. Other researchers have investigated group singing and found changes in the antibody concentrations in saliva samples. The reviewers conclude that these results, “though promising, are still preliminary and warrant more careful follow-up studies that control for effects of extraneous variables.”

As music can serve to communicate emotions, one would expect it to affect hormones linked to emotional attachment, namely vasopressin and oxytocin. Studies in ‘singing mice’ and hamsters suggest that such a connection may indeed exist. However, Chanda and Levitin report that connections between vasopressin and music haven’t been studied in humans yet, and the effects of oxytocin are difficult to assess as the hormone concentration cannot be measured in the living brain and it is unclear how meaningful peripheral concentrations really are. In one study, serum oxytocin of patients recovering from heart surgery was found to be higher in patients exposed to relaxing music. However, like the other musical connections mentioned, this aspect needs to be explored more systematically.

The picture that emerges from such studies is that the things that move or soothe our emotional minds generally have some physical basis that is still insufficiently explored, and often also can serve to improve our health and well-being in ways that are still underappreciated. All in all, it appears that researchers interested in hard scientific results no longer have to shut out everything to do with emotions.

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Vertebrate versus invertebrate neural circuits

The recent Cell Symposium ‘Genes, Circuits and Behavior’ brought together researchers working on neural circuits in vertebrate and invertebrate species. In the interest of fostering communication across the ‘backbone-divide’, we asked a number of neuroscientists from both camps for their views on the extent to which insights obtained from studies on neural circuits in one type of species are transferable to the other.



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I don’t see this as a singular ‘divide’. There are many ways to divide a field; one could also ask whether insights gained from studying the cerebellum are applicable to the hippocampus. It is clear that the insights about lateral inhibition obtained by Hartline’s study of horseshoe crab photoreceptors are applicable to all sensory systems; it is equally clear that T. Graham Brown’s insights about the nature of half-center oscillators, which were gained by studying cat locomotion, are important for understanding any central pattern generator. In order to understand the fundamental organizational principles of neural circuits, it is essential that we compare them. If you study how a neural circuit works in only one species, you cannot separate its evolutionary history from its current utility. Which of its properties are functionally significant, which are holdovers that all members of its clade have, and which are constraints imposed by development or evolutionary history? Identifying features of neural circuit features that evolved independently provides the most powerful proof of their functional role.



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The general features of the control systems for motion (sensory and network level) are similar in invertebrates and vertebrates. Moreover, recent evidence suggests that more advanced invertebrates (protostomes) and vertebrates have a common design of forebrain circuits. At the microcircuit level, a variety of invertebrate systems have contributed importantly, notably the stomatogastric system. Vertebrate circuits tend to be more complex with larger numbers of interacting nerve cells. On the other hand, vertebrate cells are simpler to analyze, since the cell body is located between the dendrites and the axonal spike initiating zone. In contrast, invertebrate neurons have their processes located in a dense neuropil in the central parts of the ganglia, and signals from dendrites and axons are transmitted passively to the unipolar cell body.



Rachel Wilson
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Biological organisms are almost infinitely varied, which makes it difficult to decide in a principled manner what organisms we should focus on. There is certainly something to be said for simply following one's heart. That said, there are two principled questions we should probably ask. Question one: how likely am I to be able to gain a satisfying answer to this question in the near future? Most of us agree on what questions are interesting, but we don't agree on what answers are satisfying. If you have a high bar for what is 'satisfying', you should consider working on an invertebrate. Question two: how might the answer to this question change how other neuroscientists think about their research? This depends on how satisfying your answer is; it also depends on whether you're studying something which is highly conserved across organisms. We really don't yet

know what is conserved, so this is a gamble. My bet is that many elemental building blocks of microcircuit connectivity and neural computation are common to invertebrates and vertebrates.



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Clear structural similarities exist in peripheral processing stages of vertebrate and invertebrate nervous systems — for example, between the nicely layered optic lobe of insects and the vertebrate retina, or the glomerular organization of the insect antennal lobe and the olfactory bulb of vertebrates. These similarities apply to functions as well. Telling examples are the convergence of spatially distributed olfactory receptors with the same odor response spectrum in single glomeruli in the olfactory system or the splitting of photoreceptor input into parallel ON- and OFF-processing channels in the early visual system of both animal groups. To what extent the actual circuits performing a particular computation are similar remains to be seen. Given the current intense investigations in both the retina and the fly optic lobe, the circuit for local motion detection might be the first case where this question can soon be answered.



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They are likely transferable in several respects: first, the functional and computational strategies in invertebrates, where they are more easily discernible, are likely to be found in vertebrates; second, the embryonic gene expression patterns designating brain structures and substructures show a high level of conservation; and third, there is emerging evidence that adult brain structures sharing embryonic gene expression patterns carry out similar tasks and use the same intercellular signaling systems. Examples of the

latter are the correspondence between the insect pars intercerebralis and the hypothalamus, and between the insect central complex and the basal ganglia, despite the lack of any anatomical similarities.



