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Colloquium Paper

This paper is an introduction to the following papers, which were presented at a colloquium entitled "Neuroimaging of Human Brain Function," organized by Michael Posner and Marcus E. Raichle, held May 29–31, 1997, sponsored by the National Academy of Sciences at the Arnold and Mabel Beckman Center in Irvine, CA.

The neuroimaging of human brain function

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The colloquium on "Imaging of Cognitive Function" speaks to the many audiences whose interests relate to efforts to map cognitive processes in the human brain. There are things of great interest in this collection of papers for specialists in cognition and neuroscience and imaging science as well as in disciplines interested in human development through education and training and others with intrinsic interest in the latest information on how the human brain supports thought. The papers were presented at a meeting sponsored by the National Academy of Sciences in its western home the Beckman Center at the University of California, Irvine.

Those whose primary interest is in cognition may wonder why they should care about brain mapping? Many of the papers here will be relevant to issues of central interest in cognitive science such as what happens in the brain while trying to read and remember verbal items (1–4), or navigate in a complex environment (5), how processing changes with practice and priming (6–8), and how experience can influence the organization of cognitive categories (4, 9).

In the past it has often been said that knowing where something is cannot be important for cognitive theory. However, knowing where can tell us important potential correspondences between quite different tasks, sometimes studied within very different parts of the cognitive science. For example, there is a very substantial correspondence between brain areas involved in phonological coding in reading words (3) and in retention of verbal information in working memory (1). Such a correspondence is implied by the cognitive theory that memory for verbal material has a phonological code. Confirmation of common brain areas provides support to this idea. The overlap between eye movements and covert shifts of attention has also been a topic in cognition. The imaging data are beginning to show much more clearly how completely the two overlap in a common anatomy within frontal and parietal lobes (10).

Thus, papers in the colloquium show the importance of knowing where something happens. However, the cognitive neuroscience approach illustrated in these papers is not at all limited to questions of where things are occurring, but also involve questions of when things happen, how strongly the brain areas react, and how brain areas change with experience. Several of the papers (e.g., refs. 3, 5, and 9) specifically relate their findings to various methods and theoretical ideas within cognitive science.

All of the papers included here also speak to neuroscientists interested in the general issue of how brains works at all levels. In addition, new communities of researchers now are, or at least should be, taking an interest in human brain mapping. Much of this new interest centers on the ability to show how brain areas change with experience (6, 7, 11). This kind of data could certainly influence people interested in how education, socialization, rehabilitation, and therapy might change both performance and brain representation.

This colloquium collection begins with six papers devoted to methods of studying brain mapping. The first three provide basic information on the most commonly used methods of mapping human brain function. The section begins with a review of the historical and physiological background of brain mapping with positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) (11). The relationship of changes in cellular activity within the brain to changes in blood flow form the basis of the signal obtained with PET and fMRI, both workhorses of brain imaging. This is followed by some of the latest developments in MRI (1) and event-related potentials (13). Whether you are just starting to follow brain mapping or are an expert, these three papers provide both important background information and a view toward the future.

The beautiful paper on flat maps (14) also provides a glimpse of a future when functional and anatomical areas will be integrated within maps of the human brain. Allowing access in great detail to studies relating function and structure within individual brains is likely to influence both the practice of medicine and neuroscience research in the decades to come. The use of flat maps will also provide a more detailed comparative anatomy of cognition. Particularly good examples of comparative anatomy by means of imaging are found in refs. 14–18.

The next two papers in the method section (19, 20) provide a perspective on methods of collecting and analyzing data arising from functional imaging studies. The masses of data available from functional imaging have required the development of new computer-based techniques both in graphics and in statistics.

The next set of six paper deals with the visual system. This section starts with two beautifully illustrated papers (15, 16) that relate maps of the visual system in human beings to those of other animals, using some of the methods pioneered by Van Essen. The visual system is constantly bombarded by input and is thus faced with the task of selection for more advanced processing. This is one important function of attention. Papers 10 and 17 examine how attention works within the visual system and emphasize the close relation of human visual attention to studies of dynamic changes in receptive fields in the alert monkey and to studies of human and animal eye movements. The next paper (5) illustrates the complexity involved in the scenes that the visual system is required to analyze in order to navigate between locations. The final paper in this visual section (9) shows how separate visual areas are used to process letters and digits. The basis for this separation appears to be the learning that takes place in different settings (e.g., arithmetic and reading classes). Postal employees who sort combined letter–digit codes appear to have greater integration of these codes. This paper, like many of those in the memory and language sections to follow, shows that experience can work to alter the organization of the human brain.

