Neuroscience Research Methods

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Introduction

Studying the brain is a powerful way to understand human development. The first years of life are a period of incredible growth and change, especially in the brain. These first years are also a period where experience and developmental processes have a large impact on the growing individual. This article introduces the reader to the field of developmental cognitive neuroscience which uses investigations of the developing brain to gain insight into the development of behavior.

There are many advantages to employing a neuroscientific approach to understanding development in infancy and early childhood. First, neuroscience methods can aid in investigating the mechanisms of development. While behavioral methods investigate the output of the mind under different circumstances, neuroscientific methods can allow for the simultaneous investigation of different systems in the brain. To illustrate, using behavioral methods, one can investigate how quickly and how long an infant looks at their caregiver's face compared to a stranger's face. The results of this study can be used to reveal changes in this behavior over development and under different circumstances. Using neuroscience research methods, one can investigate where in the brain and when in time an infant's neural responses differ when they see their caregiver's face compared to a stranger's face. This kind of information can provide insight into what neural systems are leading to the developmental changes in behavior. For example, it could be that perceptual systems are differentially responding to these faces suggesting that infants see these faces differently, and/or it could be that emotional systems differentially engage. The use of neuroscience research methods complements behavioral methods to facilitate a more mechanistic understanding of development as well as providing an understanding of how brain development and behavior change are related.

The augmentation of behavioral methods is particularly important for the investigation of infancy and early childhood where behavioral methods are highly limited. Very young populations (e.g., neonates) are characterized by highly limited behaviors, and investigating the brain can provide an important window into the complexities and the mystery of this very young brain and mind where behavioral methods might fail. Moreover, it is difficult for toddlers and even young children to follow an experimental task or verbal instructions. The use of behavioral methods can be further complicated when investigating at-risk or clinically-relevant populations, such as individuals with autism spectrum disorder (ASD), language disorders and the like. In all of these cases, neuroscience research methods can be used to gain a rich set of information about the development of these individuals and might succeed even when behavioral methods are limited. However, it should be noted that neuroscience methods should be used cautiously in this regard. Just because there is a difference in an infant or a child's neural response between two stimuli, this differential response does not mean that infant “notices” the difference or that these stimuli would result in different changes in behavior. Nevertheless, differential neural responses do give some suggestion as to what information could affect behavior and provide a view into how informational sensitivity changes with development.

Finally, and more practically, demonstrating differences in the developing brain is particularly compelling and useful when trying to communicate about development to a broader audience. Scientifically, changes in the brain and changes in behavior should be treated equivalently or even be biased towards behavior (see previous paragraph). However, researchers have demonstrated that neuroscientific results are given greater weight particularly by the general population (Horton et al., 2014). Given this, presenting neuroscience findings about development when communicating with patients or parents, when engaged in public education, or when trying to affect public policy can be beneficial in helping individuals understand and attend to the needs of infants and young children even when the children's behaviors are limited.

Thus, there are many advantages to using neuroscience research methods to study development in infancy and early childhood. Neuroscience research methods are a crucial complement to behavioral methods: they aid in investigating how development unfolds as well as in understanding the development of the brain in relation to the development of behavior. In addition, these methods are helpful when studying populations with a limited behavioral repertoire (e.g., neonates, individuals with developmental disabilities) or where subtle behavioral manipulations are very difficult (e.g., young children). Finally, neuroscience research methods can be particularly effective when communicating about infant and child development to a general audience (e.g., parents, policy makers).

This article will introduce the reader to the neuroscience research methods currently used to investigate the development of infants and young children. For each of these methods, the reader will learn about the technical and/or biological basis of the method, its strengths and limitations; and a key research finding illustrating how the method can be used to gain insight into development. When applicable, the presented findings will focus on investigations of ASD and, in particular, studies of infants who are at a high risk for ASD but are too young to have received a diagnosis (i.e., diagnostic tests for ASD are not available before two years of age). Work with this population is a powerful example of the importance of investigation of the brain early in life. Evidence suggests, for example, that there are neural changes associated with ASD that occur before behavioral evidence of ASD is present. Uncovering the neuro-developmental origins of ASD can therefore aid in understanding why ASD arises and may result in the creation of early detection tests and future therapies.

