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The Expert Brain¹

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INTRODUCTION

I was very grateful to be at the symposium and to make this contribution to the volume celebrating the achievements of Bill Chase. Bill received his MA at the University of Wisconsin and I was fortunate enough to serve as his major adviser. His MA was a remarkable contribution to the study of visual search and he pursued these issues for his PhD after I left Wisconsin to go to Oregon. It was typical of Bill's high standards that little of this work was published at the time, although it did enter into several later papers. Bill was an empirical virtuoso capable of bringing high-level theory to test. When Bill moved to Carnegie Mellon, where Newell and Simon had done so much to bring theory to psychology, I felt strongly that important things would happen, and they did. Much of the most important work was in the field of expertise, which we examine in this volume.

This symposium is remarkably well timed. Bill Chase died in 1983 yet more than 25 years later his powerful contributions are even more at the center of the stage than they were at the time of his death.

THE PSYCHOLOGY OF CHESS

The essence of Bill's contribution can be seen in the quote below from his chapter in the 1973 volume he edited (Chase & Simon, 1973, p. 279).

¹ This chapter was presented at the Chase Memorial Symposium, May 2009. The research presented in this chapter was supported by by NICHD grant 060563 to Georgia State University.

IN JAMES J. STASZEWSKI EDITOR

EXPERTISE AND SKILL ACQUISITION:
THE IMPACT OF WILLIAM G. CHASE
New York: Psychology Press Ch. 11

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brain imaging might contribute to secondary and higher education. Although there is much we do not know about how the brain achieves expertise, many may be surprised that there is already knowledge of how brain networks change with experience. Although these ideas have not often been applied to the high levels of training involved in chess (but see Righi, Tarr, & Kingon, Chapter 12 in this volume), in this chapter I try to extrapolate from what is known about the development of attention and other networks to imagine how genes and experience shape high-level skills like chess.

BRAIN MECHANISMS OF EXPERTISE

This volume is primarily concerned with the study of expertise from a strictly psychological viewpoint, but it is also true that among the many things that have happened since Bill Chase's work is an enhanced understanding of brain networks. This understanding was aided by methods for examining the human brain by changes in blood flow and blood oxygenation, which together have been called neuroimaging (Posner & Raichle, 1994). The ability to localize areas of brain activity has also revitalized non-invasive electrical and magnetic methods because it is possible to relate the two approaches and thus specify brain networks in terms of both localized brain activity and the time course of their activation. As we have pointed out elsewhere, this combination has led to the specification of brain networks related to many human activities (Posner & Rothbart, 2007). Moreover, studies which image the brain before and after learning have shown that experience can lead to sharpening the efficiency of these networks by tuning the neurons at various nodes of the network to increase their ability to carry out localized computations. Experience also strengthens the connectivity between nodes of the network, which further improves their efficiency (Tang, et al., 2010).

Two aspects of these networks are somewhat more controversial. One is the issue of what is localized. I believe that the bulk of the evidence supports the idea that these networks localize computations related to the task being performed and the overall task is orchestrated through connections between these localized brain areas. This view has certainly been supported in the areas of orienting of attention (Corbetta & Shulman, 2002; Hillyard, Di Russo, & Martinez, 2004) and as an approach to the computations involved in language (Posner & Raichle, 1994). It is certainly possible and perhaps even likely that more complex reasoning and memory retrieval processes involve less specific localization (Duncan & Owen, 2000), but these differences may be more due to our weakness in correctly specifying the operations involved than they are to problems with localization. This view of localization by mental operations does not suggest that any task is local to a particular area because all tasks studied involve a limited number of widely scattered brain areas. Nor do we think there are an infinite number of mental operations, but assuming there is some localization can allow us to use both the logical methods of cognitive science and the methods of cognitive neuroscience to specify the mental operations needed to carry out even a complex task such as chess.

