Developmental Science 5:3 (2002), pp 265–267

Introduction: new methods in developmental science

B.J. Casey[1] and Michelle de Haan[2]

1. Weill Medical College of Cornell University, USA
2. University College London, UK

This special issue of *Developmental Science* reflects a new era of methodological advances in tools for use in developmental science. These methods for imaging the structure and function of the brain will help provide insights into both new and classic developmental questions. Yet, other approaches (e.g. animal, computational and genetic methods) remain essential both for constraining the interpretation of data collected with imaging methods, and for informing general theories of behavioral and brain development. A parallel special issue of *Developmental Psychobiology* to be published this year highlights the importance of converging methodological approaches to the study of developmental science. By linking these two special issues, we hope to broaden the audience for both journals and encourage more cross talk among scientists using human and animal methods/models in the context of developmental science.

The 12 papers in this issue cover traditional as well as contemporary methods for assessing functional localization and are based on the basic principles of magnetic resonance imaging (MRI), positron emission tomography (PET), electrophysiology and other techniques. Each of these methods can be contrasted in a number of ways (refer to Table 1). In the most general sense, the methods can be divided into those that provide functional information and those that provide structural information about the brain. Functional imaging methods allow one to measure changes in brain activity associated with simultaneous changes in behavior. For example, event-related potentials (ERP), functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), near infrared spectroscopy/optimal imaging (NIRS), positron emission tomography (PET) and single photon emission computed tomography (SPECT) all are methods used to measure subtle task-induced changes in signals from the brain. In contrast, methods like magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS) and diffusion tensor imaging (DTI) are methods used to measure brain structure and chemistry. For example, MRI can be used to measure gross size or volume differences in brain regions while MRS can be used to measure the concentration of cerebral metabolites like N-acetylaspartate (NAA), creatine plus phosphocreatine (Cr) and choline-containing compounds (Cho) that have been related to neuronal loss or damage. Thus MRS can provide additional insight as to why an MRI-based measure of a brain structure may be smaller. Finally, DTI allows for measures of the regularity and myelination of fiber tracts and provides a more precise measure of myelination of fibers than traditional MRI measures of white matter volume. All three of these structural imaging methods can be correlated with behavior, but none involves simultaneous collection of behavior or the capability of measuring brain changes associated with trial-by-trial behavior.

Table 1 provides a number of ways in which these methods may be distinguished with very rough qualitative rankings of each. Transcranial magnetic stimulation (TMS) is excluded from the table because it is a special method that looks at the effects of stimulation or of inactivation of a given brain region on task performance in order to infer the functions that require that brain region. This differs from the functional neuroimaging methods covered in this issue (e.g. PET, fMRI, MEG) that enable one to view activity throughout the brain. The article by Moll and colleagues in this issue provides a more specific description of this methodology.

The methods are distinguished in Table 1 in terms of relative temporal and spatial resolution, depth of recording (i.e. superficial or deep structure recordings), relative invasiveness, expense, and ease in use with developmental populations. These rankings are very rough estimates and depend on a number of factors. For example, the depth of recording for ERP and MEG are typically thought to be at the more superficial cortical level than other imaging techniques but dipoles can be estimated for deeper structures and greater resolution can be achieved by combining these methodologies with high spatial resolution techniques such as fMRI. Likewise, in the table the temporal resolution of pharmocologic MRI (phMRI), a technique based on fMRI, is ranked low. This is because, even though fMRI has a temporal

Address for correspondence: B.J. Casey, Sackler Institute for Developmental Psychobiology, Joan and Sanford I. Weill Medical College of Cornell University, 1300 York Avenue, Box 140, New York, NY 10021, USA; e-mail: bjc2002@med.cornell.edu

Table 1 *Qualitative approximate rankings on distinguishing characteristics are provided for the methods of diffusion tensor imaging (DTI), electroencephalography (EEG), event-related potentials (ERP), functional magnetic resonance imaging (fMRI), magneto-encephalography (MEG), magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), near infrared spectroscopy/ optimal imaging (NIRS), positron emission tomography (PET) and single photon emission computed tomography (SPECT)*

