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Contents

1 Origins of executive attention

Michael I. Posner and
Mary K. Rothbart

The work of Paul Baltes, which was recognized at this meeting, involves an understanding of individual differences in development over the life span. A major topic on which Baltes worked (Baltes & Kunzmann, 2004) was wisdom in the elderly. He recognized the importance of understanding the psychological components that form the basis of wisdom. The executive attention network is one such component. In this chapter we examine our work designed to discover the origins of executive attention in infancy, trace its anatomy, and examine how genes and experience influence its development.

The executive attention network is one of three neural networks involved in attention. These networks serve different functions, have different neural anatomies, and involve different neuromodulators (Posner & Fan, 2008; Rueda, Posner, & Rothbart, 2004). The first two networks, the alerting and orienting networks, involve maintenance of an alert state and orienting to attend to potentially meaningful incoming stimuli.

The third network, the executive attention network, functions to monitor and resolve conflict between information that is being processed by other brain networks (Botvinick, Braver, Barch, Carter, & Cohen, 2001). This conflict resolution function, which involves both the promotion and suppression of activation in other networks, may be central to conscious self-regulatory efforts. Because self-regulation plays such an important role in early child development, we have sought to understand the origins of self-regulation from several perspectives. We first examine changes in self-regulation during infancy. Then we consider how genes and environment shape this development. Finally we examine changes in this network late in life.

Developmental origins

Much of the work on attention networks rests upon our ability to image brain activity using methods like functional magnetic resonance imaging. This method is less available for use with infants and young children because of the difficulty in their keeping still. However, many studies of adults have shown that brain areas involved in attention and other cognitive functions give rise to electrical activity that can be sensed by scalp electrodes (Posner, Sheese, Odludas, & Tang, 2006). Our strategy for the study of development has been to use tasks similar to those found to activate attentional networks in adults and to monitor brain activity by use of large numbers of scalp electrodes. The patterns of electrical activity recorded from the scalp can then be related to underlying brain areas that are parts of the attentional network (Posner et al., 2006).

We (Posner & Rothbart, 2007) have been interested in how the attention system develops in infancy and early childhood. The development of executive attention can be easily assessed both by questionnaire and cognitive tasks after about 3 to 4 years of age. At this age parents can identify the ability of their children to regulate their emotions and control their behavior in accord with social demands. However, in infancy it has been difficult to pose questions that refer to effortful control because most regulation seems automatic or involves the caregiver's intervention. Obviously, infants cannot be instructed to press a key in accord with a particular rule.

Infancy

We have been examining executive attention in infancy to see whether we can predict later executive attention and effortful control from infant behavior. Detecting errors has been an important method for producing activation of the executive attention network (Bush, Luu, & Posner, 2000). One study examined the ability of 7-month-old infants to detect errors (Berger, Tzur, & Posner, 2006). In this study, infants observed a scene in which one or two puppets were hidden behind a screen. A hand was seen to reach behind the screen and either add or remove a puppet. When the screen was removed, infants of 7 months looked longer when the number was in error than when it was correct (Wynn, 1992)

Whether the increased looking time involved the same executive attention circuitry active in adults during error detection is unknown. Berger and colleagues (Berger, Tzur, & Posner, 2006) replicated the Wynn study, but they used 128-channel EEG to determine the brain activity occurring during error trials in comparison with that found when the infant viewed a correct solution. Results indicated that the same EEG component over the same electrode sites differed between conditions for both infants and adults. The adult data started to differ between correct and error trials around 200 ms in a component called the frontal N2. This EEG component has been shown to come from the anterior cingulate gyrus and/or surrounding mid-frontal areas (Dehaene, Posner, & Tucker, 1994). The infant waveforms showed the same departure between error and correct trials at about 300 ms. It is usual for infant electrical activity to be somewhat slower, but overall it appears that the same brain anatomy is involved as in adult studies. Of course, the result of activating this anatomy for observing an error is not the same as found in adults for self-made errors, where adults actually slow down after an error and adjust their performance. However, it suggests that even very early in life the anatomy of the executive attention system is at least partly in place.

