Parenting and Human Brain Development1

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# Abstract

This chapter traces important changes in brain systems between infancy and adulthood. Resting state MRI studies have traced changes in brain networks that support human behavior throughout the life span, and task related MRI studies have traced changes in networks related to acquired skills. We concentrate on the brain networks involved in language and self-regulation because both are critical skills developing between infancy and later childhood,

While all children develop similar brain networks underlying language and self-regulation, the efficiency of these networks varies among people. We examine evidence from temperament and gene X environment interactions to support the role of parenting in the child’s development of self-control and literacy. It is important for parents, educators and those involved in shaping public policy to understand what is known and to appreciate what remains to be learned about brain development. While brain development does not in itself dictate the best policies for parenting it may help to inform parents and policy makers on how best to support child development.

Key words

Attention, EEG, Gene X Environment, Language, fMRI, Self-Regulation, State

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**Theoretical background**

Introduction

It is increasingly possible to identify brain networks involved in human development, including development of those skills that allow the child to better understand and adapt to their physical and social worlds. We have learned a great deal about how the brain changes with development, and we report here on methods and important findings on brain development. Do these advances in brain study have direct implications for what parents should do and how policy makers should be spending their money? In our current state of knowledge we think not.

Advances in the study of the human brain do allow us to better understand the developing child. They even provide support for the proposal by Hebb (1949 ) and others (Posner & Rothbart, 2007) that neural networks may be a key to developing an integrated psychology. However, brain findings at present have only weak connections to behavior, and it is at that level where parenting occurs. To offer advice, we would need to extrapolate from brain findings to behavioral findings. For example, brain studies may help us identify a very early age at which parents can enrich language experience. However, what the nature of the intervention should be, e.g. whether to increase the number of words the parent directs toward the child, or ask the parent to repeat using a new word in a number of settings, we cannot say.

On the other hand, parents do benefit from learning about brain development .They can take into account such findings as the degree to which children’s self-regulation is generally slow to develop, the early importance of infant orienting, and the importance of individual differences among children, but this does not result in specific advice for parents.

A previous review of parenting was based largely on studies of developmental pathology, concluded that parent actions influence brain development, but called for more research linking the behavior of typical children to the brain (Belsky & de Haan, 2011). In this review we concentrate on normal brain development. This chapter concentrates on two areas of brain research, language and and self-regulation. We deal only with the brain of the developing child, leaving aside the substantial new research on adaptations of the caregiver’s brain to parenthood (for reviews see Abraham, Hendler, Zagoory-Sharon, & Feldman, 2016; Kim, Strathearn, & Swain,2016).

Our emphasis in this chapter is on methods that can illuminate brain networks involved in language and attention. The need to understand language and its development has long been recognized, and an extensive literature is available on children's order of acquisition of language-related skills. They demonstrate that language development is not simply a process taught by parents or their surrogates. Rather the acquisition of language demonstrates a clear interaction between genetic effects and the environment into which the infant is born. Because of more recent studies in brain development, we have learned much more about the details of this process, giving us a better understanding of how language develops

We also examine attention and the child’s development of self-regulation. As in language, brain networks of attention are due to common genetic factors in interaction with experience.. Some of the individual differences in the efficiency of attention networks have been traced to gene X environment interactions that involve parenting in conjunction with child temperament. Individual differences in the efficiency of executive attention are related to parents’ reports of their children’s ability to regulate their behavior (Effortful Control; Rothbart, 2011; Rothbart & Rueda, 2005). Effortful Control (EC) and self regulation as measured in childhood has been found to have extensive consequences for successful outcomes of adults (Moffitt et al., 2011).

Methods of examining brain changes

To begin this chapter we review methods for examining brain changes during development. These include early studies of the brains of infants and children who came to be studied after death, and newer methods for examining structural and functional change using brain imaging.

*Anatomy*

Methods for examining brain changes during development began with studies of the brains of infants and children who died early in life, followed by newer methods that examine images of the living brain. The human brain roughly quadruples in weight between birth and six years of age, by then reaching 90% of its adult volume (Brown & Jernigan, 2012). From 1939-1967, Conel (1939-19 67) examinedinfant and child brains from autopsies. Over the decades, he was able to examine under a microscope changes in number of synapses, their density and the increased complexity of dendritic trees. In all areas of the cortex, he found that synaptic density increased after birth and then declined, reaching adult levels first in the primary sensory cortex and much later in frontal areas (Huttenlocher & Dabholkar, 1997).

*Structural Images*

Structural imaging using magnetic resonance imaging (MRI) provides further support for the increase and then decrease in neurons (grey matter) with age, , as measured by both cortical thickness and surface area (Wierenga et al., 2014). However, even larger changes in brain size are due to increases in myelinated fibers (white matter), which increase linearly from infancy to adulthood (Zilles, 2005). The axons of long projections are myelinated earlier that those connecting the two hemispheres, while myelin in the association areas takes the longest time to develop and shows the largest individual differences during development (see Brown & Jernigan, 2012, for additional information on structural changes in development).

Structural findings point to the importance of connectivity between neural areas during development. Functional imaging of adults using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) has consistently shown that most common human tasks involve a number of brain regions, with these often including both the cortex and sub-cortical areas (Posner & Rothbart, 2007). Because widely separated brain areas are connected in carrying out even very simple cognitive tasks, such as shifting attention between areas of the visual field, the role of white matter connections is critical in the efficiency and timing of task performance.

*Task related functional imaging*

Functional MRI cognitive research began by subtracting images of the brain obtained during an experimental task from those i in a closely related control task. While subtraction provides evidence on the brain areas involved in a task, methods such as Electrical and Magnetic Encephalography and Dynamic Causal Modeling can indicate when and in what order these brain areas are activated (Posner, Sheese, Odludas, & Tang, 2006). Functional imaging based on correlations of MRI activation across brain areas can help examine communication between these areas (Posner et al., 2006). Most tasks involve a network of brain areas which must be orchestrated during performance. In many tasks, young children activate more brain areas during a task and often show more extensive activation within each area than young adults (Brown & Jernigan, 2012).

While task related fMRI can trace changes with development, the ages that could be studied have been limited by the ability of children to carry out task instructions. However, it is now possible to trace the changes in brain connectivity that occur during early development by examining brain activity while the person is at rest (rsMRI; Raichle, 2009).

*Resting State Imaging*

Resting state methods can be applied at any age because they do not require the use of a task. One of the brain networks known to be active during rest is the executive attention network (Dosenbach et al., 2007; Fair et al., 2009). Studies have shown that frontal midline nodes of the executive attention network are present during the first months of life (Gao et al., 2013), although connectivity with other brain structures is sparse. A significant increase in connectivity is evident by 2 years of age (Gao et al., 2009) and continues to develop slowly across the childhood years (Fair et al., 2009). During infancy and early childhood, most brain networks involve short connections between adjacent brain areas, but long connections important for self-regulation develop slowly over childhood (Fair et al., 2009; Gao et al., 2009). Although some of these results may be due to movement of young children during the scan, behavioral data also indicate that many long connections develop in later childhood and beyond. For example, there is a large improvement in reaction time (RT) between 7 year olds and adults when performing the Attention Network Test (ANT), whic involves long connections between sensory and motor areas (Voelker, Rothbart, & Posner, 2016).