Characteristics	Less →				More
Ability to measure both cortical and deep structures	NIRS		MEG ERP, EEG	SPECT	PET, MRS, fMRI, phMRI, DTI
Temporal resolution	MRI DTI MRS	phMRI	PET SPECT	fMRI NIRS	EEG, ERP MEG
Spatial resolution	ERP EEG	MEG	SPECT	PET	NIRS, fMRI, DTI MRI, phMRI
Invasiveness of method		ERP EEG NIRS MEG	fMRI MRI DTI MRS	phMRI	PET SPECT
Expense of method		EEG ERP NIRS	fMRI DTI MRI MRS	phMRI	PET SPECT MEG
Ease of use with developmental populations	PET SPECT	phMRI	fMRI	MRI DTI MRS	EEG, ERP NIRS

resolution of only a few seconds or less, comparison of task-induced changes associated with pharmacological challenges with fMRI may require hours or days between scan acquisitions for wash out or activation of a specific pharmacological agent.

The distinguishing characteristics of the various imaging methods such as spatial and temporal resolution are fairly straightforward and thus more easily ranked in Table 1, but other aspects are less clear and so less easily ranked in this way. For example, a very important aspect of all the techniques is their relative signal-to-noise and contrast-to-noise (i.e. task-induced change relative to background noise). Many variables come into play in calculating the relative signal strength or power of a method to detect task-induced changes. The degree to which signal change can be detected involves averaging across data acquisitions both within and between subjects and for any method, there are costs associated with increasing the power to detect signal change. For example, before more recent advances in 3-D PET acquisition, several data points would be averaged both within and between subjects. While this may increase the ability to see task-induced changes in cerebral blood flow, the spatial resolution is compromised by having to smooth and register the images across several subjects rather than a single subject. Most of the functional imaging methods described rely on averaging several data acquisitions during experimental task conditions to enhance the ability to see task-induced changes. This strategy is not dissimilar from behavioral methods that rely on the collection of several behavioral trials within an experimental condition to calculate mean reaction times and error rates across subjects. Few methods have sufficient strength to detect reliable single trial results, although these data have been reported both with fMRI and magnetoencephalography (MEG) most commonly in time-series plots or correlations of single trial signal change with single trial behavioral data.

Another domain of interest is the ease of use of each technique with infants and children. This depends on a number of factors, but an important one is the relative sensitivity of the method to motion. Frankly, motion is a problem that must be addressed for all the methods and so if included in the table would show all the methods clustered to the right. However, some methods, such as EEG, are relatively less sensitive to motion compared to others (e.g. MEG), and thus provide an advantage in this sense for work with young children. For methods that are very sensitive to motion, future advances in child-friendly head restraint systems will help data acquisition in children. Another important factor when considering the use of a technique with developing populations is the invasiveness, or relative risk, of the method. This issue is specifically addressed by each of the authors, particularly those describing methods that rely on the use of radioactive isotopes and/or stimulation.

To conclude, a basic take home message from this special issue is that there is no single method that can

fully address developmental questions centered around themes of functional localization, nor is functional localization the main goal emphasized in this collection of papers. Instead, we hope that this issue in conjunction with the parallel issue of *Developmental Psychobiology* on 'Converging methods approach to developmental science' emphasizes the importance of a converging methods approach and the role of advanced methodology in formulating and constraining our theories of development.

Acknowledgements

This special issue would not have been possible had Mark Johnson, the Editor, not had the foresight to invite an issue on imaging methods in developmental science. We also appreciate the wonderful contributions by each of the contributors and the thoughtful comments and detailed reviews by so many. Special thanks go out to Elizabeth Spelke for her thoughtful commentary and Douglas Arnold, Matthew Davidson, Sabine Kastner, Nim Tottenham, Kathleen Thomas and Michael Worden for their constructive comments and reviews.