Hebb's Neural Networks Support the Integration of Psychological Science[1]

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Abstract

In a recent paper and forthcoming volume, the former President of the American Psychological Association, Robert Sternberg, calls for an effort to reintegrate psychological science (Sternberg, in press; Sternberg & Grigorenko, 2001). In this paper we argue that D. O. Hebb, beginning with his technical volume in 1949 and continuing through a series of introductory textbooks, has convincingly presented the basis for such integration. The basis for this integration lies in understanding how genes and experience shape neural networks underlying human thoughts, feelings, and actions.

Why has not Hebb's accomplishment been generally recognized as providing the needed integration for psychology? We suggest that the methods available to Hebb, mostly animal research and behavioural human experiments, were not sufficient to provide empirical methods for linking his conceptual nervous system to real events in the human brain. This methodology has now been provided by neuroimaging. While Hebb also recognized the importance of studying individual differences in intelligence and affect, there were also no methods for exploring the specific genes that were an important source of these differences. The human genome project has provided new methods for exploring this issue. Hebb's basic idea, together with the new methodological tools and new disciplines (e.g., cognitive, affective, and social neuroscience), all based on network views, give abundant evidence of the value of employing the converging operations strategy advocated by Sternberg and Grigorenko (2001).

It is important that psychology recognize the need for integrating cognitive, affective and, social neuroscience with psychology, because many of the theoretical questions that need to be addressed by neuroimaging and genetic studies are exactly those that a century of psychologists have explored. The neuroscience approach provides crucial constraints for psychological theories, but also benefits from a closer connection with the psychological level of analysis.

The Challenge

In their paper, Sternberg and Grigorenko (2001) argue for a multiparadigmatic and multidisciplinary integrated psychology to replace what they regard as a badly fragmented discipline. They outline three bad habits that they regard as symptoms of the fragmentation of the field. These are: a) the use of single methodologies, b) the identification of scholars with the psychological subfields of social, clinical, etc., and c) adherence to single paradigms such as behaviourism, cognitivism or psychoanalysis.

Their paper traces various efforts to provide a unified psychology by Kimble (1994), Staats (1999), Magnusson (2000), and others. They also propose their own ideas, including the importance of using converging methods selected from different levels of analysis and the important role of graduate training in producing needed skills for integrative research. They also discuss political and social reasons why some oppose integration, and what can be done by organizations to foster it.

We believe that the scientific basis for the integration is already on the scene, and that potentially integrated efforts under the names of cognitive, affective, and social neuroscience have already appeared. Functional neuroimaging requires the use of a task to activate brain areas. The usual strictures in the design of such tasks stem from cognitive studies, and they are now being taught and used by imagers. In addition, the combination of fMRI, EEG measures and lesions provide a toolkit of methods. Although there are many disagreements about the appropriate converging methods and how to best analyze imaging data, there is little question that a new generation of imagers are employing sophisticated and convergent methods.

In our paper, we trace the background to these efforts in the work of D. O. Hebb. We then summarize important new developments that have increased the applicability of Hebb's ideas to many new topics. We

1 We chose to explore our work by examining whether the framework for integrating psychology developed by D. O. Hebb when combined with new methods, could produce the integration of psychology that Robert Sternberg has discussed in recent publications. This work was supported by a McDonnell 21st Century Grant and by NIMH grant MH 43361.

Figure 1. D. O. Hebb

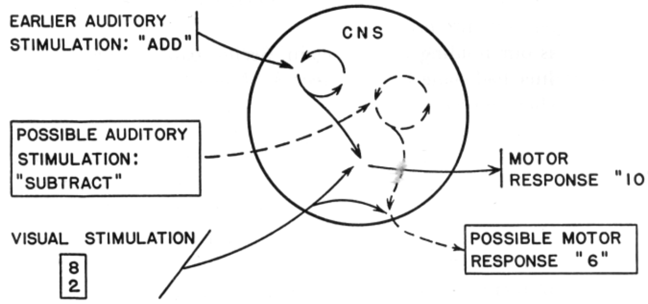

Figure 2. Hebb (1958, Figure 18) applies a network approach to simple mental arithmetic.

give specific illustrations, showing how various areas of psychology, including cognitive, developmental, clinical, social, and personality psychology, and adjacent disciplines such as behavioural evolution and psychoanalysis, can be examined within the integrated framework that Hebb provided. We try to update the scientific basis for unifying psychology that Hebb advocated and illustrate why it would be desirable to use this as the basis for psychology, but leave to others the formidable task of negotiating the political issues raised by Sternberg.