In contrast, the ability to resolve conflict, which is necessary in daily life to maintain a coherent behavior designed to reach goals, and which involves the executive attention network, shows little or no improvement beyond seven years (Rueda et al., 2004). These findings suggest that control structures related to executive attention may be present in infancy, but they do not have the connectivity required to exert full control over voluntary behavior until later in development. We discuss executive control more fully under the section on development of attention.

Individual Differences

Our understanding of brain networks common to all humans makes it possible to view individual differences as variations in the efficiency of these networks. Network efficiency is influenced by variation in genes and by the gene X environment interactions that shape the child’s temperament.

Temperament

The development of the individual child depends upon their temperament and its influence on the child’s interaction with their environment (Rothbart, 2011). Temperament refers to the basic dimensions of reactivity to the environment and self-regulation that differ among children. Parents often do not become believers in temperament until after the birth of their second child (Putnam, Sanson, & Rothbart, 2002). It then becomes clear that the same techniques of child rearing that worked well with one infant may not be effective with the new baby. n. Temperament involves genetic factors but is not limited to them. Intermediate between the DNA inherited by the child and the effects of parenting are the environmental effects that influence the expression of DNA, which is called epigenetics. There is some evidence that methylation of DNA may affect such dimensions of temperament as negative affect and surgency (Fuemmeler et al., 2016), but additional studies are needed in this relatively new field.

Dimensions of temperament such as surgency (iactivity level and positive affect), negative affect, (fear, frustration and distress), together with orienting and soothability can be studied in caregiver reports based on observaton of their infants (Putnam, Sanson, & Rothbart, 2002; Rothbart, 2011). Later, effortful control, which measures the ability of children to regulate their own behavior, is reported by parents. Effortful control (EC) has also been shown to relate to development of the brain’s executive attention network. In infancy, self-regulation depends more upon alerting and orienting networks which by then are well developed. These networks sustain the waking state and allow the infant to be soothed through distraction.

We will be examining how genes interact with the environment during infancy and early development. However, early temperament ratings are often more predictive of later behavior than are direct predictions of behavior from genes. This is probably because temperament summarizes the influence of a large number of genes, each one with a small effect, and because temperament measures include effects of experience as well as genes. Moreover, experience cannot be inferred from an environmental stimulus, because the same stimulus can lead to quite different experience depending on the child’s temperament (Rothbart, 2011). However, understanding how temperament and genes are related to the environment can serve to improve our understanding of the mechanisms of development.

Genes and Environment

Imaging studies have revealed the importance of connectivity between brain areas. In fact, efficiency of connections between neural areas in newborn infants predicts later cognitive function. In a large longitudinal study, Lee and colleagues (2017) found that diffusion tensor imaging (DTI) of white matter connectivity at birth predicted better performance on cognitive tests at age two. This finding emphasizes the importance of genetic and prenatal factors in laying down the basic connective structure on which much of performance is based. Although many genes are common to everyone, differences in attention and cognition are partly dependent upon variations within the genome. This has been shown clearly in studies of attention networks (Fan, Fossella, Summer, Wu, & Posner, 2003). Of course, which genetic variations are inherited depends upon the parents, but not upon the actions of parents.

In theory, it is possible to manipulate the environment to provide either an enriched or an impoverished environment. Ethical issues obviously make it difficult to conduct experimental studies with humans, although natural variations in environments can provide quasi-experimental studies. Animal research has provided evidence that cortical thickness can be changed by placing the mice in environments of increased complexity (Diamond, Krech, & Rosensweig, 1964). These are important findings and we discuss them below in the section on interventions.

# Development of Language and Attenition

In this section we review studies of brain development that can be linked to some of the most important tasks undertaken by parents and children starting in infancy.

Language

The study of language acquisition makes major contributions to our understanding of human brain development. There are several reasons for this. Language is a species specific characteristic of all human cultures. wheras the specific language learned is a clear contribution of the caregivers. Moreover, studies of adult human language use have benefitted from imaging studies of the human brain, so that some of the networks involved are known.

The overall level of a child’s language skill has a powerful impact on the ability to form relationships with others and to succeed in a wide range of cognitive tasks. Improvement in our understanding of how to optimize language development and to treat and rehabilitate disorders of language development will have profound consequences for both a basic understanding of human development and for human society.

Everyone recognizes the influence of the parents in the specific language the child develops but often do not recognize how early that influence is shown. If given an opportunity, two month old infants display a clear preference for the language spoken by the parents over others (Dehaene-Lambertz & Houston, 1998), and they also prefer the mother’s voice to other voices speaking the same language. **Another clear demonstration of parental influence is the importance of child-directed speech in vocabulary development (Montag, Jones, & Smith, 2015)**

What has become clear in the last twenty years is how parenting helps shape the brain system to allow for specific recognition of the phonemes of one’s native language. The phoneme is the fundamental constituent of all the world’s languages that allows discrimination among words in the language. The infant’s ability to recognize phonemes is demonstrated by presenting a single phoneme (e.g., b) several times in a row, until the infant shows reduced orienting to its presentation, and then changing to another closely related phoneme (e.g., p) to see if the infant shows an increased response. If the changed sound is within the same phonemic boundary (e.g. different forms of b) there is little or no increase in orienting, but orienting is clearly increased if a phonemic boundary is crossed to p, even when in both cases the physical change in the signal is equal.

*Phonemes*

For some time we have understood that language acquisition proceeds, roughly speaking, through stages covering the period from birth to about age 5. During this time children move from perceiving basic differences in the sound and rhythmic aspects of human language in general to controlling the detailed grammatical contrasts in their native language. Recent research has provided surprising and important new insights, particularly into what young infants bring to this task and how rapidly early native language learning begins.

INSERT BOX 1 ABOUT HERE

Between 6 and 12 months infants’ perception of the distinction between native and nonnative phonemes increases (Werker & Tees, 1984). While non-native perception declines, native speech perception shows a significant improvement. For example, Japanese infants’ discrimination of the English r-l distinction declines between 8 and 10 months of age, and at the same time American infants’ discrimination of the same sounds improves. (Kuhl et al., 2008). These discriminations predict later language skills, but in opposite directions. Improved native phoneme discrimination predicts better later language skills, while relatively better non-native discrimination is associated with poorer later language.

One way of thinking about these changes has been developed by Kuhl (2010). She sees native language improvement as the result of specific developments in the neural areas processing speech, whereas non-native language improvement reflects the basic auditory ability to discriminate phonemes such as is found in non-human animals. During early phonetic development the speech patterns directed toward infants by caregivers tend to exaggerate the features that separate phonemes in the native language. Of course, non-native phonemes do not have the advantage of such speech. Thus, speech directed toward the infant is crucial to the elaboration of the neural systems related to speech recognition and also to the infant’s production of speech during the latter part of the second year.

The importance of social interaction in the learning of phonemes is supported by the finding that non-native phonemes (e.g., mandarin phonemes for native English speakers) can be maintained by active tutoring of the infant, but the tutoring must involve a person and not merely a computerized image (Kuhl, Tsao, & Liu, 2003; See also Box 1). The extent of learning of Spanish phonemes for English speakers exposed to bilingual speech was predicted by the degree of orienting toward the tutor, suggesting that orienting is one aspect of the advantage of actual people over electromagnetic displays (Conboy, Brooks, Meltzoff, & Kuhl, 2005). Another link to orienting is that infants of less than ten months or more than two years of age look primarily at the eyes when viewing pictures of faces. However, during the period when phonemic learning takes place the infants look more frequently at the mouth (Lewkowicz & Hansen-Tift, 2012), See also Box 1.

