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Individual differences and attentional varieties

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With its own functional anatomy, circuitry, and cellular structure, attention can be viewed as an organ system. This conceptualization reframes many problems in cognitive science and permits important insights into neurological and psychiatric disorders of both children and adults. Specifically, construing attention as an organ system helps to describe the evolutionary and developmental aspects of volitional control, thus paving the road towards a better appreciation of how such factors as genetics and culture influence control systems. The efficiency of the attention networks differs across people. However, these individual differences may elucidate variation in intelligence as well as the ability to regulate affect.

Key words: **Individual differences - Attentional networks - Effortful control - Self-regulation.**

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The study of attention is a fundamental theme in the history of psychology. At the turn of the 20th century William James said that "Everyone knows what attention is. It is the taking possession of the mind in clear and vivid form of one out of what seem several simultaneous objects or trains of thought". But he also acknowledged that varieties of attention exist and that attention was not monolithic.[1] Later research identified typologies of attentional networks.[2-4] The network approach owes a lot to the early work of Donald Hebb, who outlined in his cell-assembly theory the ensemble of brain areas that might be involved in processing cognitive and emotional tasks.[5] More recent efforts have brought a great upsurge in research of attention, particularly because of new methods that have become available for imaging of the living brain, but also from lesion studies, single-cell recordings, and many other methods.[6] Indeed, the study of attention has become a large enterprise with hundreds of papers being published in the area annually.[7] While it is increasingly challenging to keep abreast with the rapid discoveries in the field, one of the emerging themes traces attention as an organ system with its own anatomy, circuitry, developmental history, and deficits.[8] This theme holds promise for the training and rehabilitation of attention in both healthy and pathological populations.[9]

At the end of the 20th century 2 methods have been particularly valuable to studying attention as an organ system: imaging of the living brain (*i.e.*, looking at the anatomical areas involved in attention), and the human genome project (*e.g.*, delivering candidate genes for the study of attentional networks). Brain imaging studies have unraveled mechanisms of attention and many other cognitive tasks for the last 15 years. For simplicity, the major results of these efforts can be summarized in 3 general statements: 1) cognitive and emotional tasks are computed by networks of neural areas,

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often widely scattered over the brain, but by no means the whole brain. Each node of the network seems to compute a different aspect of the task and together the networks orchestrate the task; 2) some networks are involved in the control of other networks. These are attentional networks, which are involved in the selection and control of networks responsible for processing sensory information and information from memory; and 3) these networks change as a function of development, learning, insult, and pathology.

Anatomy

An influential model in the field views attentional networks in terms of 3 different modules: obtaining and maintaining the alert state; orienting to sensory information; and an executive network involved in the resolution of conflict between competing areas of the brain that might be active at the same time.[4]

The orienting network relies heavily upon parietal systems, including the superior parietal lobe and the temporal parietal junction. It is involved in both orienting to visual stimuli and stimuli in other modalities. The alerting network relies heavily on thalamic areas and involves the brain's norepinepherine (NE) system including the *locus ceruleus* and cortical areas. The executive attention network relies heavily on the anterior cingulate as well as lateral areas of the prefrontal cortex.

Researchers have been able to associate these brain networks with different modulators.[10-13] The study of the neuropharmacology of attention in alert monkeys suggests that the orienting network is modulated by the cholinergic system, the alerting network by the NE system, and the executive network mainly by dopamine systems.[4] These findings distinguish between the structures involved as the sources of attention and the sites on which those structures operate. Although the sources of attentional effects may be limited to networks, attention can influence any part of the brain, including the primary sensory areas and emotional areas of the brain. One review summarized many studies looking at the role of anterior cingulate cortex (ACC) in monitoring and the resolution of conflict.[14] Although there are many disputes about the exact mental operations involved, it may be useful to think of the ACC as involved in self-regulation. Thus, when subjects are required to damp down or ward off arousing negative thoughts, this area is active.[15] Also, if they are asked to ward off more pleasant thoughts (*e.g.*, erotic movies) this area of the brain is similarly active.[16]

One can distinguish between the dorsal ACC, which is involved in cognitive tasks (*e.g.*, the Stroop effect [17] and other conflict tasks), and the more ventral part of the ACC, which is involved in emotional tasks. This was tested by setting up a Stroop-type task that (in its normal way) activated the dorsal area but when words were changed to emotional words, like "cancer", then the same task activated this more ventral area.[14] So, although much remains to be unraveled about the exact calculations of the ACC, it is reasonable to consider it as an important node in the monitoring and resolution of conflict that is involved in emotional and cognitive regulation.