This chapter focuses on the field of developmental cognitive neuroscience that involves investigations of human participants early in life. These methods heavily rely on neuroimaging methods which record the brain at a macro-level (i.e., systems-level neuroscience).
Neuroimaging is a term that broadly refers to taking pictures of the brain of a living individual. These pictures can represent either the structure or the function of the brain (see below). This chapter does not include methods for studying animal models of human development or methods used to investigate the cellular or molecular mechanisms of development (i.e., investigating the brain at a micro-level). Readers interested in these topics are referred to research articles in the fields of developmental neuroscience or developmental neurobiology.

Broadly, neuroscience research methods can be divided into two major types: Methods that record the structure of the brain and methods that record the function of the brain. Methods that investigate the structure of the brain uncover an individual's neuro-anatomy while methods that investigate the function of the brain record neural activity (e.g., neural response to a stimulus). It should be noted that there are methods that blur this distinction (e.g., resting state connectivity) but these methods will not be presented as they are beyond the scope of this chapter. In addition, the structure and the function of the brain are importantly intertwined across development; such that structural changes give rise to functional changes and, arguably, functional changes can give rise to structural changes. However, the structural/functional division remains an important one for understanding the variety of methods available to investigate early development and thus is the current focus.

Contemporary research methods in developmental cognitive neuroscience are non-invasive and have not been shown to have any deleterious side-effects. None of these methods expose participants to radiation or other harmful materials and, thus, are distinct from other techniques, such as X-rays. Moreover, even though an infant's and child's natural need to move or be held by their parent in unfamiliar environments is an important factor limiting the neuroscience methods, none of the methods reviewed here require infants or young children to be anesthetized or forcibly restricted. Indeed, basic research with volunteers is contingent upon infant or child compliance with the study and procedures are ended immediately if a parent or the researcher believes that the infant or child participant is uncomfortable or unhappy while participating.

**Structural Methods**

Historically, a number of methods have been used to investigate the structure of the developing brain. The longest-used method, and one that is still used today albeit in a limited fashion, is post-mortem investigations of the brain, whereby the structure of the brain of an individual is investigated after death. While post-mortem investigations allow for the most detailed and rigorous investigation of the structure of the human brain, they are highly limited: practically, it is very difficult to gain access to these samples; scientifically, these individuals may not represent normative development and may not be representative of the general population. In addition, this method obviously cannot be used in longitudinal studies (i.e., repeated over time within an individual with the goal of understanding developmental changes).

Today, the field is dominated by a single neuroimaging method: **magnetic resonance imaging (MRI)** (see Fig. 1). The use of neuroimaging techniques such as MRI allow for the investigation of individuals that represent normative development, they can be conducted with a large number of individuals, and they can be used longitudinally. These methods are broadly accessible to the scientific community and have a correspondingly large and rapidly expanding set of scientific findings. Another historic method for investigating the structure of the developing brain is computerized axial tomography (CAT/CT) scans. Since the advent of MRI, CAT/CT scans are largely unused for scientific research because of the need to expose participants to radiation. Thus, MRI is the dominant method for investigating the structure of the developing human brain as this method affords a number of benefits over post-mortem studies without the disadvantages of other neuroimaging methods such as CAT/CT scans.