Common Categories

How does learning change brain networks? It is common for learning on a task to decrease the number and amount of activated brain areas (Durstun & Casey, 2006). In some cases learning reorganizes the brain areas involved and in some cases it leads to enlarged areas of activation (Kelly & Garavan, 2005). Connectivity of the network can also be enhanced by practice (McNamara, Tegenthoff, Hubert et al., 2007).

Some categories are common to all members of our species and we are all experts in tasks that demand their use. An example of a natural category is faces, which can influence the infant's behavior at birth. It is believed that perception of faces in the first few months depends primarily upon subcortical structures, but by 10 months there is clear evidence that infants are dealing with faces in ways that are somewhat similar to adults (Johnson, 2004). For adults, faces activate an area of the posterior part of the fusiform gyrus, particularly on the right side, which is called the fusiform face area (Kanwisher, 2000). This brain area is part of the visual system. It probably has a role in organizing the features of the face into a whole, so that the face can be recognized through processing by more anterior areas.

A more general function of this area has been discovered, because experts in categories other than faces tend to show activation of this area for the material (e.g., dogs, birds or automobiles) in which they are expert (Gauthier, Anderson, Skudlarski, & Gore, 1999). This finding demonstrates how the function of a brain area initially associated with recognition of one particular category may through training come to be used by other categories. In this volume it is shown that an area involving the fusiform gyrus is also recruited by chess experts (Righi et al., Chapter 12 in this volume).

A similar story related to expertise underlies the visual word form area. The word form area occupies a part of the fusiform gyrus that is mainly in the left hemisphere, and has been related to chunking visual letters into a unitary whole. A good example of the importance of this brain areas is revealed by the study of a patient who, when a word was presented to the left of fixation, could only sound out the letters one by one taking many seconds to read a single word, but he could read the word fluently when presented to the right of fixation (i.e. to the left hemisphere where the word form area is located) (Cohen, et al., 2004). Imaging showed that there was interruption of the fibers that conducted information to the visual word form area from the right hemisphere occipital lobe. When words were presented to the left of fixation (i.e. directly to the right hemisphere), the patient could sound them out letter by letter although he clearly maintained his reading skills as evidenced by his performance with words presented to the right visual field (i.e. directly to the left hemisphere) so that they did reach the visual word form area. This study shows clearly that the visual word form area is a necessary condition for fluent reading.

As in the case of faces, the word form area is not used exclusively for words. There is evidence that visual objects that are involved in rapid naming tasks can

use the same area. These findings suggest the importance of the operations performed by a particular brain area that move beyond any one kind of information. A particularly striking example of this plasticity is the use of the visual system in the recognition of Braille letters (Pascual-Leone & Hamilton, 2001). Although the visual system is specialized for visual stimuli, in this case, somatosensory information used in the service of language can utilize visual mechanisms.

The visual word form area is not part of an inborn category, but becomes tuned to processes that are learned with the acquisition of the skill of reading. This brain area represents a kind of learned expertise but one that is common to many people. It is reasonable to ask if newly learned arbitrary categories such as those involved in the processing of chess also involve posterior brain areas and do these areas operate automatically to structure what is seen or are they part of a larger problem-solving process?

Newly Learned Categories

A number of years ago Steve Keele and I used nonsense patterns of 9 dots all derived from a single prototype by various distortions rules in order to explore the learning of new categorical information (Posner & Keele, 1968). Participants learned to sort the patterns into categories represented by four different prototypes. Although the participants were never shown the prototype, they made false alarms to it, saying they had seen it before and prototypes were classified correctly as often as the learned exemplars. Many studies showed that this result might be predicted as well from storage of exemplars alone as from models based on representation of the category by the prototype. However, false alarm error in a recognition memory study suggested that prototype storage might be correct. As in many behavioral controversies, this one remained unresolved.

