Bridging Cognitive And Neural Aspects Of Classroom Learning

Michael I. Posner

Department of Psychology, University of Oregon, Eugene, OR 97403-1227

Abstract. A major achievement of the first twenty years of neuroimaging is to reveal the brain networks that underlie fundamental aspects of attention, memory and expertise. We examine some principles underlying the activation of these networks. These networks represent key constraints for the design of teaching. Individual differences in these networks reflect a combination of genes and experiences. While acquiring expertise is easier for some than others the importance of effort in its acquisition is a basic principle. Networks are strengthened through exercise, but maintaining interest that produces sustained attention is key to making exercises successful. The state of the brain prior to learning may also represent an important constraint on successful learning and some interventions designed to investigate the role of attention state in learning are discussed. Teaching remains a creative act between instructor and student, but an understanding of brain mechanisms might improve opportunity for success for both participants.

Keywords: Attention, cognitive neuroscience, expert, language, neural networks, novice
PACS: not applicable

INTRODUCTION

One branch of neuroscience, cognitive neuroscience, concentrates on the understanding of how the human brain is organized. The principle method is neuroimaging of the human brain. The earliest analytic studies of the mental operations involved in complex human tasks involved reading and listening to words and were published only in the late 1980s [1]. In the twenty years since that time an amazing variety of cognitive and emotional tasks have been examined by a number of different imaging methods [2]. In most cases a small number of widely separated brain areas have been activated. In many cases different functions have been determined for these areas. By examining the correlations between brain areas constituting parts of the network it has been possible to show the overall organization of the network in real time [3]. Many networks such as those involved in attention and memory are present in some form in infancy, but experience organizes the networks and shapes them for expert performance. In this paper we examine places where understanding the networks help us shape appropriate learning experiences.

LANGUAGE

Infants come into the world with the capability of discriminating among the units of language (phonemes) in all of the world's languages. That is, if one phoneme is sounded over and over again (e.g. ba) so that its novelty effects are reduced, a recovery occurs when a different phoneme is heard (e.g. da). Thus the infant exhibits an auditory system capable of learning the phonemes to which it will be exposed. Moreover, in the period between 6 and 10 months there is a considerable shaping of this phonemic structure [4]. Those sounds to which the infant is exposed tend to solidify and form a unit, while the ability to discriminate unfamiliar sound units begins to disappear. Studies have shown that infants raised in English speaking homes can maintain their ability to discriminate phonemes in mandarin Chinese, for example, if exposed to a speaker of those sounds during this period [5]. Unfortunately, learning did not occur when the exposure was to a video rather than to an actual person. Current research is attempting to determine the most important aspects of these social interactions in hopes of being able to determine whether an electronic media presentation incorporating them could be designed. Watching the tutor in these studies indicates the elaborate methods used to maintain the interest of the infant. We simply do not know if an understanding of these methods may allow them to be duplicated by a non social computer based system. However, these findings and others like them show that the infant's auditory system is being trained by the speech patterns of their community.

Experiments with infants have also shown that the effectiveness of this training can be assayed by changes in the scalp recorded event related potentials following a change from a frequent to an infrequent phoneme [6; 7; 8]. The brain shows its discrimination of the two by responding differently when the novel phoneme occurs. Brain activity can reveal whether or not the infant is making the discrimination between phonemes. This electrical difference can be used as a measure of the efficiency of the brain in making the discrimination. Thus the effectiveness of caregivers in establishing the phonemic structure of their native and also of additional languages that they might desire to teach can be examined. It is also possible to predict later difficulties in spoken language and in reading from these recordings [7; 8]. These methods make it possible to check for the development of a strong phonemic structure by use of electrical recording in early life just as brain stem event related potentials now are widely use to allow early detection of hearing deficits in infants [8].

Numerous studies have shown that the skill of reading is heavily dependent upon the success of the child in having stored and being able to use phonemes effectively [9]. For example, studies of phonemic awareness have clearly shown that the ability to segment auditory words serves as a predictor of future success in acquiring literacy. It would be useful to be able to assess the success of parental instruction on phonemes without the need for expensive and time-consuming electrical recording. In fact this should be possible. If the infant's attention is brought to a compelling visual stimulus to which they orient they will turn their head in the direction of a novel auditory event [4]. It should be possible to deliver these visual and auditory stimuli over the web and allow the caregiver to assess the effectiveness of the child's learning. It seems likely that a clear and observable understanding of what the child is learning from their caregivers will motivate adults to provide a social and linguistic environment designed to shape the auditory systems best for future reading.