Improvement in the perception of native phonemes has also been found to be temporally related to changes in white matter tracts that connect nodes of the speech perception network. Between the middle of the first year of life and 3 years of age, there is maturation of axons entering the deeper cortical layers from the subcortical white matter. These axons provide the first highly processed auditory input from the brainstem to higher auditory cortical areas (Moore & Guan, 2001). The temporal coincidence between this change and infants’ phonetic learning indicates an important brain pathway to language. Later we review more specific white matter changes that occur prior to learning to read, and show how they predict later performance.

*Building Words and Sentences*

Studies of the neurobiology of language in speech and in the ability to learn to read have long been dominated by the classical view that emphasized the role of three well-circumscribed cerebral regions within the left hemisphere: Broca's area in the inferior frontal lobe, for planning and executing speech, Wernicke's area at the junction between the superior temporal and the parietal lobes, for the analysis and identification of speech, and the angular gyrus, for orthographic to phonological decoding during reading. However, even the earliest studies of imaging found activity in other areas, both cortical and subcortical. Among them is the anterior cingulate, a part of the executive attention network, which becomes active when participants obtain a use for a noun (Petersen et al., 1987), and which is consistently activated by the resolution of conflict between activated items.

Infants can be read sentences while they are at rest in an MRI scanner., sentences read to newborn infants activate the same posterior (Wernicke’s) and anterior (Broca’s) brain areas found to be active when adults process language (Dehaene-Lambertz, Hertz-Pannier, & Dubois, 2006). Of course, the infants do not really understand the sentences. The left hemisphere asymmetry found in most adults, however, does not appear to start until the second year of life (Emerson, Gao, & Lin, 2016). Over the first five years of life there is a steady improvement in the ability to use and understand words. Parents may guide this ability through the vocabulary and speech patterns they use with their children. One important example is joint attention in which the child tends to learn the word indicating the object of their parents attention (Baldwin, 1995). While joint attention skill is correlated with vocabulary acquisition it is not a sufficient cause and some children learn vocabulary in spite of having difficulty in joint attention (Akhtar & Gernsbacher, 2007).

In the acquisition of English and similar languages, children of 18 to 24 months begin to form early sentences by combining a noun and verb, or two nouns, using the basic word order of the adult language, and omitting function words (the, is) and inflections (plural and past tense) (Brown, 1973). Children can know that some unstressed elements, like the function words, should be included in adult sentences, even when they don’t produce these elements in their own speech.

It is estimated that children of professional class parents are exposed to 26 million words by age 3, while children from welfare families have barely half that exposure (Hart & Risley, 2003). There are clear correlations between exposure to words and later fluency in speech and reading, but many other factors may be involved in these correlations. There have also been efforts to use electronic technology to increase word exposure, but judging from the findings with phonemes (see box 1) these may not be effective.

*Bilingualism*

For much of the world’s population, knowledge of two or more languages starts early in life. In comparison with monolingual populations, the use of two languages often leads to reduced vocabulary and greater effort in achieving mastery of the primary language (Costa & Sebastian-Galles, 2017).

However, bilingualism has also related to executive attention. We have previously described the involvement of the executive attention network in the brain’s processing of language, and there is evidence that this network shows greater efficiency in bilinguals than in monolinguals. For a given level of performance, there is reduced activation in bilinguals who have learned two or more languages at the same time of life. Reduced activation indicates that for bilinguals less effort is needed to resolve conflict. It has also been argued that the improved efficiency of the executive attention network leads to improved general cognition by bilinguals. According to this view (Bialystak, 2017) bilinguals have multiple word meanings activated from their languages and must exercise control to maintain the use of one language. Switching between languages also requires control operations like resolving conflict that involve executive attention. The exercise of these control operations, particularly early in life, may lead to improved ability for control during mental arithmetic, problem solving and other forms of thought. . There is still a great deal of controversy about whether bilinguals do display better cognitive processes in tasks involving conflict resolution (Bialystok, Craik, & Luk, 2012). Nonetheless, Costa and Sebastian-Galles (2017) argue that the brain network underlying executive attention is improved in bilinguals, and Bialystok (2017) concludes that executive attention is the most likely mechanism for the improved ability to resolve conflict in bilinguals..

Advances in neuroimaging techniques have added to our understanding of the advantages and disadvantages of learning multiple languages. For bilinguals who start early in childhood, the two or more languages are activated and stored together in the brain. This requires the person to resolve conflict in understanding and using words and to be adept in switching between the two languages (Bialystok, 2017). Languages learned later in life, for example in high school, are not stored together and there is less automatic interference when retrieving items.

*Reading*

One of the best predictors of success in acquiring literacy is the number of words to which the child has been exposed by three years of age. It is also possible to learn more about the potential reading skill of the child by recording electrical activity from the scalp in response to spoken phonemes during infancy. The better the brain’s representation of phonemes, the easier it will be to acquire the written language (Molfese, 2000).

How could this be? We have reviewed above the importance of experience in the very early development of the phoneme system. Much the same is true of the ability to understand individual words. Experience with aural speech helps the infant and child to develop a strong representation of aural language. Exposure to high levels of background noise can interfere with the successful shaping of the phonemic system (Cohen, Glass, & Singer, 1973). Good representation of phonemes and words are important because one aspect of acquiring the ability to read (literacy) is being able to refer written words to speech sounds.

Sounding out individual letters and blending them into whole words during reading is called decoding. If children have a word in their aural vocabulary, they are then able to interpret the word meaning just as they would for the spoken word. Decoding skill is an important step in the acquisition of literacy and imaging studies have shown that children who have difficulty learning to read show poor activation of the phonological codes from print. A remediation program (McCandliss, Sandak, Beck, & Perfetti, 2003) that has been successful in improving children’s decoding uses a computer to introduce words with a consistent sound pattern. Over 20 sessions, new phonemes are introduced and the child practices decoding them. By scanning the brains of children before and after this training ithis program was found to be successful in teaching decoding and also in producing activation of the phonological code in poor readers, who previously did not successfully activate the sound based code during reading. This program’s use of words that differed in a single phoneme (e.g. bat vs pat) helped the child learn the importance of individual sounds in creating words. Parents may also use this method for teaching their own children decoding skills and the Dr. Suess books shown one example of the use of phoneme discrimination skills in reading.

Nevertheless, those who have learned only decoding skills are not necessarily fluent readers and often do not choose to read. Fluent reading depends upon the development of a visually based word form system. This system has been localized to the fusiform gyrus of the left occipital lobe (Molko et al 2002).

Even in 4-6 month old ifnats there is evidence of strong organization of a face recognition system along with other high level visual brain areas similar but not identical to those in adults (Deen et al., 2017). There is also evidence that the neural pathways into the visual word form area are present well before literacy begins (Saygin et al., 2016). Moreover, the efficiency of these early pathways predict how well the child will be able to read visual words several years later, after literacy is achieved. The process of developing the visual word form system, in addition to promoting fluent reading, also allows face recognition to become more lateralized to areas of the right hemisphere (Dehaene, Cohen, Morais, & Kolinsky, 2015). Indeed the higher the level of reading skill, the stronger is the lateralization of the face system. Because of this influence of fluency on the face recognition system, too early acquisition of literacy may have have a detrimental effect of aspects of face recognition. The acquisition of literacy, unlike bilingualism, does not appear to influence the executive attention system described in the next section of this chapter (Dehaene, Cohen, Morais, & Kolinsky, 2015).