While many tasks that activate the ACC require language (*e.g.*, variants of the Stroop), using an adaptation of the Erickson flanker task we have developed a short behavioral test—the attention network test (ANT)—that is language-free and can be performed by nonhuman primates, healthy as well as pathological populations, and young children.[18] Using the ANT provides a way to measure the separate attentional networks that many other studies have described, within one relatively short task. Comparison of our paradigm with 2 other common conflict control tasks showed that all 3 tests activated an area of the ACC and the prefrontal cortex.[19] The activated regions were slightly different; however, with a common conjunction area. These findings suggest the existence of a brain network which is involved in this aspect of self-regulation.

Individuality is important both in its own right and for studying the role genetic variation may exact on the effects of these networks. Using the ANT one can get a measure of a subject's ability to resolve conflict, or cognitive regulation. Reaction time results from the ANT suggest relative independence between the congruency condition and the alerting and orienting conditions. The alerting network has a strong thalamic activation; the orienting network relies on both superior and inferior areas of the parietal lobe; and the conflict or executive network involves the ACC and lateral prefrontal cortex.[4, 20]

Development and individual differences

Using a pediatric version of the ANT, researchers compared the child ANT at ages 6-10 years with adults.[21] The overall reaction time and error rate decreases. Moreover, each of the attentional networks seems to have its own developmental time course: latency on the conflict network (*i.e.*, time to resolve conflict) drops by the age of 7 years, but thereafter remains constant; the orienting network seems to be in place even as young as age 4 years (although in more complex situations where orienting is combined with different domains there may be a later development) *; and alerting network continues to develop all through adolescence and into adulthood.[21, 22] In general, children experience difficulty in maintaining the ANT task set when there is no cue that prepares them to get ready. Thus, the ability to maintain task sets in the absence of specific instructions seems an important aspect of later childhood.[23]

Studying the development of attentional networks affords better insights into how these control circuits manifest in everyday life. For example, a child behavior questionnaire where parents report on the ability of children to control their own behavior (*e.g.*, to collect their toys or come to dinner when summoned) can represent a notion of effortful control.[23-25] Evidence suggests that during childhood executive attention is correlated with effortful control and effortful control has been shown to correlate with the important ability to delay a reward. Such efforts (*i.e.*, relating a rather precise but limited attentional measure to questionnaire reports) pave the road to understanding the neural mechanisms of broad questions concerning the role of these mechanisms in the everyday life of a child.

During adolescence effortful control and executive attention are both negatively related to antisocial behavior.[26] Other findings have suggested that the role of effortful control may be culturally determined.[27] For example, by using the a questionnaire in the United States and the People's Republic of China, individuals from the United States used effortful control to govern negative affect (*i.e.*, it is considered inappropriate to display much negative affect also in adulthood). In children from the People's Republic of China, however, effortful control was related to the control of extroversion, or positive affect (*i.e.*, in Chinese society, intense pleasure and profuse positive affect are deemed inappropriate). Thus, the ability to relate attentional networks to control mechanisms (in cognitive and emotional tasks) to questionnaire measures gives us an opportunity to examine the cultural effects in these individual differences. It also provides us an entry into the examination of genetic effects.

*) It may also be the case for many conflict tasks relying on other networks involved in planning and other higher level functions.

Genetics and individual differences

A few recent studies examined some of the genetic effects on these attentional networks. An obvious candidate was the DRD4 gene, because it had been shown to be related to some of the behaviors that occur in ADHD.[28, 29] Genotyping 200 people and looking at different alleles (*i.e.*, polymorphisms) in the DRD4 genes, researchers found that those alleles were significantly related to performance on the conflict network but not the reaction time itself or to other networks.[30-33] In fact, both the DRD4 and MAOA genes have alleles that exact different levels of efficiency in resolving conflict. Examining the brain scans of smaller subgroups of this initial sample performing the ANT in the scanner, the data showed significant differences between people with the 2 alleles in the ACC (*i.e.*, the central node in the conflict and self-regulatory network).[34] Thus, these results allow us to relate the behavioral differences to the actual underlying networks.