Longitudinal study

Our most recent longitudinal study also began with infants of 7 months (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). We studied eye movements that occurred when attractive stimuli appeared in a fixed sequence of locations on a screen in front of the child. On most occasions the children moved their eyes to the stimulus, but on some occasions they moved their eyes to the location where the stimulus was about to appear prior to its presentation. We argued that these anticipatory movements represent an early form of executive attention, because they rely upon a voluntary response that anticipates the visual event. In support of the idea that the anticipatory movements reflected the executive attention system, we had previously found that 3.5-year-olds showed a correlation between performance in voluntary key press tasks and their correct anticipations when performing in the visual sequence (Rothbart, Ellis, Rueda, & Posner, 2003).

In the first session of our longitudinal study we used the eye movement task adapted from Clohessy, Posner, and Rothbart (2001). Infants were also given one task in which they were presented with novel objects and one in which they looked at novel but somewhat disturbing masks (Sheese et al., 2008). Correct anticipatory looks were related to more hesitant initial approach to the toys, including longer latencies to initial reaching and to longer duration of looking without physically touching the toy. Infants rated by their parents as higher in Extraversion also showed shorter latencies to physically engaging with the toys and higher frequencies of engagement. These results suggest that an early form of executive attention may allow for the dampening of positive affect and inhibition of related approach tendencies. Correct anticipatory looks were also positively related to greater use of sucking as a self-soothing mechanism during the mask presentation. These results indicate that anticipatory looking is related both to caution in reaching toward novel toys and to aspects of the regulation of distress in infancy. They also suggest that executive attention is present in infancy and can serve as one basis for the regulation of emotion.

Genetic and evolutionary origins

The 7 repeat allele of the DRD4 gene has been linked to ADHD and to the temperamental quality of risk taking. Adults and children with the 7 repeat allele have been shown to be higher in the temperamental quality of risk taking and to be at higher risk for attention deficit disorder than those with smaller numbers of repeats (Auerbach et al., 1999; Swanson et al., 2000).

In one series of studies (Auerbach et al., 1999) it was found that the orienting of 2-month-old infants as rated by parents and observed during inspection of toys was related to the presence of the 7 repeat allele of the dopamine 4 receptor gene. This allele appears to interact with a gene related to serotonin transmission (5HTT) to influence orienting.

Evidence that environment can have a stronger influence in the presence of the 7 repeat allele has been reported by others (Bakermans-Kranenburg & van IJzendoorn, 2006; van IJzendoorn & Bakermans-Kranenburg, 2006). In addition, the same group (Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, & Juffer, 2008) also performed a parenting training intervention and showed that the training decreased externalizing behavior, but only for those children with the DRD4 7 repeat allele. This finding is important because assignment to the training group was random, thus ensuring that the result is not due to something about the parents other than the training.

In our longitudinal study we used cheek swabs to extract DNA and determined the genetic variation in a dozen of the genes that had been connected to attention in the adult studies (Sheese, Voelker, Rothbart, & Posner, 2007). These children had been seen when they were 7 months old, but the genotyping took place when they returned to the laboratory at about 2 years of age. In addition, we added an observation of caregiver–child interaction in which the children played with toys in the presence of one of their caregivers. Raters observed the caregiver–child interaction and rated the parents on five dimensions of parental quality according to a schedule developed by NICHD (1993). Parent dimensions scored were: support, autonomy, stimulation, lack of hostility, and confidence in the child. Although probably all of the parents were concerned and caring, they did differ in their scores, and we divided them 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.

What we were interested in was whether parent reports of the child's impulsivity and risk taking were related to the child's carrying the 7 repeat allele of the DRD4 gene, the parent's scores on parenting quality, or an interaction of gene and parenting. We found a strong interaction effect. For children without the 7 repeat polymorphism, variations in parenting within the range we examined were unrelated to the children's scores on impulsivity and risk taking. For children carrying the 7 repeat gene variant, however, variations in parenting mattered.

It seems paradoxical that the 7 repeat allele associated with developmental psychopathology (attention deficit disorder) is under positive selective pressure in recent human evolution (Ding et al., 2002). Why should an allele related to ADHD be positively selected? We think that positive selection of the 7 repeat allele could well arise from its sensitivity to environmental influences. Parenting provides training for children in the values favored by the culture in which they live. For example, Rothbart and colleagues (Ahadi, Rothbart, & Ye, 1993) found that in Western culture effortful control appears to regulate negative affect (sadness and anger), while in China (at least in the1980s) it was found to regulate positive affect (outgoingness and enthusiasm). In recent years the genetic part of the nature–nurture interaction has been given a lot of emphasis, but if genetic variations are selected according to the sensitivity to cultural influences that they produce in children, this could support a greater balance between genes and environment. Theories of positive selection in the DRD4 gene have stressed the role of sensation seeking in human evolution (Harpending & Cochran, 2002; Wang et al., 2004). Our new findings do not contradict this emphasis but suggest a form of explanation that could have even wider significance. It remains to be seen whether the other 300 genes estimated to show positive selection would also increase an individual's sensitivity to variations in rearing environments. We will be examining additional longitudinal data to test these ideas further.

