EDITORIAL

Challenges and Methods in Developmental Neuroimaging

Eveline A. Crone,[1,2]* Russell A. Poldrack,[3] and Sarah Durston[4]

[1]*Leiden University, Institute for Psychological Research, Leiden, The Netherlands*
[2]*Leiden Institute for Brain & Cognition, Leiden, The Netherlands*
[3]*University of Texas, Austin, Imaging Research Center and Departments of Psychology and Neurobiology, Texas, US*
[4]*Rudolf Magnus Institute of Neuroscience, University Medical Center, Utrecht, The Netherlands*

Even though the developing human mind has been studied for centuries, it is only recently that scientists have gained access to a set of methodological tools that allow examination of the complex relation between children's thoughts and behavior and the developing and maturing brain. This special issue was inspired by a 3-day interdisciplinary symposium entitled "Challenges and Methods in Developmental Neuroimaging," held at the Trippenhuis of the Royal Netherlands Academy of Arts and Sciences (KNAW) in Amsterdam in May 2009. We aimed to bring together junior and senior scientists in this field to evaluate whether and how neuroimaging techniques have resulted in greater understanding of the relation between the developing mind, brain, and behavior, and discuss how neuroimaging can increase this understanding in the future.

There has been a dramatic increase in the use of brain imaging techniques to investigate the developing mind and brain since the first article using functional MRI (fMRI) with children was published in 1995 [Casey et al., 1995]. A current search for articles using fMRI with children in PubMed results in a count of 634 articles, highlighting how rapidly the field has developed. Despite these advances, the actual mapping of brain activation to mental function still holds several challenges. Scientists in this research area are very enthusiastic about what developing neuroimaging has brought us and can bring us, but also warn against overly simplistic application and interpretation of these methods. Three of the future challenges are highlighted below.

Brain Structure

Longitudinal research examining changes in brain structure with development within individuals has shown that cortical white matter increases approximately linearly with age throughout childhood and adolescence, whereas cortical gray matter, which reflects neuronal density and the number of connections between neurons, follows an inverted-U shape over development, peaking at different ages depending on the region [Gogtay, et al. 2004; Sowell et al., 2004]. A handful of studies have examined how structural brain development is correlated with cognitive function, as expressed for instance by Intelligence Quotient (IQ), and these studies show that region-specific changes in cortical thickness in prefrontal cortex can differentiate between children who are low, middle, or high in IQ [Shaw et al., 2006]. It is also believed that critical or sensitive periods in learning—a developmental window when children acquire new abilities that cannot be learned with the same success during other periods of life—are the result of synaptic changes that allow a great speed of functional reorganization in response to changing environmental demands [Blakemore and Choudhury, 2006]. For example, language undergoes a rapid increase during child-

*Correspondence to: Prof. Eveline A. Crone, Leiden University, Institute for Psychological Research, Leiden, The Netherlands. E-mail: ecrone@fsw.leidenuniv.nl

Received for publication 10 February 2010; Accepted 17 February 2010
DOI: 10.1002/hbm.21053
Published online 28 April 2010 in Wiley InterScience (www.interscience.wiley.com).

hood; children can learn to speak multiple languages fluently, an ability which can no longer be achieved with the same ease and precision in adulthood. It is well known that regions that are important for language production change rapidly during this same period, suggesting a strong link between brain and cognitive development [Huttenlocher and Dabholkar, 1997]. The exact relation between changes in brain structure and the relation to brain function and behavior is currently being explored, but is not well understood. These relations are further complicated by biological variation in hormone levels, especially in adolescence when puberty hormones are on the rise. Finally, an exciting future prospect is the combination of structure-function investigations with genetics. An important challenge for future research will be to understand the relation between the characteristics of changes in brain structure, genetics, biological variability, and brain function. These approaches are discussed in this special issue in the review articles by Paus, Shaw et al., Blakemore et al., and Casey et al.