MRI can provide different types of images to investigate the structure of the developing brain at a macroscopic level. A magnetic resonance (MR) scanner uses a combination of very strong magnetic fields (e.g., 3 Teslas, or 3T; the average refrigerator magnet is 5 milliteslas) and radio waves to generate images of the brain. (The reader can refer to relevant websites provided below for more information about the technology behind MRI.) A single MR scanner can be programmed with different sequences to collect different types images. These different types of images are all recognized as types of MRI, as they are collected with an MR scanner, yet they provide different views of the structure of the brain and can be used in isolation or collectively (see Functional: fMRI for the use of MRI to collect functional measures of the brain as well). A major disadvantage of MRI is the limited spatial resolution so that individual neurons and other cellular or molecular aspects of the brain cannot be individuated. However, the brain can be studied at the macroscopic level. For example, the structure of the brain can be broadly divided into white and gray matter, where white matter is the myelinated axons connecting neurons and the gray matter is the cell bodies and dendrites of the neurons and unmyelinated axons. While individual neurons cannot be imaged using MRI, white and gray matter of the brain as a whole, as well as broadly-defined regions of the brain (e.g., the motor system) can be imaged and quantified. Indeed, two of the most common of these methods, referred to as T1-weighted and T2-weighted images, differently contrast white and gray matter along with the cerebral spinal fluid that surrounds the brain. These types of images can be used to quantify how much white and gray matter is present in the brain and how these types of matter change over development both for the entire brain as well as for subregions of the brain (e.g., the visual system). Newer techniques, such as diffusion tensor imaging (DTI), can be used to investigate both the quantity and organization of white matter in the brain. Each of these structural images of the brain are commonly used in combination with functional images of the brain (see Functional Methods: fNIRS and fMRI). MRI, in sum, is a single neuroimaging technique that allows researchers to collect a number of different types of images and information about the structure of the developing brain.

MRI has been used to reveal the complex and non-linear development of the macroscopic structure of the human brain. Changes in gray matter are characterized by an overall thickening of the cortex followed by a prolonged thinning of the cortex. This general pattern occurs along with increases in the surface area of cortical regions. While this is the overall developmental pattern of the gray matter of the cortex, it is highly variable and dynamic processes of developmental change and experience appear to affect the gray matter of the cortex,
Figure 1  Magnetic resonance imaging (MRI) is a powerful method for investigating the structure of the developing brain. **Top left:** MR scanner (Tomáš Vendíš [https://commons.wikimedia.org/wiki/File:Petmr.jpg, https://creativecommons.org/licenses/by-sa/4.0/legalcode]). **Top right and bottom:** Changes in white matter over the first 4 years of life derived from a combination of T1- and T2-weighted images, a type of structural image obtained from an MR scanner ($VF_m =$ myelin water fraction). Reprinted from Dean, D.C., O'Muircheartaigh, J., Dirks, H., Waskiewicz, N., Walker, L., Doernberg, E., Piriyatinsky, I., Deoni, S.C.L., 2015. Characterizing longitudinal white matter development during early childhood. Brain Struct. Func. 220 (4), 1921–1933.

sometimes resulting in thicker and sometimes thinner cortices. These processes are currently under active investigation. While the causes of these changes in the gray matter are not known in great detail, investigating differences in the development of gray matter reveals differences in the structural development of the brain. For example, investigations into developmental changes in gray matter have been found to relate to an infant's risk for developing ASD: Hazlett et al. (2017) found that the expansion in the surface area of several regions in the first postnatal year of life (i.e., 0–12 months of age) differ between infants at low- and high-risk for developing ASD owing to familial risk.

Turning to the development of the white matter of the brain, white matter has a very protracted developmental trajectory with changes in white matter being documented into the young adult period (Barnea-Goraly et al., 2005). In addition, recent studies with a large number of healthy participants have revealed that the first two years of life are a period of extremely rapid development for white matter. For example, Dean et al. (2015) found that the most rapid increases in white matter occur in the first year and a half after birth.