An important way to improve children’s printed vocabulary is for the parent to engage in reading with the child. There is substantial evidence from both high and low income countries that interactive reading with the child improves vocabulary, literacy acquisition and directed attention (Engle et al., 2007, Montag et al., 2015; Vally Murray, Tomlinson, & Cooper, 2015).

Attention and Self Regulation

The importance of parenting in developing brain networks related to attention and self-regulation is perhaps less obvious than for language, but attention is certainly of no less importance than, and is critical to language acquisition. Evidence that self-regulation involves a high level executive attention network has led us to group the areas of attention and self-regulation together. Adult studies have identified three brain networks, which involve different functions of attention. These are the alerting, orienting and executive control networks (Petersen & Posner, 2012). In anatomically oriented functional imaging studies, the orienting network is often called the frontal parietal (FP) network, while the executive network is called in the Cingulo-Opercular network (CO; Dosenbach et al., 2007). The networks, their anatomy, time course and neuro-modulators involved are illustrated in Figure 8.1. There are other valuable frameworks for the classification of attention, for example, differentiating bottom up from top down control (Amso & Scerif, 2015). We believe, however, that it is important to distinguish between the orienting and executive network, both of which can have top down components, in order to grasp the transformation in attention that takes place between infancy and early childhood.

INSERT FIG 1 ABOUT HERE

Several of the networks involved in attention can be examined using the Attention Network Test (ANT), developed to study individual differences in the efficiency of the alerting, orienting and executive brain networks (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Rueda et al., 2004) In addition to adult research the ANT can be used to study attention in children of about 4 years and above (Posner et al 2014).

The ANT uses differences in reaction time (RT) between task conditions to measure the efficiency of each network. Each trial begins with a cue (or a blank interval, in the no-cue condition) that informs the participant that a target will be occurring soon, or where it will occur, or both. The target always occurs either above or below fixation, and consists of a central arrow, surrounded by flanking arrows. The flankers point either in the same direction as the target arrow (congruent) or in the opposite direction (incongruent). Subtracting RTs of congruent from incongruent target trials provides a measure of conflict resolution and assesses the efficiency of the executive attention network. Subtracting RTs obtained in the double-cue condition (where the cue serves as a warning but does not provide information about the target location) from RTs in the no-cue condition, gives a measure of alerting due to the presence of a warning signal. Subtracting RTs to targets at the cued location (spatial cue condition) from trials using only a central cue, gives a measure of orienting, because the spatial cue, but not the central cue, provides valid information on where a target will occur. The ANT thus uses reaction time differences to measure individual efficiency of the alerting, orienting and executive networks (Fan et al., 2002). In subsequent work, ANT reaction times have been shown to be somewhat reliable (Macleod et al., 2010) and have been used to trace the development of attention networks from 4 years to adulthood.

Below we discuss the development of the attention networks in infancy and childhood. Attention in infancy is less developed than later in life and the functions of alerting, orienting and executive control are less independent during infancy. We first examine alerting and orienting, and then consider executive attention in relation to the development of self-regulation. The method for measuring these variables must be different in infancy than later, when voluntary responses can be directed by the experimenter. Efforts have also been made to design tasks that can be performed by infants that tap into the same networks of brain areas shown in Figure 8.1.

*Alerting*

The early life of the infant is very much concerned with changes in state. Sleep dominates at birth and the waking state is relatively rare.. The newborn infant spends nearly ¾ of the time sleeping (Colombo & Horowitz, 1987), and many of the changes in the alert state depend upon external input. Arousal of the central nervous system involves input from brain stem systems that modulate activation of the cortex. As in adults, primary among these is the locus coeruleus, the source of the brain’s neuromodulator norepinephrine. It has been shown that the influence of warning signals operates via this brain system, since drugs that block norepinephrine also prevent the changes in the alert state that lead to faster reaction time after a warning signal (Marrocco & Davidson, 1998). It is likely that the endogenous changes in alertness during waking that take place without external input also involve this system.

There is a dramatic change in the percentage of the infant’s time in the waking state over the first 3 months of life. By the 12th postnatal week, the infant has become able to maintain the alert state during much of the daytime hours. This ability still depends heavily upon external stimulation, much of it provided by the caregiver.

Within the waking state, the level of alertness varies over time. The ability of a person to sustain attention is frequently measured by examining variations in performance on a task over a relatively extended period of time, such as the Continuous Performance Tasks (CPT). In the CPT a person must respond to occasional targets while ignoring more frequent non-targets. Variations in the level of alertness can be observed by examining the percentage of correct and/or omitted responses to targets or through measures of perceptual sensitivity (*d’*) over time. With young children, the percentage of children able to complete the task can also indicate maturational differences in the ability to sustain attention. In a study conducted with preschoolers, only 30% to 50% of 3 to 4 year olds were able to complete the task, whereas the percentage rose to 70% for 4 to 4 ½ year olds and close to 100% above age 4 ½ (Levy, 1980). Even though the largest development of vigilance seems to occur during the preschool period, adults continue to show greater ability to sustain performance then children through middle and late childhood, especially under more difficult task conditions. They do not reach the adult level until approximately 13 years of age (Curtindale, Laurie-Rose, Bennett-Murphy, & Hull, 2007). This development may have important implications for parents and others who expect a child can pay attention over extended periods even when the brain’s networks do not yet support it. The slow development of the alerting and executive network may caution parents about unrealistic expectations for their child’s control of attention.

Preparation obtained from warning cues (phasic alertness) can be measured by comparing the speed and accuracy of response to targets with and without warning signals (Posner, 2008). Presentation of warning cues prior to targets allows the person to get ready to respond by increasing their state of alertness. This commonly results in faster responses, although it may also cause declines in the accuracy of the response, particularly at short intervals between warning cue and target (Posner, 1978). The warning signal interrupts the resting state and improves alerting. The brain networks active at rest and during attentive states are quite different (Raichle, 2009).

One way to examine brain changes following a warning is by registering patterns of brain-generated electrical activation (EEG) through electrodes placed on the scalp while warning cues are processed. Typically, several hundred milliseconds after a cue predicting the upcoming occurrence of a target there is a negative variation of brain activity that is sustained up until the target appears (Walter et al., 1964). This electrophysiological index is called the *Contingent Negative Variation* (CNV) and it appears to be related to a source of activation in the anterior cingulate cortex and adjacent mid prefrontal cortex (Segalowitz & Davies, 2004). The CNV and other slow waves have been related to changes from the resting state to the attentive state using fMRI (Raichle, 2009). The amplitude of the CNV increases with age, especially during middle childhood. as observed over the right hemisphere (Jonkman, Lansbergen, & Stauder, 2003) The early components of the CNV arise in frontal cortex, suggesting that the CNV is related to maturation of the frontal aspects of alerting network.

Deficits in the alerting network have been identified as a cause of Attention Deficit Disorder (Halperin & Schultz, 2006). This is one reason for the frequent warning to parents to insure good sleep patterns in their children, since sleep deprivation impairs the maintenance of the alert state. Frequent breaks during tasks may also be useful in helping to maintain the alert state in young children.

*Orienting*

Orienting to sensory information involves a brain network that includes the dorsal and ventral parietal lobe, frontal eye fields and subcortical areas including the pulvinar and superior colliculus (Corbetta & Shulman, 2002; Petersen & Posner, 2012). While orienting is most often studied using visual events, the source of orienting seems to involve the same brain network irrespective of sensory modality. However, the site at which attention influences input depends upon the input modality.