Usually elementary school children learn to read. The brain network related to reading has been extensively studied [see 10 for a review]. Of particular importance are two posterior brain areas. One of these areas lies in the left temporal-parietal boundary in the angular gyrus which lies close to auditory systems and is important for representing the sound of visually presented words. A second area is in the left fusiform gyrus and is important for synthesizing letters into a unitary visual representation (word form). Before learning to read and for dyslexic students these areas do not behave differently between words and non words. Phonics training produces more normal activation of the angular gyrus [11; 12]. Dyslexic children given sufficient phonics instruction learn to sound out words but they do not read fluently. Fluent reading only occurs with differential activation in the fusiform gyrus as subjects practice the reading skill. Arguments between phonics and whole word advocates have dogged the reading field for generations. It is instructive that brain areas benefiting from phonics instruction and quite separate from those used to package individual letters into whole word forms. Although these findings do not dictate a curriculum they do provide a good starting place for working with children to develop the skill of reading.

NUMBER

There is also evidence that areas of the brain that are involved in appreciating number carry out functions during infancy and preschool years [13; 14; 15; 16]. Infants appreciate the quantity of small numbers and can express their surprise at incorrect arithmetic operations in behavior [16] and in brain activity [14].

However, apparently some children continue to have difficulty in making the connection between a number stimulus and information about its quantity. These children are at risk for failure when they have to learn aspects of elementary school mathematics. One program (*Rightstart)* gave children at risk for failure in school a year's program of remediation that stressed the connection between numerical input and quantity [17]. After the program, trained students were better able to succeed in elementary school math than those who did not receive the training. Recently an effort has been made to train students on quantity with a computerized program that would be available on the web and would train students on understanding quantity [18].

SELF-REGULATION

In the first few months, infant's were drawn to look at novel objects. During this period not only their ability to see (visual acuity) but also their ability to orient attention has been shown to improve week by week. They also learn where they should put their eyes. In formal studies infants exposed to visual objects at regular locations learn to anticipate by moving their eyes before the stimulus is even presented [19; 20]. This laboratory skill is also important in their everyday life. Each culture has implicit rules about where one should place ones eyes during communication. Infants appear to learn these rules very easily during this early period. Of course the eyes are not a perfect indicant of attention, since one can fixate at one location and attend at another, but they provide a fairly close indicant of where attention will be placed.

There is evidence that infants in different cultures receive different forms of learning about where to look. For example, in western cultures, soothing often involves turning the infant's attention outward toward novel environmental objects [21]; while in East Asia soothing tends to involve intense interaction with the caregiver [22]. Possible consequences of this early learning are apparent in the difference between western and East Asian perception in later life. For example, in one study comparing adults' perception of scenes was found that Western people attend more to the focal objects and seek their classification, while East Asian people attend more to contextual information [23]. Although there are no studies tracing the origin of these differences, it seems likely that these differences begin in the early socialization of the systems responsible for visual orienting in infancy.

For brain areas related to attention we are starting to understand out how the efficiency of the neural networks involved are related to specific genes. The orienting network develops well in the first year of life [19]. Studies using neuropharmacology in alert monkeys suggest that the network underlying orienting of attention is modulated by the cholinergic system [24]. One group [25] genotyped their subjects and examined performance in visual search tasks known to involve orienting of attention. They found alleles of two genes to be related to the efficiency of performance on these tasks. Similarly the later developing executive attention network is modulated by dopamine and the efficiency of this network is found to be related to four dopamine genes [26; 27]. Alleles of two of those genes were used in imaging studies performed while the participants to the attention network test [28]. It was found that the alleles differed in the strength of activation of the anterior cingulate, which was an important node of the executive attention network.

These genetic studies are based on the efficiency that people with differing alleles activate the relevant attention network. It is likely that the same genes are important in building the networks that are common to all people. As in the case of attention skills that are acquired in childhood such as literacy and numeracy, attentional networks also show great commonality in the brain areas activated in adults [29]. Thus, it appears likely that there is a genetic selection of brain areas that will be recruited by skills like reading and number processing, making it possible that we may eventually understand how different alleles influence the difficulty of acquiring these skills.