The Solution

In 1949, D. O. Hebb published his epic work *The Organization of Behavior*. Hebb's book was immediately recognized as providing the potential for an integrated psychology. One reviewer (Attneave, 1950, p. 633) wrote:

> I believe *The Organization of Behavior* to be the most important contribution to psychological theory in recent years. Unlike those of his contemporaries who are less interested in psychology than in some restricted aspect thereof to which their principles confine them, Hebb has made a noteworthy attempt to take the experimentally determined facts of behavior, as they are, and account for them in terms of events within the central nervous system.

The most important basic idea that Hebb presented was the cell assembly theory outlined in Chapters 4 and 5 of his book (Goddard, 1980). Hebb argued that every psychological event – sensation, expectation, emotion or thought – is represented by the flow of activity in a set of interconnected neurons. Learning occurs by a change in synaptic strength. This change occurs when a synapse conducts excitation at the same time the postsynaptic neuron discharges. This provides a basis for the modification of synapses and shows how neural networks might be organized under the influence of specific experiences. The Hebb synapse plays a central role in modern neuroscience (see Kolb, 2003; Milner, 2003; Sejnowski, 2003). There are important new developments in the study of synapses and their role in learning, but it is clear that the basic ideas being pursued stem from Hebb's original concept of synaptic plasticity.

In later years, Hebb (1958) developed an introductory psychology textbook that integrated much of psychology using the framework provided by his 1949 theory. He applied his network theory to heredity, learning and memory, motivation, perception, thought, and development. In later editions, he extended his approach to emotions in their social contexts, and to individual differences in intelligence and abnormal psychology.

Despite his efforts and those of his followers at McGill and elsewhere, Hebb's work was not successful in providing a fully integrative psychology and many still seek to develop such an integration (Sternberg, in press; Sternberg & Grigorenko, 2001). One of the major problems with Hebb's framework was that it left no clear empirical path for the acquisition of new knowledge about how human brain networks develop, how they differ among individuals, why they break down, and how they can be restored to functioning. Most of the research by Hebb and his associates was performed on nonhuman animals, while most of psychology concerns human behavior, brain, and mind. In 1955, Hebb specifically argued for a conceptual nervous system, but there was no clear way for the behavioral research discussed to be tied to the assumed underlying human brain networks.

Several major late-20th century events seem to give improved prospects for an integration of psychological science around the ideas introduced by Hebb. Cell assemblies and phase sequences are names for aspects