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Animals predict the future. In invertebrates, signals trigger appropriate responses within the time frame of the biophysical properties of typically non-spiking neurons, the connections made by which are genetically imprinted. In vertebrates, ever-increasing loops of neuronal networks are added to the basic circuits to improve prediction of events of higher complexity and longer temporal separation by deploying action potentials for fast and distant signaling. The connections within the loops are strongly shaped by the outside world. At some level, the loops learn to disengage their reliance on external cues, a fundamental difference from invertebrates and a necessary condition for cognition. Thus, if your goal is to study cognition, choose a mammal.



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Ramon y Cajal, and Hodgkin and Huxley, taught us the importance of looking for principles of structure and function across nervous systems, a lesson we are now forgetting as we try to solve everything with one or two 'model' species. They also taught us the importance of matching the species to the particular problem. So when asked why I don't work on 'simpler' organisms, like *Drosophila* with only 100,000 neurons, as (obviously!) it will be easier to solve than mammalian neocortex, which has 100,000 neurons and 4km of 'wire' in each cubic millimetre, my answer is simple — if I want to understand the neocortex, I'd better study animals

with a neocortex, not animals with a mushroom body.



Eve Marder

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Many years ago, invertebrate circuits were often called ‘simple’. Today we know that small circuits are quite complex and show dynamics that reveal many fundamental principles of circuit function. These principles provide a library of circuit mechanisms that are almost certainly used in all large brains. Indeed, any mechanism found first in small nervous systems (for example, bursting neurons, widespread neuromodulation, electrical coupling) eventually has been revealed in larger brains. To me, the essential question is how special features arise in large networks precisely because of their size, despite the fact that many explanations of how large circuits work resort to describing them as if they were small circuits.



William Kristan

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The brains of many animals differ in their details: ionic channels, neurotransmitters, neuronal interconnections vary, even between rats and mice. General functional principles, however, are overwhelmingly similar: central pattern generators, lateral inhibition, gain control, balanced excitation and inhibition; the list of generalities across phyla is both extensive and will expand as more circuits are investigated. Finding the mechanisms underlying these principles is more tractable — and more convincing — using a nervous system that is simple enough to be able to both record the activity of many of its neurons during behavior and modify that behavior by stimulating single neurons. Yes, I want to know how human brain circuits work; that’s why I study the leech nervous system!



Rainer Friedrich

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Vertebrate and invertebrate brains show obvious differences in design principles, implying that some brain functions are not equivalent. However, many computational problems need to be solved by all brains. In these cases, insights obtained in one species will be instructive to understand brain functions in other species, even if these species evolved different strategies to perform a computation. Animal models may thus be chosen by asking: in what species can I take the most direct and quantitative approach to address my fundamental question? Small genetic model organisms have advantages for studying computational functions of neuronal circuits, irrespective of whether they are invertebrates (such as *Drosophila*) or vertebrates (such as zebrafish).



**Dmitri ‘Mitya’
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Because both vertebrates and invertebrates often live in the same environment and have similar behavior objectives, the functional requirements on their neural circuits are similar. For example, the statistics of natural visual scenes are reflected in the properties of receptive fields of neurons in the early visual systems: spatial receptive fields are center-surround and temporal receptive fields are biphasic as predicted by efficient coding/predictive coding theories. However, similar functional properties may be achieved by different mechanisms. It would be very interesting to see, by combining connectomes with the results of genetic, physiological, and behavioral experiments, how similar these mechanisms actually are. Both similarities and differences will inform our theoretical understanding of brain function.

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Book review

Marine mayhem

Derek E.G. Briggs

The Cambrian Explosion: The Construction of Animal Biodiversity
Douglas H. Erwin and
James W. Valentine
Roberts and Company 2013 x + 406
pp. ISBN 978-1-936221-03-5

The Cambrian explosion — the sudden appearance of representatives of most of the major groups of animals in the fossil record after the beginning of the Cambrian 542 million years ago — resulted in a much greater diversification of form than at any later time in Earth’s history. This event established the beginnings of animal diversity as we know it. Research on the Cambrian explosion used to be the purview of paleontologists, reliant on the evidence of the rocks. The beginning of the Cambrian was traditionally defined by the earliest appearance of fossil shells, and Charles Darwin considered this apparently abrupt appearance of animals in Earth’s history as a serious problem for his theory of evolution — where was the evidence in older rocks of the ancestral forms from which they evolved? A rich fossil record of earlier life, including the enigmatic creatures of the Ediacaran fauna, has been discovered since then, but only now are answers emerging to questions of why and how animal life exploded during the Cambrian.

The Cambrian explosion is revealed by plots of fossil diversity through time — the numbers of different shelled taxa recorded in successive stratigraphic intervals — a graph associated mainly with years of research in the library by the late Jack Sepkoski of the University of Chicago. The steep increase of diversity — nearly 20 phyla and over 90 classes of animals appeared during the 25 million years after the beginning of the Cambrian — was given added substance by the discovery of exceptionally preserved fossils. These fossil assemblages capture most of the diversity of Cambrian animals at various points in time and space and include soft-bodied animals without biomineralized hard parts.