While the orienting network develops most in infancy, the executive attention network appears to develop from 3 to 7 years of age [30]. A training study has suggested the possibility of improving the network in both 4 and 6 year old children [31]. This study randomly assigned typically developing children of these ages either to a specifically developed program for training executive attention or to a control condition. For both age groups five days of the training produces more adult like performance on attention than is found in the control group. The training exercises are adopted from work used to train monkeys to work in outer space. They involve learning to use a joystick to track moving objects, prediction of trajectories, memory and the resolution of conflict. Recording of EEG from scalp electrodes was obtained while children performed the Attention Network Task. In this task the child must ignore conflicting flankers while responding to the direction of a target. The results showed that activity in the anterior cingulate of the executive network is altered by the training. Generalization of the training to IQ tests suggests that the training effects influence non-trained cognitive processes. The strength of this study is that the anatomy, neuromodulators and genes involved in this network have been explored in prior studies, thus it provides a model for viewing how experience with a particular network might improve its efficiency.

A replication of this study used ten days of training with 5-year-old children [32]. Similar findings were obtained for the executive attention network and improvements in IQ. In this case the findings were maintained after a two-month delay. A very different approach to the same issue involved classrooms using a curriculum, *Tools of the Mind* as a means for training executive functions [33]. The year long training showed a strong improvement in assays of attention conducted before and after training.

Recently a number of studies have compared bilingual speakers with monolinguals on tasks requiring resolution of conflict like the Attention Network Test [34; 35]. One thing a bilingual practices is the ability to switch between languages and to suppress one language while speaking or reading another. The results suggest that bilinguals are better at resolving conflict even in tasks which like the ANT involve no language. Whether the bilingualism causes this difference is yet to be determined, but the results are certainly consistent with the role of training in shaping self-regulation.

EXPERTISE

Physics and other sciences are usually taught mainly in secondary schools. Even infants have a rudimentary understanding of such physical principles as solidity and motion [36]. These are demonstrated as in number by the tendency to look longer at surprising outcomes such as one object passing through another. Many researchers have established the differences between those highly trained in physics (experts) and those untrained (novices). In judging how a yo-yo placed on its rollers and given a tug on its string extended leftward, novices frequently guess that it will roll clockwise away from the direction of the tug, while most experts correctly predict a roll counterclockwise in the direction of the tug. Listening to experts discuss how they make the judgment reveals extensive semantic knowledge lies behind the judgment, but the ease and the speed of the judgment suggests that two subjects simply see the yo-yo differently [37].

Studies of the neural systems that underlie high level skill that we all have for words and faces suggest that this knowledge alters posterior visual systems, so that the highly skilled person simply sees the face or word differently. A similar result has been obtained for bird or dog experts in the area of their expertise [38]. Thus the posterior localization is not merely for categories common to all people but can be obtained from learning. These findings begin to provide a basis for understanding how the brain is changed during the estimated 10,000 hours of training necessary to obtain expertise in a domain

ACKNOWLEDGMENTS

This research was supported by the National Institute of Child and Human development by grant HD35801 to Georgia State University.