For visual events, the most frequent method of studying orienting in infancy involves the tracking of saccadic eye movements. As in adults, there is a close relation, but not identity, between the direction of gaze and the direction of the infants’ covert orienting . Eye movements can be driven by external input from birth (Richards & Hunter, 1998); however, the system continues to improve over many years in making precise movements directly to the target. Infant eye movements often fall short of the target, requiring a series of sort movements before reaching the fovea where vision is most acute (Clohessy, Posner, & Rothbart, 2001). Although not as easy to track, a shift of attention via the orienting network without eye movements (covert orienting) likely follows a similar trajectory. Studies have examined the covert system by use of brief cues that do not produce an eye movement followed by targets that do, showing that the speed of the eye movement to the target is enhanced by the cue and this enhancement becomes greater over the first year of life (Butcher, 2000). In more complex situations, for example, when there are competing targets, improvement may continue for longer periods.

For newborn infants, control of orienting is initially largely in the hands of the caregiver. By 4 months, however, infants have gained considerable control in the ability to disengage their gaze from one visual location and move it to another, and greater orienting skill in the laboratory is associated with lower temperamental negative emotion and greater soothability as reported by parents (Johnson, Posner, & Rothbart, 1991).

Orienting to sensory input is a major mechanism for regulation of distress. Infants often have a hard time disengaging from high spatial frequency targets and may become distressed before they are able to move away from the target. Caregivers may then attempt to soothe their infants by bringing their attention to novel objects. As infants orient, they are often quieted, and their distress appears to diminish. In one study (Harman, Rothbart, & Posner, 1997), infants were first shown a sound and light display and often became distressed, but when oriented to an interesting competing event, however, their signs of distress disappeared. As soon as orienting to the novel object stopped, however, the infants’ distress returned to almost exactly the levels shown prior to presentation of the soothing object. An internal system, which was termed the *distress keeper*, appears to hold a computation of the initial level of distress, so that it returns if the infant's orientation to the novel event is lost. Interestingly, infants were quieted by distraction for as long as one minute, without changing the level of increased distress reached once orienting to the distracting stimulus ended (Harman, Rothbart, & Posner, 1997).

Infants develop the ability to orient attention to external stimulation early in life, yet aspects of the attention system that increase the precision and voluntary control of orienting continue to develop throughout childhood and adolescence (Rueda et al 2004). Most infant studies examine control of eye movements. By the time children can follow instructions and respond to stimulation by pressing keys, both overt and covert orienting can be more easily measured. The cuing task has been widely used to study the development of visual orienting over the life span, and several studies have examined the development of orienting during childhood. Despite a progressive increase in orienting speed to valid cues during childhood, data generally show no age differences to the benefit in orienting provided by the cue between 5-6 years of age and adulthood (Enns & Brodeur, 1989). There is an age-related decrease in the time to disengage from a false cue and shift to the target (the cost of orienting; Enns & Brodeur, 1989; Schul, Townsend, & Stiles, 2003; Wainwright & Bryson, 2002). Aspects of orienting related to control of disengagement and voluntary orientation, which in adults depend on cortical regions of the parietal lobe, improve with age during childhood.

Resting state brain imaging data can be used to measure functional connectivity by calculating correlations between areas that are active during imaging. These studies have indicated that the orienting system shows greater connectivity during infancy than do brain areas associated with the executive attention network (Gao et al., 2009). Connections change over the life span. Infants show mostly local connections and children age 9 also show many shorter connections than do adults. Adults show more segregation of the orienting and executive attention networks and longer connections for both (Dosenbach et al., 2007; Fair et al., 2007, 2008). While there is evidence that younger participants move more and this could reduce the ability to image long connections (Power, Barnes, Snyder, Schlaggar, & Petersen, 2012), in our view it seems unlikely that this artifact will change the conclusions discussed above.

An important landmark for parents is the occurrence of joint attention (Mundy et al., 2007), when the developing child begins to pay attention to what the caregiver is attending to. Usually achieved during the first two years of life, this allows the parent to provide labels for the object to which they attend, and can greatly expand the child’s vocabulary. Unlike the acquisition of phonemes described previously, the child at this age does not orient to the parent’s mouth, but rather the parent and child orient to a common object of attention. There is some controversy over whether joint attention is sufficient to associate a word with its object (Smith & Yu, 2014) or whether some additional associative process is needed. In adults, it is clear that learning and retrieval of word meanings involves the executive system (Petersen & Posner, 2012). Since the executive network is becoming increasingly connected during the preschool years it is likely to be more involved in this form of word learning.

Joint attention is one example in which the presentation of novel objects aids the child in learning words. An imaging study (Eggebrecht et al., 2017) scanned 37 children at both 12 and 24 months during the child’s effort to initiate acts of joint attention. The connectivity found between the visual system and the fronto-parietal orienting system during initiation of joint attention increased between 12 and 24 months. There was no significant involvement of the cingulo-parietal (executive attention) network. However, if learning a new association between a visual object and its name is an outcome of joint attention, as suggested by Smith and Yu (2014), executive attention would also become involved. (Petersen, Fox, Posner, Mintun, & Raichle, 1987).

We have outlined a transition between the brain networks responsible for control in infancy and those at 3-4 years and later. At 7 months, control, including the regulation of distress (Rothbart, 2011) mainly involves the orienting network, but by 4 years, the executive network becomes dominant in self regulation. We do not believe that control through orienting ends with the preschool transition. We view adults as having dual control. Looking away from disturbing or highly arousing events is clearly a major coping strategy in adults (Rothbart & Sheese, 2007), and orienting is often a critical element in training attentional control as in meditation. However, the growing influence of executive control allows the person’s internally controlled goals to become increasingly dominant.

*Executive Attention*

In adults the executive attention network involves the anterior cingulate gyrus and the anterior insula (also called the cingulo-opercular network in fMRI studies (Petersen & Posner, 2012). These two areas of the human brain have a unique projection cell. This cell, the Von Economo neuron (Allman, Watson, Tetreault, & Hakeem, 2005), is thought to be important in communication between the cingulate and other brain areas. This neuron is not present in macaque monkeys and expands greatly in frequency between great apes and humans. The two brain areas in which Von Economo neurons are found are also in close communication, even during the resting state (Dosenbach et al., 2007). Moreover, there is some evidence that the frequency of the von Economo neurons increases between infancy and later childhood (Allman et al., 2005). There are other important differences in the evolution of connectivity between non-human primates and humans. Anatomical studies show a great expansion of white matter, which has increased more in recent evolution than has the neocortex itself (Zilles, 2005). In our view, the Von Economo neuron and the rapid and efficient connectivity it provides, is a major reason why self-regulation in adult humans can be so much stronger than in other organisms. We also think the relatively slow development of long-term connections to distant brain areas allows the executive network to provide increasing control at later ages.

It is difficult to assess executive attention in infants because as outlined above, caregivers provide most of the regulation of infant behavior. Effortful control is a high level factor derived from parent reports on children’s temperament (Rothbart & Rueda, 2005). This factor is defined as the ability to withhold a dominant response in order to carry out a non-dominant one. Parents observing their children’s specific behavior in daily life situations (for example, putting away toys on command, etc.) can readily respond to questions that relate to this factor. This can be done for children about 2 years of age and older, although aspects of orienting and emotion can be measured from early infancy (Rothbart, 2011). Below two years of age, temperament observations include scales like orienting, fear, anger, soothability and positive affect (Rothbart, 2011). Children above age 3-4 can perform tasks that involve voluntary responding, such as pressing keys to visual input. In multiple studies, higher EC in questionnaire measures is positively correlated with more efficient performance in resolving conflict in laboratory tasks (executive attention) (Rothbart & Rueda, 2005).