Importantly, these early structural changes in the brain are profoundly affected by an individual's experience. Sheridan et al. (2012) examined the amount of white matter (and gray matter) for individuals who experienced extreme psycho-social deprivation early in life in the orphanages of Romania. Comparing children who remained in these orphanages to those who were placed in foster care revealed that psycho-social deprivation had a profound impact on the structural development of the brain, such that individuals who remained in conditions of deprivation had significantly less white matter than individuals who were placed in foster care. These differences in the structure of the brain were also found to link directly to the function of the brain as measured using electroencephalography, or EEG (see Functional Methods: EEG).
Functional Methods

Just as structural imaging methods allow researchers to examine changes in neuroanatomy across development, functional neuroscience research methods allow researchers to investigate how neural activity changes with development and across different populations. As with structural methods, there are a variety of techniques for uncovering the function of the developing brain. Unlike structural methods where MRI is the dominant approach, functional methods are more diverse. Many of these methods employ entirely different approaches to recording the activity of the brain and use distinct methods of recording. For example, both the spatial (where in the brain?) and the temporal (when and how quickly?) characteristics of the brain's response are very important to consider. Functional neuroimaging methods often excel at recording one aspect of spatial–temporal neural responses in the brain to the detriment of others. Thus, each method provides a unique picture into the function of the brain and how it changes with development. This section outlines three of the most common methods used today, though this list is by no means exhaustive. Two of these methods record the same physiological signal in the brain—hemodynamic changes—and, thus, form a natural group and are reviewed together.

Electroencephalography (EEG)

EEG is a noninvasive neuroimaging method that records the activity of large populations of neurons. Electrical signals occur naturally as part of the function of neurons in the brain. When large populations of neurons operate in a coordinated fashion, the electrical activity of these neurons is recordable on the surface of the head (i.e., the scalp) using electrodes. It is important to note that these electrodes, placed on an infant or young child's scalp, do not deliver electrical activity to the participant, but instead record the electrical activity that is naturally present on the scalp as a result of this coordinated neural activity (see Fig. 2, top left). The electrical activity that is used to investigate the function of the brain using EEG is very small in magnitude. For example, an AA battery is 1.5 V. The electrical activity recorded using EEG is measured in microvolts where 1 million microvolts is equivalent to 1 V. Thus, EEG records very small fluctuations of electrical activity that are naturally present on the scalp and result from the coordinated activity of large populations of neurons in the brain.

EEG is an excellent method for investigating the functional development of the brain and is the most well-established functional neuroimaging method with many decades of excellent work and findings (Nelson and McCleery, 2008). This method is helped by the fact that is relatively easy to place electrodes on the scalp of infants and young children and present them with stimuli. In fact, for infants, sparsity or the lack of hair for many young infants makes them particularly good subjects for EEG (and fNIRS below). However, a major limitation of EEG with young developmental populations is that it is very sensitive to motion such as blinking. Like the brain, muscles also generate electrical activity when they function, but muscles produce far stronger electrical activity than the brain. Thus, muscle movements swamp the electrical signals produced by the neurons in the brain and segments of EEG recordings that co-occur with motion must be removed prior to analysis. In adult studies using EEG, participants are instructed when to blink and move but this is not possible for infants and challenging for young children. Thus, EEG recordings must be carefully inspected for motion artifacts. Despite these limitations, EEG has been used to investigate the function of the brain longer than any other method and provides an essential view on the development of the brain.

The most common way (currently and historically) of using EEG to investigate the development of the brain is to examine event-related potentials (ERP, see Fig. 2, Top). After the presentation of a stimulus (e.g., an infant seeing a face), the brain exhibits a short period of neural activity in response to that stimulus across many regions of the brain. This period of neural activity can be recorded using EEG. To create an ERP, many repetitions of this stimulus presentation and the resulting neural responses are averaged. Importantly, the neural responses are aligned across repetitions based on the timing of the stimulus presentation. This analytic method averages out the noise in the signal and reveals the electrical activity (potentials) that arise from the presentation of the stimulus (i.e., are related to this event). Thus, this analytic method for EEG reveals the ERPs that characterize the functional response to a particular stimulus.