A set of five papers deal with aspects of learning and memory. The first three concern brain plasticity consequent to various lengths of practice. In ref. 6 a few minutes of practice alters the brain areas involved in tasks as varied as generating words and learning a tactile maze. Although the brain areas differ in the two tasks, it is shown that the principle that some areas are active early in practice and then drop away while other areas increase is general to these very different situations. Ref. 7 reports that learning a simple sequence of movements involves both a short-term reduction in blood flow and a longer-term increase in the size of the brain representation of the learned sequence in comparison with unpracticed sequences. It is argued in ref. 21 that just such a form of brain plasticity underlies the distortions found in the so-called ventriloquism effect, where a visual event distorts the location of a simultaneous auditory input.

The section then turns to studies of short-term memory and priming. In the first paper (1), it is shown that a very specific system of anterior and posterior brain areas deals with verbal information, while paper 18 argues for common principles of short-term storage in quite different brains by showing that common anatomy is involved in both human imaging studies and monkey cellular studies. The final paper in this section (8) explores new uses of event-related fMRI to show both anatomy and time course in implicit and explicit learning.

The section on language includes four papers. The first three deal with reading words (2, 3, 22), while the last compares reading English with American Sign Language (4). While the heavy emphasis is on single word reading, it is argued that the brain separates the semantic analysis of individual words from areas concerned with integration of words into meaningful propositions (22). The next two papers explore the brain areas involved in processing semantic information by fMRI (2) and those involved in obtaining word sounds with PET (3). Finally, ref. 4 shows how brains of deaf signers dealing with their native language differ from those of hearing subjects reading English. In a nice analysis the paper uses hearing subjects who are native signers to separate those aspects of the findings due to knowledge of a special language and those that are due to adaptation of the brain to the lack of auditory input.

Welcome to the world of human brain mapping. We hope that you can have the same enjoyment in reading this collection as we had during the colloquium.

1. Smith, E. E., Jonides, J., Marshuetz, C. & Koeppe, R. A. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 876–882.
2. Gabrieli, J. D. E., Poldrack, R. A. & Desmond, J. E. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 906–913.
3. Fiez, J. A. & Petersen, S. E. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 914–921.
4. Neville, H. J., Bavelier, D., Corina, D., Rauschecker, J., Karni, A., Lalwani, A., Braun, A., Clark, V., Jezzard, P. & Turner, R. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 922–929.
5. Aguirre, G. K., Zarahan, E. & D'Esposito, M. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 839–846.
6. Petersen, S. E., van Mier, H., Fiez, J. A. & Raichle, M. E. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 853–860.
7. Karni, A., Meyer, C., Rey-Hipolito, C., Jezzard, P., Adams, M. M., Turner, R. & Ungerleider, L. G. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 861–868.
8. Buckner, R. L. & Koutsaal, W. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 891–898.
9. Polk, T. A. & Farah, M. J. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 847–852.
10. Corbetta, M. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 831–838.
11. Raichle, M. E. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 765–772.
12. Rosen, B. R., Buckner, R. L. & Dale, A. M. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 773–780.
13. Hillyard, S. A. & Anllo-Vento, L. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 781–787.
14. Van Essen, D. C., Drury, H. A., Joshi, S. & Miller, M. I. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 788–795.
15. Tootell, R. B. H., Hadjikhani, N. K., Vanduffel, W., Liu, A. K., Mendola, J. D., Sereno, M. I. & Dale, A. M. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 811–817.
16. Tootell, R. B. H., Mendola, J. D., Hadjikhani, N. K., Liu, A. K. & Dale, A. M. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 818–824.
17. Luck, S. J. & Ford, M. A. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 825–830.
18. Ungerleider, L. G., Courtney, S. M. & Haxby, J. V. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 883–890.
19. Friston, K. J. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 796–802.
20. McKeown, M. J., Jung, T.-P., Makeig, S., Brown, G., Kindermann, S. S., Lee, T. W. & Sejnowski, T. J. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 803–810.
21. Recanzone, G. H. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 869–875.
22. Posner, M. I. & Pavese, A. (1998) *Proc. Natl. Acad. Sci. USA* **95,** 899–905.