The problems in measuring control by the executive attention network during infancy had led us to believe that the executive network was not present until about age 3-4. While it is clear that some voluntary control is exercised in infancy, for example, 4 month old infants can make antisacades (Johnson, Posner, & Rothbart, 1994), it is possible to attribute that control to the orienting network. However, we were able to obtain direct evidence of executive attention in infancy from a study of 7-month-old infants viewing visual displays (Berger, Tzur, & Posner, 2006; Wynn, 1992). Infants orient longer when a display is in error (Wynn, 1992) and this behavior was associated with activity in a set of EEG electrodes at the frontal midline that localize to the anterior cingulate, an important node of the executive network. The typical regulation of behavior found in adults, that is, to slow down following an error, seemed not to emerge until about age 3 years (Jones, Rothbart, & Posner, 2003).

We have followed the emergence of executive attention from infancy to later childhood by using anticipatory looking in a visual sequence task (Clohessy, Posner, & Rothbart, 2001; Haith, Hazen, & Goodman, 1988). In this task , visual stimuli are placed in front of the infant in a fixed and predictable sequence of locations. The infant’s eyes are drawn reflexively to the stimuli at these locations because they are designed to be attractive and interesting. After a few trials, some infants will begin to anticipate the location of the next target by moving their eyes prior to the target presentation. Anticipatory looking occurs with infants as young as 3.5 to 4 months (Clohessy, Posner, & Rothbart, 2001; Haith, Hazen, & Goodman, 1988). However, a sequence can also involve conflict when the correct move depends on the present location of fixation. For example, consider the sequence 1,2,1,3. When fixated at position 1 there is a strong conflict between position 2 and 3 requiring a memory of where one was before moving to 1. The ability to correctly anticipate during conflict does not occur until about 18-24 months of age (Clohessy, Posner, & Rothbart, 2001).

Correct anticipation in conflict trials, however, did not allow a clear determination of whether the orienting or the executive network was controlling the responses, even when they involved anticipations. However, in a later study of 18-24 month olds the error related negativity (ERN) following an incorrect response was found to be related to childrens’ performance in the sequence learning task, and both the ERN and sequence learning predicted childrens’ performance on an executive attention task at age 2 and questionnaire measures of effortful control at age 3 (Barbero, 2016).

At three years of age we used the Spatial Conflict Task (Gerardi-Caulton, 2000) which induces conflict between the identity and the location of an object. On some trials the response key that matched the target identity was on the same side of the screen (compatible) and some on the opposite side (incompatible). At three years, the ability to respond correctly when there was conflict in the sequential looking task was related to the ability to resolve conflict in the Spatial Conflict task (Rothbart, Ellis, Rueda, & Posner, 2003). Recall that we also found at age 3-4 errors made in a conflict task began to produce slowing on the following trial. These findings converge to demonstrate that conflict is resolved by the slow development of the executive attention network during early life.

An important fMRI study (Fjell et al., 2012) involved 750 participants from 4 to 21 years of age and used a task in which a visual target is surrounded by either congruent or incongruent flanker stimuli. The participants needed to resolve conflict between the target and flankers in the incongruent condition, and the ability to resolve such conflict is a measure of the efficiency of executive attention. Up until 7 years of age, the size of the right anterior cingulate was the best predictor of childrens’ ability to resolve conflict, as measured by reaction time differences between congruent and incongruent flankers. In the same study, diffusion tensor imaging (DTI) suggested that overall reaction time (RT) is most related to the efficiency of white matter connections. This study supports the anatomy results described previously in illustrating the importance of white matter connectivity between the anterior cingulate and other brain areas as a key component of self-regulation.

The development of executive attention has also been traced into the primary school period (Rueda et al., 2004), using RT to incongruent flankers to measure children’s ability to resolve conflict. Overall, children’s reaction times were much longer than adults, but considerable development in the speed of resolving conflict was observed from age 4 to about 7 years of age. The ability to resolve conflict on the flanker task, as measured by increases in RT and errors with incongruent compared to congruent flankers, remained about the same from age seven to adulthood. When the difficulty of the conflict task is increased by other demands, however, such as switching rules or holding more information in working memory, further development of conflict resolution is found even between late childhood and adulthood (Davidson, Amso, Anderson, & Diamond, 2006).

The findings to date suggest that orienting is playing some of the regulatory roles in early infancy that will later be exercised by the executive network. Parenting may also play an important role in the early development of the executive attention network, perhaps partly through the presentation of novel objects that have been shown in adults to activate the executive network (Shulman et al., 2009). Parent emotional availability may also be important in the early development of executive attention. One study of five year olds, using a go-nogo RT task, a measure of delay of gratification and a third task requiring following complex rules, found that children whose parents showed high emotional availability had better scores in the last two tasks and more efficient networks related to the go-nogo task, although in this task there was no difference in performance (Shneider-Hassloff et al., 2016).

*Attention and the Control of Emotion*

The ventral portion of the anterior cingulate (ACC) and adjacent orbital frontal cortex connects mainly to limbic regions and its function as would be expected from it sconnections is related to the control of emotions (Bush, Luu, & Posner 2000; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). The more dorsal part of the cingulate connects more strongly to cortical areas in the frontal and parietal lobes and thus to cognitive control. There is evidence of increased connectivity between the dorsal ACC and auditory areas when attending to speech, whereas switching to visual input is reflected in increased connectivity between the ACC and occipital lobe (Crottaz-Herbette & Menon, 2006). The developmental data cited in the last section (Perlman & Pelphrey, 2001) and some new adult findings (Jahn, Nee, Alexander, & Brown, 2016) support separate functions for the ventral and dorsal ACC and show that both develop strongly between 5 and 8 years of age. There is further evidence of some substantial overlap in the ventral ACC between negative emotion and cognitive control suggesting these two functions are not always separate (Shackman et al., 2011).

Parent reports of their 7 month old infants’ positive affect are related to reports of infants’ duration of orienting and predict the later to resolve conflict at age 7 (Posner, Rothbart, Sheese, & Voelker, 2014). Research suggests that even at 9-10 months, some aspects of sustained orienting can involve the executive system. For example, Kochanska, Murray and Harlan (2000) found that children’s focused attention observed in the laboratory at 9 months predicted measures of their effortful control in preschool.

Studies of resting state MRI at birth suggest early development of a node in the mid-prefrontal cortex adjacent to emotional control parts of the ACC (Gao et al., 2009). These findings provide some support for the idea that emotional control develops more quickly than cognitive control during early life, although there is strong overlap in their later development. While the data are not completely clear on this point, it is of obvious important for parents to foster the development of emotional control during infancy through soothing and other methods.

*Executive Control and Adolescence*

One striking feature of adolescent behavior is the tendency toward high levels of risk tasking such as drug and alcohol abuse, accidental death, and unprotected sex (Eaton et al., 2008). These behaviors appear to depend in part upon the relative speed of maturation of frontal control systems as opposed to striatal reward systems. According to this view, the activation of the reward systems can overwhelm the ability of cognitive and emotional controls in this age group.