ERPs reveal a complex cascade of co-ordinated neural activity in response to a stimulus that unfolds over approximately 1 s. There are many distinguishable features to this burst of activity that are believed to represent the activity of a series of brain regions. These different features are referred to as components in the ERP and are often labeled based on the important characteristics of the components (e.g., from the ERP in Fig. 2, P1, N1). Explaining the origins of the names and meanings for the components is beyond the scope of this article (see Nelson and McCleery, 2008). However, it is important to note that there are many of these components that occur within 1 s of neural activity revealing the complex temporal nature of the function of the brain.

While ERPs (and EEG more generally) excel at revealing the complex temporal nature of neural function, they are highly limited in revealing the spatial nature of neural responses (i.e., the regions of the brain that produce these components in the ERP). Currently, methods are being developed with the aim of improving the spatial nature of ERP, such as cortical source localization. In addition, other neuroimaging methods that are related to EEG, such as magnetoencephalography (MEG), provide better spatial resolution while continuing to provide excellent temporal resolution. As both are not yet commonly used in the literature and have important limitations, particularly for early developmental populations, the current chapter focused on EEG as a neuroimaging method that reveals the temporal, but not spatial, nature of neural activity.

There is an incredibly rich literature using ERPs to investigate the function of the developing brain in infancy and early childhood and to compare across typical and atypical development. Overall, this literature has found that with development there is increased efficiency of the processing of stimuli over time (e.g., increased speed of processing) and increased differentiation or specialization of neural function (e.g., increased activity in components) as infants and children develop. This pattern of development is often disrupted when
Infants are at-risk for developmental disorders or when there are differences in behavior (e.g., as a result of a developmental delay). To illustrate, Elsabbagh et al. (2012) collected EEG data from 6-month-old infants while they viewed a picture of a face turning its gaze either towards or away from the infant (Fig. 3, top right). Since differences in processing both eye gaze and faces are impaired in individuals with ASD, the authors hypothesized that ERPs would differ in response to these stimuli for infants who were at high risk for developing ASD compared to infants who were at low risk. Elsabbagh et al. found that infants at low risk exhibited stronger differences in their ERPs between these two events. This finding suggests that functional neural differences related to the development of ASD are present early in life and arise in response to social stimuli. Moreover, together with research by Hazlett et al. (2017), this finding also reveals that infant at-risk for developing ASD exhibit differential brain development even if they are not later identified with ASD. This latter finding in particular reveals both the sensitivity of these methods as well as the broader finding that there is a complex interrelation among brain development, behavioral development, and developmental outcome.

**Hemodynamic Approaches**

Two common methods for investigating the function of the developing brain record the same physiological signals in the brain and, thus, form a natural grouping. These methods, functional near-infrared spectroscopy (fNIRS) and fMRI, both record hemodynamic signals. Neural activity is metabolically demanding and, as such, has an impact on the circulatory system. A period of localized neural activity
first results in a small, brief increase in deoxygenated hemoglobin (deOxy-Hb), followed immediately by a compensatory large and sustained increase in oxygenated hemoglobin (Oxy-Hb) and subsequent decrease in deOxy-Hb (see Fig. 2, bottom). Thus, the circulatory system systematically responds to localized neural activity in the brain. This relation between the circulatory system to local changes in neural activity is referred to as neurovascular coupling. The characteristic response that the circulatory response exhibits to neural activity is referred to as the hemodynamic response (hemo = blood, dynamic = changes).

