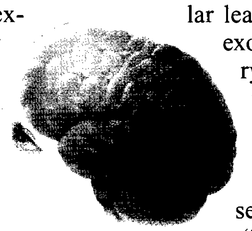
tor learning, Wickelgren does not touch on recent findings about the cerebellum's participation in nonmotor functions.

Evidence for a much broader cognitive role of the cerebellum comes from numerous sources. Human patients with cerebellar lesion have demonstrated nonmotor deficits in various domains, for example, in problem-solving, error detection, and language (*1*). Functional neuroimaging studies have shown cerebellar activation for many tasks that do not include motor components. For example, as described in a *Science* report by Gao *et al.* (*2*) and an accompanying News article ("The cerebellum: Movement coordinator or much more?" 26 Apr. 1996, p. 482) by Marcia Barinaga, activations in deep cerebellar nuclei and in the cerebellar hemispheres have been found related to tactile stimulation and discrimination and to proprioceptive feedback (*3*) in the absence of motor performance. The cerebellum also activates consistently during various types of language performance, even when motor speech components are subtracted (*4*). Cerebellar involvement has been further demonstrated for problem-solving (*5*) and working memory (*6*) tasks. While for technical reasons many early imaging studies did not cover the cerebellum, more recent studies suggest that the cerebellum is one of the most consistent loci of activation across a great variety of nomnotor cognitive tasks (*7*). All these findings indicate a general cognitive and sensory role (in addition to movement) for the cerebellum.



The cerebellum, which may be involved in motor learning

Our group demonstrated, in a 1997 *Science* report (*8*), a dissociation between movement-related and nonmotor attentional activations within the cerebellum. We showed that motor activation was located in the anterior paleocerebellum, whereas attention-related nonmotor activations were found more laterally in the neocerebellum. Thus, while our knowledge of its regional functional organization is incomplete, the cerebellum is not a functionally homogeneous structure. Neuroanatomical studies (*9*) underline the extensive and region-specific connectivity between the cerebellum and the cerebral cortex, especially in regions such as the dorsolateral prefrontal cortex (*10*), known to be crucially involved in working memory, problem-solving, and executive functions. Because synaptic survival depends on afferent-driven activation, it is highly unlikely that such massive connections to cerebral association cortices are gratuitous and nonfunctional. Instead, they further support the cerebellar role in diverse nonmotor cognitive and sensory functions across domains.

Trying to account for the cerebellar role in motor and nonmotor domains, we have described (*11*) the fundamental cerebellar functions as prediction and preparation. These functions are based on cerebellar learning of sequences, both of exogenous (for example, sensory) and endogenous neural activity (for example, through afferents from cerebral cortex). After learning to identify initial components of a sequence, the cerebellum can "predict" subsequent components of the sequence and can thus "prepare" the physiological state in remote systems that are required for a given perceptuomotor or cognitive process (for example, by lowering neural response thresholds in a functionally appropriate neocortical region). Feedback from such remote systems leads to continued fine-tuning of cerebellar prediction and preparation in response to changing internal and external conditions.

Ralph-Axel Müller
Department of Cognitive Science, University of California, San Diego, La Jolla, CA 92093, USA. E-mail: amueller@cogsci.ucsd.edu

Eric Courchesne
Department of Neuroscience, University of California, San Diego. E-mail: ecourchesne@ucsd.edu ecourchesne@ucsdedu

Greg Allen
Joint Doctoral Program in Clinical Psychology, San Diego State University/University of California, San Diego. E-mail: dallen@ucsd.edu

References

1. H. C. Leiner, A. L. Leiner, R. S. Dow, *Hum. Brain Map.* **2**, 244 (1995); J. D. Schmahmann, Ed., *The Cerebellum and Cognition* (Academic Press, San Diego, CA, 1997).
2. J.-H. Gao *et al.*, *Science* **272**, 545 (1996).
3. M. Jueptner and C. Weiller, *Brain* **121**, 1437 (1998).
4. J. A. Fiez and M. E. Raichle, in *The Cerebellum and Cognition*, J. D. Schmahmann, Ed. (Academic Press, San Diego, CA, 1997), pp. 233–254.
5. S.-G. Kim, K. Uğurbil, P. L. Strick, *Science* **265**, 949 (1994).
6. J. E. Desmond, J. D. Gabrieli, A. D. Wagner, B. L. Ginier, G. H. Glover, *J. Neurosci.* **17**, 9675 (1997).
7. G. L. Shulman *et al.*, *J. Cognit. Neurosci.* **9**, 624 (1997).
8. G. Allen, R. B. Buxton, E. C. Wong, E. Courchesne, *Science* **275**, 1940 (1997).
9. J. D. Schmahmann, *Hum. Brain Map.* **4**, 174 (1996).
10. F. A. Middleton and P. L. Strick, *Science* **266**, 458 (1994).
11. E. Courchesne and G. Allen, *Learn. Mem.* **4**, 1 (1997).