However, Knowlton and Squire (1993) showed that patients whose memory had been impaired by brain lesions were at a great disadvantage in remembering exemplars but dealt very well with the prototype. These studies suggested that extraction of the prototype might not involve the mid-temporal brain regions found important for explicit storage. This general idea has been confirmed by neuroimaging studies (see Smith, 2008, for a review). Newly learned categories of a variety of visual material seem to produce activation of a posterior brain area often more strongly on the right side.

The idea that new learning builds a visual representation, highly abstracted as in the case of the prototype, from the input fits very well with one idea from the Chase and Simon work. It suggests that the chess master has within the visual system a sufficiently abstract representation so that a newly seen game of chess might be analyzed in terms of already known chess positions. However, for this to work to produce the memory of the chess master, it should work quickly and automatically, that is without any conscious intent to see the material as related to prior chess games. One way of examining this issue is to compare conditions when people are asked to explicitly recall an item with situations in which they

can make use of the material, but do not explicitly have to remember it. Studies using word completion presented normal people and amnesic patients with a list of words and after an interval presented a three-letter cue either taken from one of the words on the list or not. Subjects were asked either to explicitly recall the word on the list that began with the cue or to give the first associated word to the cue (Graf, Squire, & Mandler, 1984; Shimamura, 1986). Normal subjects did much better than patients with amnesia under the explicit recall task, but amnesiacs recalled as many words from the list as normals when the task was implicit. Moreover, in fMRI studies, implicit use of the primed word seemed to involve a portion of the right posterior cortex (Buckner et al., 1995).

In order to determine if this activation represented an early priming by the stored information, a high density EEG study was run (Badgaiyan & Posner, 1997). It was found that right posterior electrodes, consistent with the fMRI activation, differed between primed and unprimed words in the implicit condition during the first 150 msec after input. These data suggested that right posterior activation of information was contacted automatically and rapidly after the input cue. On the other hand, activations in the explicit condition were mostly in the hippocampal and frontal areas.

The studies cited above use rather artificial conditions of learning isolated words or nonsense patterns. One may ask if the same general mechanism is involved with more natural categories learned by experts. Tanaka and Curran (2001) used event-related electrical potentials to show that experts in dogs and birds show differences in the event-related potentials in brain areas associated with the perception of faces when viewing materials related to their expertise. An early component of the event-related potential (about 170 msec) was associated in the recognition of familiar objects for experts but not for novices. Thus there appears to be a general neural mechanism by which learning can influence posterior brain areas that can greatly improve the efficiency of handling concepts. The recent finding with chess experts shows that the same principles are involved in learning chess (Righi et al., Chapter 12, in this volume).

Another feature of the brain circuits related to expertise including faces, word form and artificial and natural categories is that they involve frontal areas in addition to the posterior area of activation. In the case of visual words, for example, frontal areas including the left ventral frontal area and the anterior cingulate are active within 150 msec after input, almost as fast as some of the posterior areas (Abdullaev & Posner, 1998). In general, the frontal and posterior areas work together over a long time interval to integrate diverse information related to the problem solution. For example, in the case of generating the use of a noun, which takes about 1100 msec, the frontal areas are in communication with posterior areas related to semantics at 450 msec (Nikolaev et al., 2001). In general, brain studies have argued that there is close communication between frontal, posterior and subcortical areas in generating the solution to problems, even those much simpler than what is involved in chess. The recent study of chess expertise also shows the importance of a number of frontal areas, suggesting that here too chess is similar to other learned categories.