These hemodynamic responses occur over ~10 seconds after neural activity occurs (Fig. 2) and are an indirect measure of neural activity. As reviewed in the previous section, EEG records the neural activity while it is occurring (see above), and ERPs occur over the 1–2 s of coordinated neural activity that follows the presentation of a stimulus. By contrast, hemodynamic measures record the circulatory responses to neural activity that occur over several seconds after stimulus presentation. EEG signals are recorded in microvolts and reflect the electrical activity directly produced by populations of neurons in the brain. Hemodynamic measures are recorded in various units of oxygen concentration (e.g., changes in oxygenated Hemoglobin and deoxygenated Hemoglobin as recorded with fNIRS). These measures of the circulatory system are directly and systematically related to activity in the brain but are a separate response from a separate system. Thus, hemodynamic approaches to neuroimaging record an indirect, but highly reliable, signal of neural responses.

One of the major benefits of hemodynamic-based neuroimaging methods is their strong ability to spatially localize neural signals. Hemodynamic methods are often referred to when we see a part of the brain “light up” in a study or when a popular press article refers to finding regions in the brain that respond to a particular type of stimuli. These inferences are possible because the hemodynamic responses to neural activity are highly localized, and the methods used to record these signals have a high degree of spatial certainty (i.e., the activity recorded in a channel of fNIRS or a voxel of fMRI is highly likely to reflect neural activity in that same region). This excellent spatial localization is in contrast to EEG where the mapping between the signals recorded and the spatial origin of these signals is a difficult
problem that has a high degree of inherent uncertainty. Thus, compared to EEG, hemodynamic neuroimaging methods allow for a high-degree of spatial precision and allow researchers to localize to the region of the brain responding to a particular stimulus or task.

By contrast, hemodynamic signals do not provide reliable temporal information about neural responses. While EEG is able to characterize the brain's response to a stimulus in incredible temporal detail, the hemodynamic response records responses several seconds after this neural activity is complete. Thus, hemodynamic responses present a summary of neural responses and, as such, collapses across the temporally complex signals that EEG provides. Thus, the difference between hemodynamic and EEG-based methods of neuroimaging are often considered as having a temporal–spatial trade-off.

**Functional Near-Infrared Spectroscopy (fNIRS)**

fNIRS is a method of recording the hemodynamic response using light. FNIRS uses the same technology as a pulse oximeter, a device widely used in the medical field to record oxygenation of an individual's body by placing a red light on one of their extremities. FNIRS adapts the same principles of a pulse oximeter to record changes in oxygenation in the brain. When using FNIRS, researchers place a cap embedded with low-intensity light sources and light detectors on a participant's head (see Fig. 3 bottom left). This cap allows for the recording of hemodynamic responses in channels located between light sources and detectors.

FNIRS is an excellent method for conducting neuroimaging recording with young developmental populations because it is relatively robust to motion and can allow infants and children to sit on their parents’ lap, and thus play and engage with stimuli in a way that is familiar to them. When specifically designed for recordings with infants, the cap is quite light and comfortable for them to wear.

The major limitation of fNIRS, compared to fMRI (see next section), is that the need to create channels on the surface of the brain results in spatial limitations in the recordings. First, the distance between the sources and detectors must be relatively large (e.g., between 2 and 3 cm) in order to record signals in the brain and, thus, the channels created between the sources and detectors are also relatively large. By contrast, it is standard for fMRI to record in voxels that are an order of magnitude smaller (3 mm) and it is possible for high-resolution scanners to record in much smaller measurements. Moreover, fNIRS channels can only record from the surface of the cortex while fMRI can record throughout the brain including very deep structures. Thus, compared to fMRI, fNIRS has considerable limitations in the spatial resolution and field of view of the hemodynamic signals it can record.