Cosmic Chirality

Experiments designed to discriminate between the left- and right-handed helical conformations of a synthetic variation of the nylons led to the discovery that attachment of a random distribution of nearly an equal population of mirror isomers as pendant groups to the helix led to a complete excess of the helical sense preferred by the

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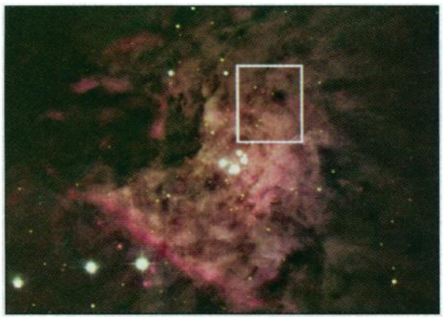
majority enantiomer (*1, 2*). In qualitative terms, this phenomenon, which is termed Majority Rule, arises from the excess energy of the helical reversal, a state the system tries to avoid. The system has been found to be quantitatively described by an approximation derived from a one-dimensional Ising model subject to a quenched random chiral field, in analogy to a theory that applies to one-dimensional magnetic materials (*3*).

An enantiomeric excess of about 12% of the groups pendant to the helix causes the optical activity to be identical to the situation of the enantiomerically pure pendant groups, while even a 2% enantiomeric excess gives rise to one-third of the full optical activity. Given the energy terms associated with the chiral bias favoring one helical sense and the excess energy of the helical reversal, the theory derived from the Ising model allows prediction of the helical sense ratio for any enantiomeric excess and also remarkably predicts that, within certain limits, reducing the chiral bias will increase the influence of the majority enantiomer, thus giving higher optical activities: The importance of the minority objection is predicted to override the force of the majority preference.

There is no reason for the effect to be limited to one polymer structure, and, in fact, early work on isotactic vinyl polymers in Italy after the discovery of Ziegler-Natta polymerization showed smaller versions of the same effect, as did



Homochirality of biological molecules may be explained by observations of light from part of the Orion Nebula (box)

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early studies on polypeptides derived from mixtures of enantiomeric amino acids.

In their report "Circular polarization in star-formation regions: Implications for biomolecular homochirality" (31 July, p. 672), Jeremy Bailey *et al.* suggest that a small enantiomeric excess produced by light from nebulae could be amplified by some mechanism, which could have led to the origin of homochirality on Earth. The Majority Rule effect is one such mechanism. The prerequisite for this chiral amplification is a stable helix, a conformational state that is common in biological phenomena, which is then subject to the influence of the mixed chiral information.

Mark M. Green
Herman F. Mark Polymer Research Institute, Polytechnic University, 6 Metrotech Center, Brooklyn, NY 11201, USA. E-mail: mgreen@duke.poly.edu

Jonathan V. Selinger
Center for Bio/Molecular Science and Engineering, Naval Research Laboratory, Code 6900, 4555 Overlook Avenue, SW, Washington, DC 20375, USA. E-mail: selinger@karma.nrl.navy.mil

References

1. M. M. Green *et al.*, *J. Am. Chem. Soc.* **117**, 4181 (1995).
2. M. M. Green *et al.*, *Science* **268**, 1860 (1995).
3. J. V. Selinger and R. B. L. Selinger, *Phys. Rev. Lett.* **76**, 58 (1996).

Preparing Graduate Students in Biology

In the editorial "Training for today's marketplace" (*Science*'s Compass. 31 July, p. 645), Elizabeth Marincola and Frank Solomon address the conflict resulting from the fact that academic primary investigators train many times the number of scientists required to replace themselves. The unavoidable result is that there are many more trained scientists than there are tenured academic research positions. This result really should not be a problem because there are many alternative jobs on the market in nonacademic positions, either still in basic research or in other related fields.

In my opinion, the problem arises because of two shortcomings in the educational process. In my recent experience at the Massachusetts Institute of Technology in the Biology Department (1989 to 1995), absolutely nothing was done to prepare graduate students for careers outside of academic research. Furthermore, many (although not all) of the professors at MIT continually indoctrinated us with the idea that the only noble, pure, and truly successful career path was that of academic research. If educators would accept that this is not the case and that they should do something to prepare students for other career paths, maybe we would not have the problems revealed in the survey the authors discussed.

The only solution that the authors suggest is still essentially an academic research position. In fact, this type of position is reminiscent of the hierarchical systems seen in some European countries and Japan. In reality, as detailed in at least one recent article (*1*), there are many alternative career opportunities that are experiencing growth. This is where many of these Ph.D. graduates will end up, and there is nothing wrong with that.

Andrew J. Gale
Scripps Research Institute, 10550 North Torrey Pines Road, La Jolla, CA 92037, USA. E-mail:agale@scripps.edu

References

1. H. Phillips, *Nature* **393**, 493 (1998).