Other findings suggest that another gene is related to this network, the COMT gene.[35] Also, alleles of cholinergic genes may be related to the orienting network (*i.e.*, to the ability to carry out visual search tasks).[36-38] Work on the role of genes in these attentional networks and other cognitive networks underlying human performance is still in its infancy. These effects tend to be relatively small and probably no single gene is going to turn out to be the most important gene determining individual differences. Instead, there are probably going to be a number of genes or possibly also a number of interactions. However, this work can open up an opportunity to examine not only individual differences but how genes actually build the physical basis of the neural networks that we study. For example, the DRD4 gene, which is important for the conflict or executive network, has been knocked out in mice showing that the mice with the knocked out gene perform less exploration of their environment.[39] More precise tests of attention are planned for these animals and it seems possible as we develop animal models of some of these networks that we will be able to tell more focally how genes carry out the task of building the networks that are common among individuals as well as what alleles might account for individual differences.[40]

Individual differences and neural networks have often been kept separate. Nonetheless, the opportunity to bring them together holds promise for psychology because it permits the study of human behavior while concurrently coupling individual differences with the general properties of attention.[40] As important as the genetic basis of individual difference is, however, most individual differences probably are not a result of differences in genetic alleles. As I have alluded to previously, differences found between cultures may well dependent upon socialization or learning processes in those cultures and less upon genetic differences.

Attentional training and individual differences

Attentional networks are trainable. Because attentional networks probably develop between ages 2 and 7 years, researchers used attentional training with 4 year-old children (*i.e.*, midway in the developmental process but also because 4 year-olds are a lot easier to work with than younger children). Based on training methods developed for macaque monkeys in Stroop-like experiments,[41] researchers have adapted these tasks for children.[21] However, unlike monkeys who can work for many thousands of trials, parents do not typically like to bring their children in for many days of training. Instead the researchers opted for a brief five-day training course.[42] Realizing that this minimal level of training would be unlikely to have a large effect on the child's behavior, the investigators hoped for some small effect that would make it sensible to expose children to more detailed attentional training. Accordingly, EEG measurements were collected on the first and the last day while the children performed on the ANT, in addition to intelligence tests and temperament questionnaires.[23]

The EEG results were the most striking: the frontal midline showed a negative-going wave called the N2 – a waveform putatively coming primarily from the ACC, and is more negative in incongruent than in congruent trials. At least in adults, N2 waves seem to mirror the conflict resolution operations performed in the ACC. Examination of this area of the scalp both pre and post-training was revealing: the post-training waveform in the experimental group, shows that the response to incongruent was more negative than the response to congruent trials – a very clear N2. Howe-ver, this waveform was present neither in the pretest, nor in the control group (*i.e.*, either pre or post-training). In fact, the 4 year-olds' post-training waveforms were similar to the adult data – with activation restricted to the midline frontal or left lobe. Thus, the behavioral and EEG results suggest that even a brief five-day training can provide a certain change to make the attentional networks of 4-year-olds more adult-like.[42]

Another noteworthy finding is the pre and post-training difference in intelligent quotient (IQ), suggesting the generalization of these effects: the experimental group improved significantly on the matrix part of a child version of the Ravens test. These improvements appear to be in the underlying neural networks involved in conflict resolution and may generalize to a different task. Similar results have been found in training of attention deficit hyperactivity disorder (ADHD) children where 8 year-old children undergoing working memory training produced a significant increase in IQ score.[43-45] Thus, increasing evidence suggests that attentional networks are amenable to training.[42] These findings hold promise for education and other applications.[46]

Conclusions

Attention should be contextualized as an organ system: operating through specific networks that carry out different functions. These networks develop in early life (*e.g.*, at least the orienting and conflict networks are developed very early; the conflict network, at least using the ANT, is developed only up to age 7). In addition, specific genes influence these attentional network differences. These findings not only form a way of studying individual differences, but pave the road to understanding how genes shape the common networks that underlie cognition and emotion. Recent findings suggest that training influences these networks: following a relatively brief training course, conflict resolution improves (*i.e.*, the underlying networks look more adult-like in the trained subjects than in the nontrained subjects). Future research should extend these findings to demonstrate how this kind of attentional training may influence and enhance performance in other domains and applications. Finally, pathologies can also illuminate our understanding of attentional networks. Because attention can be affected by a wide range of pathologies, the efficiency of attentional networks is probably of limited diagnostic value. However, attentional networks may help in the design of useful rehabilitative interventions.