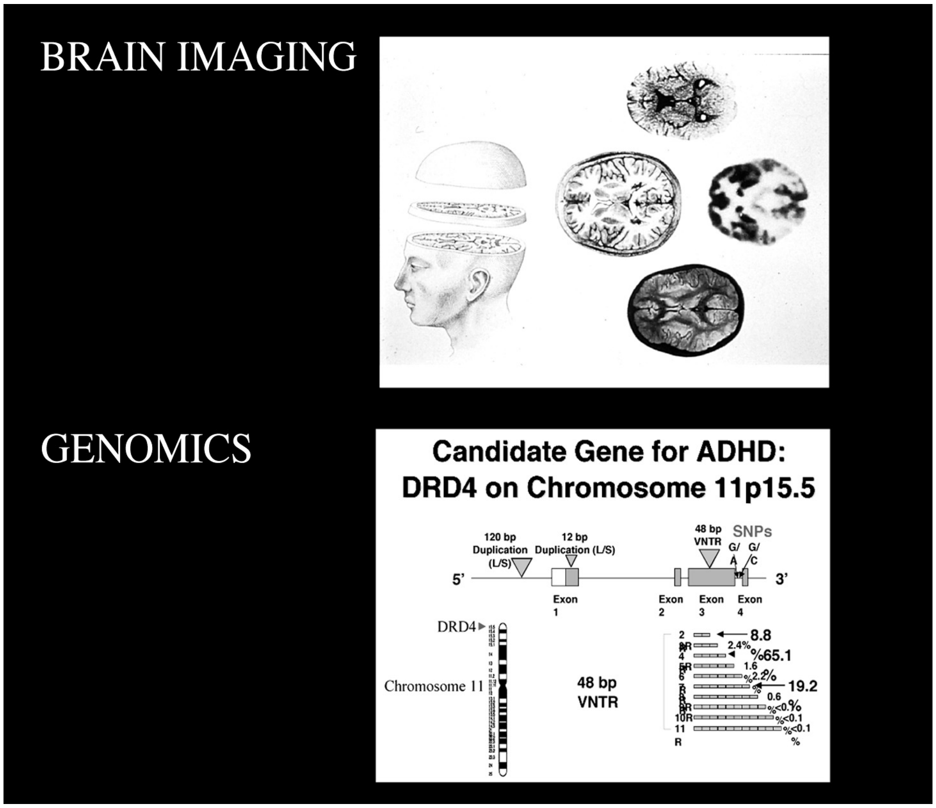

Figure 3. Major methodological developments of the late-20th century include brain imaging and the human genome project.

of neural networks. First, thanks to work on the computational properties of neural networks (i.e., Rummelhart & McClelland, 1986), we are now in a much better position to develop detailed theories integrating information from physiological, cognitive, and behavioral studies.

Second, development of a set of new methods often called neuroimaging allows us to examine neuronal activity in terms of localized changes in blood flow or metabolism by positron emission tomography (PET) or changes in blood oxygenation by functional magnetic imaging (fMRI). By using tracers that bind to different transmitters, PET can also be used to examine transmitter density. By measuring electrical (EEG) and magnetic (MEG) signals outside the skull, the time course of activation of different brain areas localized by fMRI can be measured (Dale et al., 2000). Pathways of activation can also be imaged by use of diffusion tensor imaging, a form of MRI that traces white matter tracts. In addition to the study of naturally occurring lesions, interrupting information flow by transcranial magnetic stimulus (TMS) can produce temporary functional lesions of pathways (see Toga & Mazziotta, 1996, for a review of these and other methods). These methods provide a toolkit that can be used alone or used together to make human brain networks accessible for detailed physiological study.

Some have thought that the influence of imaging has been merely to tell us where in the brain things happened (Utall, 2002). Certainly many, perhaps even most, imaging studies have been concerned with anatomical issues. However, imaging also probes the basic neural networks that underlie all aspects of human thought, feelings, and behaviour (Posner, 2004a). They have and are being applied to study of spatial cognition, verbal processing, memory, music, object recognition, self-control, emotions such as fear and pleasure, and aspects of individuality. The full significance of imaging for viewing brain networks, examining their computation in real time, exploring how they are assembled in development, and their plasticity following physical damage or training, are common themes in current research that are just beginning to reach their potential.

Third, the mapping of the human genome (Venter et al., 2001) offers the potential for an increased understanding of the physical basis for individual differences in temperament and personality. Many genes exhibit a number of relatively high frequency variants (polymorphisms) that can code for different physical configurations that in turn can alter the efficiency of a network. For example, different forms (alleles) of genes forming dopamine receptors can lead to different efficiency in binding to dopamine and thus differences in underlying neural networks. In a number of cases, it has been possible to relate these genetic differences to individual performance in tasks involving the network (see Fossella & Posner, in press, for a review). Research based on genetics also provides an important approach to the development of characteristics of neural networks common to all members of the species.

We recognize that not all topics of psychology have been sufficiently explored to illustrate this framework, and that limitations in our knowledge prevent us from exploring all of the areas where these developments can be applied. However, attention and temperament areas of our work, can be used to consider how a large number of psychological questions can be explored using the neural network framework outlined by Hebb. Attention serves as a basic set of mechanisms that underlie our awareness of the world and the voluntary regulation of our thoughts and feelings. The methods used to understand attentional networks in terms of anatomy, individual differences, development, and plasticity can be applied readily to explore networks related to other aspects of human behavior.

Any approach based on neural networks raises the issue of crude reductionism. Many agree that all human behavior must ultimately be traceable to brain activity, but would also correctly argue for the importance of cognitive experiments, behavioural observations, and self-report as important elements of psychological science. We hope to illustrate in this chapter how important such methods are, and how they can be fully integrated within a brain network framework, as Hebb illustrated in his *Textbook of Psychology*.