REFERENCES

1. R. Parasuraman, P.M. Greenwood, R. Kumar, and J. Fossella, *Psychol Sci*, **16,** 200-207 (2005).
2. M.I. Posner, M.K. Rothbart, and B.E. Sheese, ,*Developmental Science*, **10,** 24-29 (2007).
3. J. Fan, B.D. McCandliss, J. Fossella, J.I. Flombaum, and M.I. Posner, *Neuroimage,* **26,** 471-479 (2005).
4. A.B. Clohessy, M.I. Posner and M.K. Rothbart, *Acta Psychologica* **106,** 51-68 (2001).
5. M.M. Haith, C. Hazan, and G.S. Goodman, *Child Dev,* **59,** 467-469 (1988).
6. T.K. Guttorm, P.H.T. Leppanen, A.M. Poikkeus, K.M. Eklund, P. Lyytinen, and H. Lyytinen, *Cortex,* **41(3),** 291-303 (2005).
7. K. Wynn, *Nature*, **358,** 749-750 (1992).
8. H.F. Chua, J.E. Boland, and R.E. Nisbett, *PNAS* **102,** 12629-12633 (2005).
9. S.M. Carlson and A.N. Meltzoff, *Developmental Sci* **11**, 282-298 (2008).
10. A. Diamond, S. Barnett, J. Thomas, and S Munro, *Science*, **318**, 1387-1388 (2007).
11. M.H. Bornstein, C.S. Tamis-LeMonda, J. Tal, P. Ludemann, S. Toda, C.W. Rahn, et.al. *Child Dev,* **63**, 808-821 (1992).
12. J. Fossella, T. Sommer, J. Fan, Y. Wu, J.M. Swanson, D.W. Pfaff, et al. *BMC Neurosci,* **3,** 14 (2002).
13. M.I. Posner and M.K. Rothbart, *Educating the Human Brain*, Washington D.C., APA Books, 2007.
14. M.I. Posner, B.E. Sheese, Y. Odludas and Y. Tang, *Neural Networks*, **19**, 1422-1429 (2006).
15. H. Barth, K. La Mont, J. Lipton, and E.S. Spelke, *PNAS* **102,** 14116-14121 (2005).
16. J. Tanaka, and T. Curran, *Psychol ,Sci*, **12**, 43-47 (2001).
17. L. Feigenson, S. Dehaene, and E.S. Spelke, Core systems of number. *Trends Cogn Sci,* **8(7)**, 307-314 (2004).
18. Y. Anzai, "Learning and use of representations for physics examples" in *Toward a General Theory of Expertise*, edited by K.A. Ericsson & J. Smith, Cambridge UK:Cambridge University Press, 1991, pp. 64-92.
19. D.L. Molfese, *Brain and Language,* **72(3),** 238-245 (2000).
20. S.A. Griffin, R. Case, and R.S. Siegler, "Rightstart: Providing the central conceptual prerequisites for first formal learning of arithmetic to students at risk for school failure" in *Classroom Lessons: Integrating Cognitive Theory*, edited by K. McGilly, Cambridge, MA: MIT Press, 1995, pp. 25-50.
21. A.J. Wilson, S.K. Revkin, D. Cohen, L. Cohen, and S. Dehaene, *Behav Brain Funct*, **2,** (2006).
22. P.K. Kuhl, F.M. Tsao, and H.M. Liu, *PNAS,* **100,** 9096-9191 (2003).
23. K.E. Stanovich, A.E. Cunningham and B.B. Cramer, J *Exp Child Psychol* **38**, 175-190 (1984).
24. C. Harman, M.K. Rothbart, and M.I. Posner, *Motiv and Emotion,* **21***,* 27-43 (1997).
25. R.T. Marrocco, and M.C. Davidson, "Neurochemistry of attention" in *The Attentive Brain*, edited by R. Parasuraman, Cambridge, MA: MIT Press, 1998, pp. 35-50.
26. A. Berger, G. Tzur, and M.I. Posner, *PNAS* **103**, 12649-12553 (2006).
27. J. Fan, J.A. Fossella, T. Summer and M.I. Posner, *PNAS,* **100,** 7406-7411 (2003).
28. B. McCandliss, I.L. Beck, R. Sandak, and C. Perfetti,. *Sci Stud of Read,* **7**, 75-104 (2003).
29. M.I. Posner, and B.D. McCandliss, "Brain circuitry during reading", in *Converging Methods for Understanding Reading and Dyslexia*, edited by R. Klein and P. McMullen, Cambridge, MA: MIT Press, pp. 305-337, 1999.
30. M.R. Rueda, M.K. Rothbart, L. Saccamanno, and M.I. Posner, *PNAS*, **102,** 14931-14936 (2005).
31. M.K. Rothbart, M.I. Posner, M.R. Rueda, B.E. Sheese, and Y-Y. & Tang, "Enhancing self regulation in school and clinic", in *Minnesota Symposium on Child Psychology Meeting the Challenge of Translational Research in Child Psychology* Hoboken NJ:John Wiley, Vol. 35, 2009, pp. 115-158.
32. M.R. Rueda, J. Fan, J. Halparin, D. Gruber, L.P. Lercari, B.D. McCandliss, et al. *Neuropsychologia,* **42,** 1029-1040 (2004).
33. S. Shaywitz, S. *Overcoming Dyslexia*, New York:Knopf 2003.
34. P.K. Kuhl, *PNAS,* 11855-11857, (2000).
35. M. Cheour-Luhtanen, K. Alho, K. Sainio, K., Reinikainen, K., Renlund, M., Aaltonen, O. et al., *Developmental Neuropsychology,* **13,** 167-174 (1997).
36. E. Bialystok, I.M. Craik, C. Anthony and A.C. Ruocco, *QJ Exp Psychol*, **59**, 1968-1983 (2006).
37. S.E. Petersen, P.T. Fox, M.I. Posner, M.Mintun and M.E. Raichle, *Nature* **331**, 585-589 (1987).
38. E. Spelke, "Core knowledge", *in Functional Neuroimaging of Visual Cognition* edited by N. Kanwisher and J. Duncan, Oxford:Oxford Univesity Press, 2002, pp. 29-55.