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References

1. James W. The principles of psychology. New York: Dover; 1890.
2. Fan J, Raz A, Posner MI. Attentional mechanisms. In: Aminoff MJ, Daroff RB editors. Encyclopedia of Neurological Sciences. New York: Elsevier Science; 2003;1:292-9.
3. Posner MI. Cognitive neuroscience of attention. New York: Guilford Press; 2004.
4. Raz A. Anatomy of attentional networks. Anat Rec B New Anat 2004;281:21-36.
5. Posner MI, Rothbart MK. Hebb's Neural networks support the integration of psychological science. Can Psychol 2004;45: 265-78.
6. Posner MI. The Achievement of Brain Imaging: Past and Future. In: Kanwisher N, Duncan J, editors. Attention and Performance. New York: Oxford University Press; 2004.p.505-28.
7. Cavanagh P. Attention Routines and the Architecture of Selection. In: Posner MI editor. Cognitive Neuroscience of Attention. New York: Guilford Press; 2004.p.13-28.
8. Posner MI, Fan J. Attention as an Organ System. In: Pomerantz JR, Crai MC editors. Topics in Integrative Neuroscience: From Cells to Cognition. Cambridge, UK: Cambridge University Press; 2004.
9. Robertson IH. The rehabilitation of attention. In: Stuss DT, Winocur G, Robertson IH editors. Cognitive Rehabilitation. Cambridge, UK: Cambridge University Press; 1999.p.302-13.
10. Beane M, Marrocco RT. Cholinergic and Noradrenergic Inputs to the Posterior Parietal Cortex Modulate the Components of Exogenous Attention. In: Posner MI, editor. Cognitive Neuroscience of Attention. New York: Guilford Press; 2004.p.313-25.
11. Marrocco RT, Davidson MC. Neurochemistry of attention. In: Parasuraman R editor. The Attentional Brain. Cambridge, MA: MIT Press; 1998.p.35-50.
12. Witte EA, Davidson MC, Marrocco RT. Effects of altering brain cholinergic activity on covert orienting of attention: comparison of monkey and human performance. Psychopharmacology (Berl) 1997;132:324-34.
13. Witte EA, Marrocco RT. Alteration of brain noradrenergic activity in rhesus monkeys affects the alerting component of covert orienting. Psychopharmacology (Berl) 1997;132:315-23.
14. Bush G, Luu P, Posner MI. Cognitive and emotional influences in anterior cingulate cortex. Trends Cogn Sci 2000;4:215-22.
15. Ochsner KN, Bunge SA, Gross JJ, Gabrieli JD. Rethinking feelings: an FMRI study of the cognitive regulation of emotion. J Cogn Neurosci 2002;14:1215-29.
16. Beauregard M, Levesque J, Bourgouin P. Neural correlates of conscious self-regulation of emotion. J Neurosci 2001;21:RC165.
17. Stroop JR. Studies of interference in serial verbal reactions. J Exp Psychol 1935;18:643-61.
18. Fan J, McCandliss BD, Sommer T, Raz A, Posner MI. Testing the efficiency and independence of attentional networks. J Cogn Neurosci 2002;14:340-7.
19. Fan J, Flombaum JI, McCandliss BD, Thomas KM, Posner MI. Cognitive and brain consequences of conflict. Neuroimage 2003;18:42-57.
20. Fan J, McCandliss BD, Fossella J, Flombaum JI, Posner MI. The activation of attentional networks. Neuroimage 2005;26:471-9.
21. Rueda MR, Fan J, McCandliss BD, Halparin JD, Gruber DB, Lercari LP *et al*. Development of attentional networks in childhood. Neuropsychologia 2004;42:1029-40.
22. Rueda MR, Posner MI, Rothbart MK, Davis-Stober CP. Development of the time course for processing conflict: an event-related potentials study with 4 year olds and adults. BMC Neurosci 2004;5:39.
23. Rothbart MK, Ellis LK, Rueda MR, Posner MI. Developing mechanisms of temperamental effortful control. J Pers 2003;71:1113-43.
24. Rothbart MK, Ahadi SA, Hershey KL, Fisher P. Investigations of temperament at three to seven years: the Children's Behavior Questionnaire. Child Dev 2001;72:1394-408.
25. Rothbart MK, Ellis LK, Posner MI. Temperament and self regulation. In: Baumeister RF, Vohs KD editors. Handbook of self regulation. New York: Guilford Press; 2004.p.357-70.
26. Ellis LK, Rothbart MK, Posner MI. Individual differences in executive attention predict self-regulation and adolescent psychosocial behaviors. Ann N Y Acad Sci 2004;1021:337-40.
27. Posner MI. Tenth Annual George A. Miller Distinguished Lecture at the Annual Meeting of the Cognitive Neuroscience Society, Miller Lecture. San Francisco: Cognitive Neuroscience Society; 2004.
28. Swanson J, Oosterlaan J, Murias M, Schuck S, Flodman P, Spence MA *et al.* Attention deficit/hyperactivity disorder children with a 7-repeat allele of the dopamine receptor D4 gene have extreme behavior but normal performance on critical neuropsychological tests of attention. Proc Natl Acad Sci U S A 2000;97:4754-9.
29. Swanson J, Posner M, Fusella J, Wasdell M, Sommer T, Fan J. Genes and attention deficit hyperactivity disorder. Curr Psychiatry Rep 2001;3:92-100.
30. Fan J, Wu Y, Fossella JA, Posner MI. Assessing the heritability of attentional networks. BMC Neurosci 2001;2:14.
31. Fossella J, Posner MI, Fan J, Swanson JM, Pfaff DW. Attentional phenotypes for the analysis of higher mental function. Sci World J 2002;2:217-23.
32. Fossella J, Sommer T, Fan J, Wu Y, Swanson JM, Pfaff DW *et al.* Assessing the molecular genetics of attention networks. BMC Neurosci 2002;3:14.
33. Fossella JA, Sommer T, Fan J, Pfaff D, Posner MI. Synaptogenesis and heritable aspects of executive attention. Ment Retard Dev Disabil Res Rev 2003;9:178-83.
34. Fan J, Fossella J, Sommer T, Wu Y, Posner MI. Mapping the genetic variation of executive attention onto brain activity. Proc Natl Acad Sci U S A 2003;100:7406-11.
35. Diamond A, Briand L, Fossella J, Gehlbach L. Genetic and neurochemical modulation of prefrontal cognitive functions in children. Am J Psychiatry 2004;161:125-32.
36. Greenwood PM, Lambert C, Sunderland T, Parasuraman R.Effects of apolipoprotein E genotype on spatial attention, working memory, and their interaction in healthy, middle-aged adults: results From the National Institute of Mental Health's BIOCARD study. Neuropsychology 2005;19:199-211.
37. Greenwood PM, Sunderland T, Putnam K, Levy J, Parasuraman R. Scaling of Visuospatial Attention Undergoes Differential Longitudinal Change as a Function of APOE Genotype Prior to Old Age: Results From the NIMH BIOCARD Study. Neuropsychology 2005;19:830-40.