Despite these limitations, the use of fNIRS has substantially expanded our knowledge of the early developing brain and is a very important method for uncovering the localized neural responses of early developmental populations. Aslin et al. (2015) reviewed contributions of fNIRS (and fMRI) studies to our understanding of infant cognition. Since that time, there have been other seminal findings, and fNIRS has been ever increasing our understanding of the early developing brain and the neural basis of behavior and cognition in young infants and children. For example, fNIRS has been used to uncover the differences in brain development of infants who are at-risk for developing ASD. In particular, Sarah Lloyd-Fox, Mark Johnson and colleagues have used fNIRS to uncover the development of cortical responses to social stimuli (e.g., a person playing peek-a-boo with an infant compared to a moving toy, a person vocalizing compared to the sounds of a mechanical toy) that occur in the first year of life. Recently, they found that development of these neural responses to social stimuli was impaired in infants who would go on to be diagnosed with ASD (Fig. 3 bottom right, Lloyd-Fox et al., 2018). These fNIRS recordings of infants provide further evidence that there are differences in early brain development that precede the emergence of ASD, and these responses arise from localized regions of the infant brain that have been shown to selectively respond to social stimuli.

**Functional Magnetic Resonance Imaging (fMRI)**

In addition to being a very powerful method for investigating the macro-structure of the developing brain (see Structural Methods above), MRI can also be used to record the function of the brain. This method is called functional magnetic resonance imaging (fMRI). FMRI uses the MR scanner to record hemodynamic changes in the brain.

One of the major benefits of fMRI, over all other functional neuroimaging methods, is that it allows function to be investigated alongside a detailed recording of the structure of an individual's brain as both structural and functional measures are collected in the same session using the same scanner. Indeed, in practice, fMRI employs both structural and functional information collected from an MRI scanner, and it is the superposition of these images that are presented in scientific papers: fMRI papers employ a structural image of the brain superimposed with a color coded functional image indicating the regions found to be functionally engaged during the experimental task. By contrast, fNIRS recordings do not collect structural images of an individual (that requires an MRI scanner) and, instead, fNIRS color-coded functional images are considered in relation to population-level atlases of the brain that are derived from the brains of many individuals. While the use of population-level atlases is a sound one, it doesn't allow for the quantification of the variation in neuroanatomy that is found between individuals and increases the uncertainty of the spatial localization of fine grained neural responses. Thus, the ability to record both structural and functional measures of the same individual in the same recording session is a major benefit for fMRI. Another major benefit of fMRI, compared to fNIRS, is the increased spatial resolution and the ability to record hemodynamic signals throughout the brain (see above).

The major limitation of fMRI is the difficulty in the acquisition of the recordings. Specifically, MRI is very sensitive to motion, and even a small amount of motion (e.g., changes of head position in centimeters or less) results in unusable recordings. Moreover, recordings in research scanners specialized for cognitive neuroscience are collected when participants are lying down and are encased in a tight tube to allow for the scanner to operate around their head (Fig. 1). This environment (i.e., the MR environment) is very prohibitive of the types
of tasks that can be employed and creates very difficult circumstances in which to collect recordings with early developmental populations as they cannot be instructed on how to behave or be expected to reduce their motion based on instructions.

Despite these severe limitations for developmental work, fMRI has been used successfully with young infants and children. However, the majority of these studies have been conducted while infants are asleep and, thus, are most conducive to structural scans. However, the small literature of fMRI in infants and young children is a very important one, even though it is currently highly limited. Some of these studies approach this task by playing stimuli to infants while they are asleep and measuring their neural responses. These studies have focused on auditory stimuli and have found that the infant brain starts to become specialized to human speech in the first months of life (e.g., Shultz et al., 2014). Still fewer studies have recorded neural activity in infants while they are awake in the scanner. These studies generally have an extremely high participant attrition rate (i.e., infants who were consented to participate but for whom recordings were not sufficient to be included in the final sample) indicating the great difficulty in collecting fMRI with infants. These studies have focused on infant neural responses to visual stimuli (Biagi et al., 2015; Deen et al., 2017). Despite the incredible difficulties in recording fMRI with awake infants, fMRI is an extremely important method. It will be important to use for future investigations as it allows access to recordings in regions that are not available using any other method currently and provides a more direct comparison with adult findings (unlike fNIRS).

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Relevant Websites