One illustration of this idea is found in a study of children, teenagers and adults in a go, no-go task involving the presentation of happy, sad or neutral faces (Casey, Galvan, & Somerville, 2016; Somerville, Hare, & Casey, 2011). While the three ages had similar correct responses, the teenagers made more false alarms, that is, they more frequently pressed the key when a non-target was presented, than younger or older ages. A brain scan conducted during this task showed greater activity in teens than other ages in the ventral striatum, an area of the brain related to reward processing. The right ventral frontal area was mainly activated in no-go trials, and was thought to be involved in the actual inhibition of a response; activation in this area declined linearly with age and was positively correlated with false alarms. The authors interpret these findings as suggesting a stronger influence of reward stimuli on the teen age brain than found at other ages. However, there is later evidence that during the teen age years there is a change from control by the ventral (emotional) to more dorsal (cognitive) midline areas, suggesting an increase in cognitive control during the teen age years (Silvers et al., 2016).

A different methodological approach is to examine resting state MRI across ages. Although there are many methodological issues in comparing different ages, including possible changes in amount of movement in the scanner, it appears that ventral striatal reward areas show greater activity during the adolescent years than for children and adults. The ventral striatum is one of the few brain areas in which the task related activation discussed in the previous paragraph converges with the resting state data (Stevens, 2016).

While there are inconsistencies between many studies of brain changes in adolescence (Stevens, 2016), the data so far suggest that risk taking may be due to a stronger striatal reward activity than at other ages. It will be important for future studies to employ longitudinal studies to relate earlier effortful control to the ability to manage the transition to adolescence

*Genes and parenting*

In this chapter, we have examined how brain networks develop in the life of the infant and child. This analysis has focused on behaviors involved in attending, understanding speech and reading. While these networks are common to all humans, they also differ in efficiency. Part of this difference depends on genetic variations known to exist among individuals and in part upon differences in cultural or individual experience. One approach to research in this area is to outline interactions between genes and parenting, since parents are most frequently the primary social contact for infants and young children.

The Attention Network Test (see Figure 8.1) was used to discover genetic variations that influence various attentional networks (see Table 8.1). Because each network was primarily associated with one or two neuromodulators it was possible to test whether genetic polymorphisms linked to their function influenced the speed of responses associated with that network. This provides much more than the usual association of genes with a task because each network is specially related to a set of genetic variations, Table 8.1 shows the results of these studies with adults, which provided our choice of the genes to study in infant and child development. The association of the executive attention system with dopamine (see Table 8.1) suggests genes related to dopamine transmission might be important in the development of attention networks.

Insert Table 1 about here

One gene identified is the dopamine 4 receptor gene (DRD4). The 7-repeat allele of the DRD4 gene has been linked to ADHD and to the temperamental dimension of risk taking. There has been considerable evidence that the environment in the form of mother’s sensitive parenting, can have a strong influence in the presence of the 7-repeat alleles but not when it is absent (Bakermans-Kranenburg & van Ijzendoorn, 2006; van Ijzendoorn & Bakermans-Kranenburg, 2006). The same group (Bakersmans-Kranenburg et al., 2008) also performed a parent training intervention. The intervention sought improvement in parental sensitivity to their children and to increase and improve interactions between parents and child. It was found that training decreased children’s externalizing behavior, but only for children with the DRD4 7 repeat allele. This finding is important because assignment to the training group was random, insuring that the result was not due to something about the parents other than the training.

In a longitudinal laboratory study (Sheese, Voelker, Rothbart, & Posner, 2007), raters observed caregiver/child interactions and rated the parents on five dimensions of parent quality according to a schedule developed by NIMH: support, autonomy, stimulation, lack of hostility and confidence in the child. Although all of the parents were likely concerned and caring, they did differ in their scores. We divided the combined scores at the median into two groups. One of the groups was considered to show a higher quality of parenting, and the other a lower quality.

We found a strong interaction between genes and parenting. For children without the 7-repeat polymorphism, variations in parenting were unrelated to the children’s scores on impulsivity and risk taking. For children carrying the 7-repeat gene variant, however, variations in parenting quality mattered. Children with this allele and high quality parenting showed normal levels of risk taking, but those with lower quality parenting showed very high values for risk taking (Sheese et al., 2007).

How could variation in genetic alleles lead to enhanced influence of cultural factors like parenting? The anterior cingulate receives input on both reward value and pain or punishment, and this information is clearly important in regulating thoughts and feelings. Dopamine is the most important neuromodulator in these reward and punishment pathways. Thus, changes in the availability of dopamine could enhance the influence of signals from parents related to reward and punishment.

We also found that the COMT genotype showed an interaction with parenting quality. However, unlike the DRD4, it operated through the attention even at age 2. The relation of the COMT gene to attention may help to explain the contribution of this gene to both stability and flexibility in the behavior of 7 month old infants (Markant, Cicchetti, Hetzel, & Thomas, 2014). Those infants with the Val allele were faster to reach for novel toys during the motor approach task and received higher scores on the temperament measure of approach to novelty. Those with the Met allele showed enhanced dishabituation to the novel stimulus during the habituation task and received higher scores on the temperament measures of sustained attention and behavioral regulation.

It is important to consider the multiple mechanisms by which genes may influence behavior. One method of doing so would be to examine how genes influence children’s brain networks that have been shown to be related to parental variables such as maternal sensitivity (Swingler, Perry, Calkins, & Bell, 2014). Clearly one important mechanism lies in the executive attention network we have been discussing in this chapter, but other pathways may also influence behavior. Although genes clearly have important effects on child behavior it is important to recognize that many genes, often with small individual effects, are involved. These small effects and the presence of GXE interactions make predictions for genes to later behavior *very difficult.*

GxE influences are currently being studied across a broad array of genetic variants and environmental events. A review reporting failure of replication for some the early findings included a plea that there be more theory driven research in this area (Weeland, Overbeek, de Castrow & Mathys, 2015). The attention based approach described here is theory driven, but in looking for the meaning in GxE interactions, they are often interpreted in terms of temperamental variability.

Behavioral research on temperament and its relation to children’s outcomes has been reviewed by Rothbart and Bates (2006) and Rothbart (2011). In these reviews, early distress proneness was found to predict later problem behaviors, with irritable distress (anger) predicting both internalizing and externalizing problems and fearful distress predicting only internalizing problems. Interactions of temperamental distress proneness with environmental measures have also been found. Distress prone children show more negative effects of low quality parenting, poverty and adversity than children who are not distress prone.

Temperamental Surgency (active, sensation seeking and approach tendencies) predicts externalizing problems and more surgent children have more positive outcomes than less surgent children raised in institutions. Effortful control, linked to executive attention seems to generally predict positive outcomes. Effortful control is an important moderator of negative outcomes, with effortful control predicting lower negative outcomes of poor environments or low quality parenting.

*Interventions*

In this section, we consider two general types of interventions that may assist in the development of attention and perhaps other cognitive functions. One form of intervention is called network training because it involves training in a particular cognitive task or computerized game. A second form of training, called state training, involves reaching a brain state that will foster attention and self-regulation. State training includes aerobic exercise (Hillman, Erickson, & Kramer, 2008) and mindfulness meditation (Tang & Posner 2009), Both network and state training interventions often require the involvement of parents, and in some cases the parent is trained to carry out the intervention (Neville et al., 2013).