38. Parasuraman R, Greenwood PM, Kumar R, Fossella J. Beyond heritability: neurotransmitter genes differentially modulate visuospatial attention and working memory. Psychol Sci 2005;16: 200-7.
39. Grandy DK, Kruzich PJ. A Molecular Genetic Approach to the Neurobiology of Attention Utilizing Dopamine Receptor-Deficient Mice. In: Posner MI editor. Cognitive Neuroscience of Attention. New York: Guilford Press; 2004. p. 260-8.
40. Posner MI, Mayr U, Awh E, Keele SW. Developing individuality in the human brain: a tribute to Michael I. Posner. 1st ed. Washington, DC: American Psychological Association; 2005.
41. Washburn DA. Stroop-like effects for monkeys and humans: processing speed or strength of association? Psychol Sci 1994;5: 375-9.
42. Rueda MR, Rothbart MK, McCandliss BD, Saccomanno L, Posner MI. Training, maturation, and genetic influences on the development of executive attention. Proc Natl Acad Sci U S A 2005;102: 14931-6.
43. Klingberg T, Fernell E, Olesen PJ, Johnson M, Gustafsson P, Dahlstrom K *et al*. Computerized training of working memory in children with ADHD--a randomized, controlled trial. J Am Acad Child Adolesc Psychiatry 2005;44:177-86.
44. Klingberg T, Forssberg H, Westerberg H. Training of working memory in children with ADHD. J Clin Exp Neuropsychol 2002;24:781-91.
45. Olesen PJ, Westerberg H, Klingberg T. Increased prefrontal and parietal activity after training of working memory. Nat Neurosci 2004;7:75-9.
46. Posner MI, Rothbart MK. Influencing brain networks: implications for education. Trends Cogn Sci 2005;9:99-103.

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