Brain Function

The most commonly used method to map cognitive functioning to brain function is fMRI. Using this approach, it is possible to examine brain functioning in vivo in developing and other populations while they are asked to perform cognitive tasks [Casey et al., 2005]. Despite the possibilities that this methods offers, there are several limitations inherent in this technique, such as the correlative nature of the data and the difficulty in making “reverse inferences” from brain activation to mental function [Poldrack, 2006]. Empirical reports are typically based on general subtraction contrasts (e.g., difficult task versus easy task) but the relation with predictive power for prior or subsequent behavior remains unclear. A challenge for future work in this field will be to understand the dynamics of brain function and its relation to task behavior and the underlying cognitive processes, in both typically and atypically developing populations. Suggestions for successful fMRI research are discussed in this special issue in the review articles by Luna et al., Galvan, Church et al., Poldrack, and Konrad.

From Theory to Data or Vice Versa?

Textbooks on cognitive development are now incorporating brain development as an explanation of developmental improvements in a wide area of skills [Blakemore and Frith, 2005; Goswami, 2008] and neuroscientists are speculating about how brain development results in changes in cognitive function [Shaw et al., 2006]. Despite this mutual interest, the two research areas (developmental psychology and neuroscience) are still segregated and there remains a gap between our knowledge of brain and behavioral development. Developmental neuroimaging studies tend to be data driven rather than theory driven; that is, they tend to be inspired more by the prospect of finding differential maturational trajectories of specific structures and functions than by predictions derived from theoretical perspectives on behavioral changes. It is not uncommon that developmental changes in cognitive function are interpreted as the simple maturation of a single brain area, ignoring the absence of a direct relation between individual differences in brain function and behavior, or the networks in which this brain area is active. Thus, a third challenge will be to bring behavioral and neuroscience theories together so that they inform and complement each other, and allow for confirmation or falsification of theories based on interdisciplinary perspectives. This and other suggestions for future research are discussed in the commentary by Karmiloff-Smith.

The objective of the symposium was to bring together junior and senior scientists in the field of developmental neuroimaging and to tackle difficult and important questions. The meeting was successful in bringing together multidisciplinary perspectives and generating much discussion. Many of the senior scientists contributed review articles to this issue, with a focus on their field of expertise. In these reviews, the authors have discussed the important questions in developmental imaging research in their fields of expertise and have provided guidelines for future scientists exploring this exciting area.

The task for future scientists will be to utilize converging evidence from theory, task behavior, brain structure, and brain function to better understand developmental changes and individual differences in cognitive function. The goal of this special issue is to provide a deeper understanding of these complex issues, and to work towards possible solutions.

ACKNOWLEDGMENTS

We thank the Netherlands Science Foundation (NWO Joint Forces Network Grant, Brain and Cognition program), the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Young Academy for providing funds for the workshop preceding this special issue.

REFERENCES

Blakemore SJ, Frith U (2005): The Learning Brain: Lessons for Education. Oxford: Blackwell Publishing.

Blakemore SJ, Choudhury S (2006): Development of the adolescent brain: Implications for executive function and social cognition. J Child Psychol Psychiatry 47:296–312.

Casey BJ, Cohen JD, Jezzard P, Turner R, Noll DC, Trainor RJ, Giedd J, Kaysen D, Hertz-Pannier L, Rapoport JL. (1995): Activation of prefrontal cortex in children during a nonspatial working memory task with functional MRI. Neuroimage 2:221–229.

Casey BJ, Tottenham N, Liston C, Durston S. (2005): Imaging the developing brain: What have we learned about cognitive development? Trends Cognit Sci 9:104–110.

Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis AC, Nugent TF 3rd, Herman DH, Clasen LS, Toga AW, Rapoport JL, Thompson PM. (2004): Dynamic mapping of human cortical development during childhood through early adulthood. Proc Natl Acad Sci USA 101:8174–8179.

Goswami U (2008): Cognitive Development: The Learning Brain. Hove and New York: Psychology Press, Taylor & Francis.

Huttenlocher PR, Dabholkar AS (1997): Regional differences in synaptogenesis in human cerebral cortex. J Comp Neurol 387:167–178.

Poldrack RA (2006): Can cognitive processes be inferred from neuroimaging data? Trends Cognit Sci 10:59–63.

Sowell ER, Thompson PM, Leonard CM, Welcome SE, Kan E, Toga AW. (2004): Longitudinal mapping of cortical thickness and brain growth in normal children. J Neurosci 24:8223–8231.

Shaw P, Greenstein D, Lerch J, Clasen L, Lenroot R, Gogtay N, Evans A, Rapoport J, Giedd J. (2006): Intellectual ability and cortical development in children and adolescents. Nature 440:676–679.