Summary

Chase and Simon showed clearly that high-level skill in chess made a huge difference in the way memory for a new arrangement of chess pieces was structured. According to them, the semantics of the situation automatically structured memory for the location of the pieces, allowing the chess master to circumvent the limits of memory. The study of brain systems fully bears out these ideas and advances our knowledge of the mechanisms involved. Natural categories common to all people, such as faces, and both meaningful and meaningless categories, including those involved in chess positions, acquired by learning, whether in the laboratory or outside, all have an initial activation in posterior visual systems. This activity primes related input early in processing, thus structuring the new input in terms of past learning. Some of these findings come from studies that do not involve the complexity of chess, but they do provide insight into how the brain of the chess master works to structure the new board and to suggest possible moves. The ability to structure input has vast consequences for all types of learning. Although all our examples use visual input, we know that the same central mechanisms are involved in orienting to all sensory modalities and it seems likely that auditory and somato-sensory input would involve the same principles although the locations of stored information would be different. These mechanisms can be and have been applied to other forms of learning and problem solving, for example, in mathematics (Anderson, 2007), science, and the arts (Posner & Patoine, 2010).

INDIVIDUAL DIFFERENCES

A second goal of our chapter is to use brain research to examine the issue of whether there are individual differences which could in principle influence the ability of people to become chess masters, as suggested by Chase and Simon (1973). Since there are no reports on the genes involved in individual differences in chess, I can only summarize what we have learned about how genetic variation influences the development of brain networks in general and of attention in particular. I have worked extensively on attention networks and I believe some of what has been found can help us to understand individual differences in the ability to learn chess.

One of the major contributions of brain research is to help tie together common mechanisms of attention, learning and reasoning with differences among individuals in the same functions. For example, attention has involved three brain networks associated with alerting, orienting and executive control. We developed a test that gives a specific score for each network. We found that each of these networks has a range of scores reflecting individual differences in the efficiency of the network (Posner & Rothbart, 2007). In the case of the executive network, studies have shown that differences in the efficiency of resolving conflict from cognitive tasks correlates with parental reports of their child's ability to control their emotions and behavior, a factor called effortful control (Rothbart &

Rueda, 2005). Both executive attention and differences in effortful control among adolescents influence areas of the anterior cingulate and or mid-frontal cortex (Bush, Luu, & Posner, 2000; Whittle et al., 2008).

Each of the networks related to attention has a dominant neuromodulator (Green et al., 2008): dopamine for the executive network, acetylcholine for orienting, and norepinephrine for alerting. Because of these associations we predicted that differences in the dopamine alleles would be related to scores on executive attention, alerting scores to norepinephrine and orienting scores to cholinergic genes. Work with adults to date has largely supported this idea (Green et al., 2008).

Development of Attention Networks

The attainment of high-level skills in chess must rely upon brain plasticity to reflect the learning. Studies of human brain development have begun to reveal important changes during childhood that might provide clues to the nature of that plasticity. One of these changes involves focalization of activity during the performance of cognitive tasks (Durstun & Casey, 2006). During child development, cognitive tasks come to activate fewer brain areas and those activated are smaller with advancing age. It is as though task performance is more finely tuned with development. Some of these effects are similar to what has been found in adults with practice, which also tends to reduce the number and size of brain activations. On the other hand, studies of resting fMRI in children from 9 years to adults show changes in connectivity during development, which range from predominant local connections to more global connections (Fair et al., 2009). These two effects have led to what might seem opposite views of development. The activation data suggest increasing age produces more focal activity, while connectivity studies suggest more distributed activity in older children and adults. However, these changes in activation and connectivity may work together both in development and with practice to produce more efficient networks with smaller and more tuned local activity and broader and more diffuse connectivity. This might support the findings discussed in adults, which show that high skill learning produces strong posterior regions of focal activation and rapid connections to frontal brain areas.

Recent studies have examined the brain activity of infants and young children at rest using fMRI (Fransson et al., 2007; Gao et al., 2009). These results have shown evidence of sparse connectivity between brain structures during infancy with a strong increase in connectivity at 2 years (Gao et al., 2009) and later (Fair et al., 2009). In studies of neonates, the parietal areas, prominent in the orienting of attention network, show strong connectivity to lateral and medial frontal areas. By age 2, the anterior cingulate, which has been implicated in self-regulation, shows stronger connection to frontal areas and to lateral parietal areas. These findings suggest that the control structures related to executive attention and effortful control may be present in infancy but do not exercise their full control over other networks until later. In accord with this view we

have reported that error detection activates the mid-frontal and/or cingulate areas at 7 months (Berger, Tzur, & Posner, 2006), although the ability of an infant to take action based on errors seems not be present until 3–4 years of age (Jones, Rothbart, & Posner, 2003).