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. Another interaction has been reported between the serotonin transporter and parental social support on the temperamental dimension of behavioral inhibition or social fear (Fox et al., 2005). To explain this interaction, Fox, Hane, and Pine (2007) argue that those children with a short form of the serotonin transporter gene who also have lower social support from parents show enhanced attention to threat and greater social fear. In our study, however, we did not find that attention was the mechanism by which the genetic variation influenced the child's behavior. In our study there was no influence of the 7 repeat allele on executive attention: rather, the gene and environment interacted to influence the child's behavior as observed by their caregiver. It is important to consider the multiple mechanisms by which genes may influence behavior. Clearly one important mechanism lies in the executive attention network we have been discussing in this chapter, but there must be other pathways that influence the same behavior.

In more recent work we have found a gene–environment interaction that does work through attention. One of the strongest links between adult individual differences in executive attention and genes is the COMT gene (Blasi et al., 2005). Moreover a study of 7–14-year-old children (Diamond, Briand, Fossella, & Gehlbach, 2004) found a similar effect at this age. In most studies one genotype (Val/Val) shows better performance in a variety of tasks than does the other (Met/Met). Another approach to the gene has been to construct a haplotype consisting of three different polymorphisms in the gene. Versions of this haplotype have been shown to be closely related to the perception of pain (Diatchenko et al., 2005). Executive attention and pain have both been shown to involve the anterior cingulate gyrus.

In both 7-month-olds and 2-year-olds, the genotype and the haplotypes proved to have a relation to aspects of performance in the visual sequence task, and overall the haplotype was more strongly linked to performance. At 2 years of age it was possible to examine the relation between parenting as measured by the NICHD parent–child interaction (see previous section) and variations in the COMT gene (Voelker, Sheese, Rothbart, & Posner, 2009). An interaction was found between the genetic variation and parenting quality in determining performance in the visual sequence task. In particular those 2-year-olds with higher quality parenting and the haplotype that included the Val/Val genotype were superior in the task. This confirms that even during infancy, genetic variation can influence the executive attention network.

Experiential origins

The presence of large individual differences in attention starting early in life and the importance of parenting for behaviors such as activity level and impulsivity suggest that the ability of children to handle the school situation may depend upon the joint interaction of genes and environment. The relation of genetic factors to the functioning of the executive attention system does not mean that the system cannot be influenced by experience. Indeed, the gene–environment interaction discussed above suggests that sensitivity to the environment might be built into genetic variation. In addition, training-oriented programs have been successful in improving attention in patients suffering from different pathologies.

To examine the role of experience on the executive attention network, we have developed and tested a five-day training intervention using computerized exercises. We tested the effects of this training during the period of major development of executive attention, between 4 and 7 years of age (Rueda, Rothbart, McCandliss, Saccamanno, & Posner, 2005). We hoped to observe improvements in conflict resolution following training and adapted methods that had been used to train monkeys for work in space (Rumbaugh & Washburn, 2003). The training began with the children learning to use a joystick. First they moved a cat to the grass so as to avoid mud. Over trials, the grass shrank and the mud increased, requiring more careful control of the cat. These skills were then used to teach prediction, exercise working memory, and, finally, to give children practice in resolving conflict. Children who went through the training were compared with a randomly selected control group who were engaged with interactive videos.

Before and after training the children performed the Attention Network Test while their EEG was recorded. The children who had undergone attention training showed clear evidence of improvement in the executive attention network following training in comparison with the control children. As discussed earlier, the N2 component of the scalp-recorded averaged electrical potential has been shown to arise in the anterior cingulate and is related to monitoring or resolution of conflict (van Veen & Carter, 2002; Jonkman, Sniedt, & Kemner, 2007). We found N2 differences between congruent and incongruent trials of the ANT in trained 6-year-olds that resembled differences found in adults. In the 4-year-olds, the training seemed to influence more anterior electrodes that have been related to emotional control areas of the cingulate (Bush et al., 2000). These data suggest that training altered the network for the resolution of conflict in the direction of being more like what is found in adults.