Many studies of training executive attention have been carried out in children (Diamond & Lee, 2011; Rueda et al., 2005; Rueda, Checa, & Combita, 2012), using computerized exercises designed to improve conflict resolution (Rueda et al., 2005, 2012), or through more general school curricula designed to exercise aspects of executive functions (Diamond & Lee, 2011). These studies have often demonstrated improvement in executive attention tasks (Diamond & Lee, 2011) as well as transfer to cognitive tests such as IQ (Rueda et al., 2005, 2012). While there is evidence that self-control scores in childhood can predict adult performance (Moffit et al., 2011) there are no studies showing that direct training of the executive network in children can improve adult outcomes. Although most of the work on training using video games has been done with adults and most of the work on school curricula has been done with children, there is little evidence that training is limited to any one age.

The issue of generalization of network training has been much disputed (Posner, Rothbart, & Tang, 2015). Successful generalization of network training methods has been reported more consistently for very young participants and for the elderly (Rueda et al 2012; Posner et al 2015), with less evidence for generalization among young adults. In addition, children raised in poverty or low SES have more frequently been found to improve with training (Lipina & Posner, 2012; Neville et al., 2013). Although there is some evidence that participants with poorer initial scores show more improvement from attention training (Rueda et al., 2005) the extent and generality of these finding is not yet clear.

Meditation is a state training method that works to resist mind wandering and produce an attention focus. Five different styles of meditation have been involved in over 400 clinical trials (Ospina et al., 2008), but one style of meditation, mindfulness meditation, has shown effectiveness in improving attention, mood and stress (Tang et al 2007) and dominates current studies. Mindfulness meditation involves a set of mental practices designed to achieve control over the direction of attention. This is done by either focusing on a specific content (e.g., ones’ breathing or a word or mantra) or by achieving a relaxed state in which attention is brought back from wandering, but is not focused on a particular content. Recent meta-analyses on the effects of meditation (Sedlmeier et al., 2012), have reported functional changes in brain activation and structural changes in brain gray and white matter after training (Cahn & Polich, 2008; Fox et al., 2014; Vago & Silbersweig, 2012). The meditative state is often accompanied by changes in measures related to autonomic activity, which can be used as a biomarker for monitoring meditative states (Cahn & Polich, 2008; Vago & Silbersweig, 2012). The central nervous system also undergoes changes following meditation training. Consistent structural changes reported in a meta-analysis of meditation studies (Fox et al., 2014) have been found in the ACC and insula parts of the executive attention network (Petersen & Posner, 2012). Recently longitudinal studies of adults over periods of a week to several months have compared mindfulness meditation training compared to relaxation training (Tang et al., 2007, 2010). These studies allow random assignment of participants to conditions and can attribute cause to the training. They have found evidence of white matter changes surrounding the ACC, along with improved executive attention, and lowered stress in the training group (Tang et al., 2007).

# Limitations and The Future

The studies cited here most often include only a brief and blurry snapshot of the complex changes that occur over development.. Our picture of the human brain is as yet very incomplete and subject to many methodological difficulties. Two major methods for examining development by use of MRI are resting state MRI and task specific MRI. The findings from these two methods have not yet been integrated to achieve a more complete view of how the brain changes in development, and neither method has been well integrated with genetic studies. Nevertheless, in this chapter we have been able to examine some of the tools for studies of the human brain and mind during development. These tools may allow a deeper understanding of how the developing brain makes possible the changes in language and in attention that occur early in life. Future research should allow us to use these tools to understand how developmental changes in functional activation and connectivity relate to the specific behavioral markers at the same age. For example, how do changes in brain activation relate to differences found in functional connectivity and in the volume of white and grey matter? Is there a fixed order of these changes, or does their speed and order depend on whether they result chiefly from development or from practice on a task? Better coordination of human and non-human animal work may also allow us to determine the relationship of changes found with non-invasive imaging to those seen in studies of the microanatomy and circuitry of brain areas in animal research.

Of particular difficulty is knowing what aspects of change in the brain are related to which behavioral consequence, especially when the differences are based on adversity, SES or poverty. A few years ago neuroscience viewed human brain plasticity as questionable. Now grey and white matter changes are known to occur with experience and with new learning, but we are unsure about what kind of brain changes produce many of the very obvious behavioral changes found in infancy and childhood.

Longitudinal studies could allow us to better trace out this relationship. To do so may require the use of methods that remain relatively stable across ages. Resting fMRI allows testing different ages without the need to develop comparable tasks for different ages (Fair et al., 2009). The discovery that the EEG signal for error detection involves similar brain areas at 7 months as it does for adults provides another means of examining an event that may be comparable across differences in age. The greater use of analytic behavioral observations (e.g., anticipatory eye movements, the Attention Network Test) and parent observation of temperament may foster the mapping of changes in mental operations and behavior to brain changes. The growing knowledge of genetic and epigenetic methods have only just begun to influence research in human development. Genetic variation has been related to individual differences in behavior (Posner et al., 2014). Moreover, it seems likely that the genes related to individual differences in the three networks are also involved in building the common networks underlying attention in all people. Thus studies designed to relate the expression of these genes to key aspects of behavior would aid us in understanding how genetic variation influences the individual neural networks that underlie developmental differences.

While we know that some genetic variants interact with environmental experience in producing outcomes, we do not yet know the mechanisms involved, since genetic variations are expressed at numerous places in the brain and often in a number of places in the body. As the mechanisms by which genes can be altered by the environment are enlarged in the field of epigenetics we may learn more about how training has its influence on development.

# Summary and Conclusions

The language by which children communicate and shape their own verbal thoughts is provided by the language they hear from their caregivers. As we have seen in this chapter, during infancy the phonemic base of the native language is solidified in a way that can be measured from scalp electrodes and in turn shapes later speech and the acquisition of literacy. This is likely achieved by improved communication among neurons that encode the various sounds representing phonemes in the native language (Kuhl, 2010). At the same time non-native phonemes become weaker as their representations are not subject to such improvement.

The conversion of self-regulation from an orienting (frontal-parietal) to an executive (cingular-opercular) network may be influenced by events such as the presentation of novel objects during early infancy (Shulman et al 2009) and the somewhat later development of joint attention (Mundy et al 2007). These are among the ways in which the parents may be able to influence long range connections between neuronal areas that will eventually allow the executive network to control behavior in the service of the current goals of their child. The sensitivity of the parents to the emotional needs of their child interacts with the child’s genetic and temperamental endowment, and together they influencethe child’s behavior.

There is much we do not know. However, a better understanding of human brain development may help parents to provide an environment that takes advantage of the child’s native endowment and helps to compensate in cases where it might be lacking. The brain is a somewhat plastic instrument which, through interaction with the environment, allows the child’s capacities to be supported and strengthened.

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Figure 1 Caption

The Attention Network Test (ANT) is illustrated on the left of the figure

The test measures the efficiency of brain networks in children and adults by the speed of responding to whether a target stimulus points left or right. The bottom left column illustrates that the executive attention scores are calculated by the time to resolve conflict by subtracting the time to respond when all stimuli are in the same direction as the target from reaction time when incongruent stimuli are present. Alerting cues (top of column 1) indicate when the target will occur and orienting cues (middle of column 1) indicate where the target will occur. An alerting score is obtained by subtracting reaction times following a warning signal from those for unwarned trials. The orienting score is obtained from subtracting reaction times from trials indicating the target location from those without an orienting cue. The alerting, orienting and executive scores are related to the time course of brain activity by EEG (column 2), to the location of activation by fMRI (Column 3) and to chemical modulators (Column 4). Figure 1 is reprinted with permission from Rueda et al 2015.