These studies usually examine functional connectivity between brain regions in resting fMRI. They are interpreted as being caused by improved myelination of white matter pathways over the years of development. Recently (Tang et al., 2010), we showed that white matter changes, as measured by diffusion tensor imaging, can also occur with a relatively brief period of mental practice.

Based in part on these imaging findings, we (Rothbart et al., 2011) suggested that the orienting network might play an important role in early emotional control and that caregivers might use orienting as a means of helping their child to develop self-regulation by other means. However, later in childhood and in adulthood, it appears to be the executive network that is most important in cognitive and emotional control.

There is ample evidence that as organisms develop, they produce both more focal activity in some brain areas and stronger connectivity between areas. These same mechanisms may also form the basis for what happens as expertise develops through learning. A further step would be to understand how experience and genes work together during development as a way of illuminating their potential role in expertise. The next section reviews evidence on the shaping of early networks by genes and experience.

Genetic Influences on Development

We have been conducting a longitudinal study on genetic influences on development from 7 months of age through the preschool years. We have reported on parts of this study up to 2 years of age and in this chapter review these findings together in an effort to examine how attention networks are shaped in early development (Sheese et al., 2007; Sheese et al., 2008; Voelker et al., 2009).

One goal of this work was to understand the how the early development of orienting and executive attention networks might influence control of emotions and cognition.

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 et al., 2007). The children in this study were initially 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, at age 2, 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 all of the parents were likely 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.

The 7-repeat allele of the dopamine 4 receptor gene (DRD4 gene) has been linked to attention deficit disorder 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 high risk for attention deficit disorder than those with smaller numbers of repeats (Auerbach et al., 1999; Swanson et al., 2001).

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 DRD4 gene. This allele appears to interact with a gene related to serotonin transmission (5HTT) to influence orienting.

In our longitudinal study, 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 (Sheese et al., 2007). 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 quality made a large difference. For those children with the 7-repeat and high quality parenting, their impulsivity and risk taking were average while those with the 7-repeat and low quality parenting, impulsivity and risk taking were very much higher.

Evidence that environment can have a stronger influence in the presence of the 7-repeat alleles has been reported by others (Bakermans-Kranenburg & van IJzendoorn, 2006; van IJzendoorn & Bakermans-Kranenburg, 2006). In addition, the same group (Bakermans-Kranenburg et al., 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 insuring that the result is not due to something other than the training. Three replications show that the presence of the 7-repeat allele makes parenting more influential on the behavior of the child. The parent training study suggests that the presence of the 7-repeat allele is critical to the influence of parent training but of course more evidence on this point would be important. A study with adults also illustrates the role of the 7-repeat allele in behavior (Larsen et al., 2010). In this study adults with the 7-repeat allele showed a stronger influence of their peers on alcohol consumption than adults who did not have this allele.

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 their 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 the 1980s) it was found to regulate positive affect (outgoingness and enthusiasm). In recent years the genetic part of the nature by nurture interaction has received 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 their 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. At two years of age 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. However, by 4 years of age when the executive attention network was better connected (Rothbart et al., 2011) there was a clear interaction between effortful control and the presence of the DRD4-7 repeat (Sheese, Rothbart, Voelker, & Posner, 2012). This finding shows the importance of considering the development of brain networks in determining the influence of genes on behavior.

An important gene X environment interaction that has been shown to work through attention in adults is the COMT gene (Blasi et al., 2005). A study of 7- to 14-year-old children (Diamond et al., 2004) found a similar effect on attention at this younger 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 both have been shown to involve the anterior cingulate gyrus.