We also found a significantly greater improvement in a measure of intelligence in the trained group compared to the control children. This finding suggested that training effects had generalized to a measure of cognitive processing that is far removed from the training exercises. The parents did not report changes in temperament over the course of the training, but this was expected because parents had only the short time between assessment sessions on which to base their ratings.

Recently a replication and extension of this study was carried out for 5-year-olds in a Spanish preschool (Rueda, Checa, & Santonja, 2008). Several additional exercises were added, and ten days of training were provided for both experimental and control groups. As in the previous study, the randomly assigned control group viewed child-appropriate videos for the same amount of time as the intervention group was trained. A follow-up session for all children was also given two months after the training. Unlike the control group, trained children showed improvement in intelligence scores, as measured by the matrices scale of the K-BIT, following training. In addition, the trained group maintained this improvement over the two months without further training, while the control group did not. Additionally, the training of attention also produced beneficial effects on performance of tasks involving affective regulation, such as the Children's Gambling Task (Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

We hope that our training method will be evaluated along with other such methods both as possible means of improving attention prior to school and for children diagnosed with ADHD and other attention-related disorders. However, we have no expectation that our exercises are optimal or even better than other methods. The study of attention training as a whole suggests that networks can be shaped both in informal ways and by formal training. With the availability of imaging and related methods it should be possible to design appropriate methods for children of various ages and with various forms of difficulty. Our studies certainly support the importance of educational designs in improving the lives of children.

Brain connectivity and life span development

Many studies of attention involve young adults, often undergraduates. The three networks described above have been examined in behavioral and genetic studies, and these have been summarized in several papers (Raz & Buhle, 2006; Posner & Fan, 2008). The infant and child studies described in this chapter are usually compared with studies of young adults in attempting to determine whether development or training of other variables are producing adult-like performance.

Of course, development does not end with young adults. There have been many studies documenting an increase in reaction time and a decrease in accuracy, and a reduction of problem-solving ability and fluid intelligence in elderly persons when compared to young adults (Salthouse, 2005). These are generally not longitudinal studies because of the years involved, and like all cross-sectional research they may be subject to bias in the selection of people at various ages. Despite this problem, studies using modern imaging methods carried out with elderly persons have provided some insight into changes that occur later in life that are closely related to the brain networks we have been examining.

In one study, Pardo et al. (2007) used positron emission tomography to examine metabolism in 46 persons 18–90 years of age. They asked which areas of the brain showed the clearest decline in metabolism with age. The strongest association was in the anterior cingulate gyrus. This decline in metabolism in the anterior cingulate may be a reason why aging brings difficulty in self-regulation. However, some studies of aging persons using the conflict score from the Attention Network Tests have found no increase in the time to resolve conflict with age, unless the participants had been diagnosed with Alzheimer's dementia (Fernandez-Duque & Black, 2006).

In another important study, Fair et al. (2009) showed that the connectivity between the anterior cingulate and more posterior brain areas when at rest was very poor in early childhood and showed a marked increase for older children and adults. In a study of resting connectivity in aging adults (Andrews-Hanna et al., 2007) it was also found that connectivity between midfrontal and posterior areas showed a marked decline in old age. While there was some overlap in strength of connectivity between younger and older adults, the most connected older adult was only at the mean of the younger adults.

There is also new evidence that meditation methods used to train adults can improve executive attention (Tang et al., 2007). Meditation can also be used with aged subjects. In this case, the connectivity reported to be reduced with aging (Andrews-Hanna et al., 2007) was found to be partly restored (Tang et al., 2010).

While genotype stays constant over the life span, the influence of genes may be even greater in old age than for younger persons. Nagel et al. (2008) examined the influence of the COMT gene on executive attention and working memory. They found genetic effects to be even stronger in the elderly than those found in younger adults.

Frontal white matter connectivity has a very long history of development in childhood and adolescence. Thus, overall, the studies of aging tend to support the general idea that connections between brain areas that develop slowly may be especially vulnerable to the influence of aging.

Aspects of executive attention appear to be present in infancy. There is also evidence of further development during childhood. We have found a role for genetic variation and for experience in this developmental process. At about 4 years of age parents can report on their child's effortful control, and we can use voluntary tasks such as the Attention Network Test to examine executive attention. We are currently carrying out studies at 4 years of age in our longitudinal sample. When this study is complete, we hope we will have additional data on this important development.

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