In both 7-month-old children and 2-year-olds, the genotype and the haplotypes related to the COMT gene proved to relate to aspects of performance in a task involving orienting of attention, 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 last section) and variations in the COMT gene (Sheese, Voelker, 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 provides additional support for the idea that genetic variation can influence attention networks in early development.

Parenting and the Transition

We have argued for a transition between two control networks that are active during the period of our study. According to this view, during infancy, control is principally exercised by the orienting network but by 4 years and later this control involves the executive network. If this is correct, how does the transition take place? We believe this transition is mediated through exercise of the orienting network which produces increased connectivity for the executive network. Support for this view comes in part from an adult study (Shulman et al., 2009) in which the presentation of a novel object recruits the executive network (cingulo-opercular, in their terms) to supplement the orienting network (the ventral parietal frontal network, in their terms) which is active when the objects are not sufficiently novel. If this mechanism is present in infancy, it could mean that caregivers provide impetus for the development of self-regulation when they exercise executive systems through the presentation of novel objects.

Research by Bernier, Carlson and Whipple (2010) shows that maternal sensitivity, mindfulness and autonomy-support at 15 months were correlated with their child's later executive functions at 18 to 26 months, suggesting a relationship between earlier parent-child relationship on the development of self-regulatory activities. Our data at age 2 showed that parental quality interacted with the 7-repeat allele of the DRD4 gene to influence the temperamental dimensions of impulsivity, high intensity pleasure and activity (Sheese et al., 2007) and at age 4 the same gene influenced aspects of attention and emotion although these effects no longer interacted with parenting. The COMT gene at age 2 also interacted with parenting (Voelker et al., 2009) to influence orienting tasks and at age 4 also influenced attention but did not interact with parenting quality.

These findings suggest that aspects of parenting as reported and/or observed at ages 1-2 years influences the developing child's attention networks

and behavior. Although these findings are qualified by individual differences in genetic variation, they still show that parents can play a role in shaping the child's behavior.

These data suggest that both genetic and parental influences are important in the shift between orienting and executive control attention networks. We believe that the use of novel objects as instruments to soothe and interest children early in life is one tool to foster the development of self-regulation. These findings in childhood lead us to expect that in addition to long continued training, genetic variation may also play a role in who is likely to become an expert in chess and other learned skills.

Genes and Expertise

In one sense we all develop expertise in attention so the attention networks can serve as a model for understanding the role of genes and experience in any form of expertise. Despite the long training with attention, just as in other forms of expertise, there are large individual differences. It seems likely that individual differences in attention, motivation and memory may well be important determinants of who will be willing to put in the needed hours to become an expert in any particular domain.

The data clearly show that differences in attention are due in part to genetic variation, in part to experience and also to the interaction of the two. How these various causes of individuality combine may differ for any form of expertise we study. However, in accord with the position of Chase and Simon, studies of attention show that adults find it possible to improve their attention skills by various forms of training. For example, studies of target detection show that the speed and efficiency of orienting to visual targets can be improved by training in video games (Green & Bavalier, 2003). We have shown that meditation training can improve attention (Tang et al., 2007). In this case just 5 days of training are sufficient to improve some of the ability to resolve conflict as measured by the Attention Network Test (ANT). This is true even without any specific training of the network. Longer training changed the brain state by changing the efficiency of connections between the anterior cingulate and other brain areas (Tang et al., 2010). It is striking that these same mechanisms of changes in connectivity also occur during normal development. The same genes responsible for the development of the network related to attention may also play a role in their strengthening by specific training. These findings fit with the evidence of Chase and Simon that many years of practice may be important for expertise, but qualifies it to recognize that genetic and other differences may influence the effectiveness and/or the willingness to pursue the practice.

We are still a long way from understanding the biological constraints on the acquisition of expertise for high-level skills like chess, but the work to date suggests methods and results related to the argument made for what Chase and Simon called the "talent for chess."

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