Brain Networks

Most neuroimaging studies, regardless of the specialty field, have found that a small number of often widely distributed anatomical areas are active during any task. In several fields of research, each area of activity (node) can be associated with a particular function or mental operation (see Posner, 2004a, for a review). A number of these nodes are active during a given task. The organization of these nodes in real time constitute a network roughly like Hebb's cell assembly, but involving brain areas rather than individual cells. Of course not all authors agree on exactly what is the function of each node, and some feel that parts of the brain (e.g., frontal lobes or subcortical areas) are more likely to carry out a number of functions.

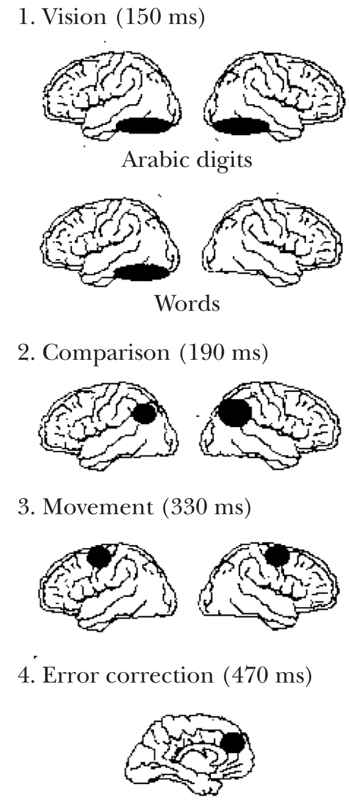

Figure 4. Anatomy of simple mental calculation (Adapted with permission from Oxford University Press.)

A good example of such a network is from the work of Dehaene (1997) on a simple numerical task (see Figure 4). For the task of determining whether a digit was above or below 5, he found areas of the occipital lobe involved in decoding the input number which differed based on the type of input. A parietal area was sensitive to the distance of the digit from 5, and represents what he calls a number line. The anterior cingulate was active on those trials in which there was an error. This imaging work provided a strong anatomical story to flesh out the hypothetical network that Hebb (1949) (see Figure 2) outlined for mental arithmetic.

The results of neuroimaging research provide an answer to the question of whether thought processes are localized. Although the network that carries out cognitive tasks is distributed, the mental operations that constitute the elements of the task are localized. Building upon the idea of localization of underlying operations, imaging methods are now being applied to studies of the circuitry, plasticity, and individual development of such neural networks. Working together with cellular and genetic methods, there is

TABLE 1

Function	Structures	Modulator
Orient	Superior parietal Temporal parietal junction Frontal eye fields Superior colliculus	Acetylcholine
Alert	Locus coruleus Right frontal and parietal cortex	Norepinephrine
Exec. Attn.	Ant. cingulate Lateral ventral Prefrontal Basal ganglia	Dopamine

movement toward a more unified view of the role of the human brain in supporting the mind.

Attentional Networks

Functional neuroimaging has allowed many cognitive tasks to be analyzed in terms of the brain areas they activate, and studies of attention have been among the most-often examined in this way (Corbetta & Shulman, 2002; Driver, Eimer, & Macaluso, 2004; Posner & Fan, in press). Imaging data have supported the presence of three networks related to different aspects of attention. These networks carry out the functions of alerting, orienting, and executive control (Posner & Fan). A summary of the anatomy and transmitters involved in the three networks is shown in Table 1.

Alerting is defined as achieving and maintaining a state of high sensitivity to incoming stimuli; orienting is the selection of information from sensory input; and executive control involves mechanisms for monitoring and resolving conflict among thoughts, feelings, and responses. The alerting system has been associated with thalamic as well as frontal and parietal regions of the cortex (Fan et al., in press). A particularly effective way to vary alertness has been to use warning signals prior to targets. The influence of warning signals on the level of alertness is thought to be due to modulation of neural activity by the neurotransmitter norepinepherine (Marrocco & Davidson, 1998).

Orienting involves aligning attention with a source of sensory signals. This may be overt, as when eye movements accompany movements of attention, or may occur covertly without any eye movement. The orienting system for visual events has been associated with posterior brain areas, including the superior parietal lobe and temporal parietal junction, and in addition, the frontal eye fields (Corbetta & Shulman, 2002). Orienting can be manipulated by presenting a cue indicating where in space a target is likely to occur, thereby directing attention to the cued location (Posner, 1980). Event related functional magnetic resonance imaging studies have suggested that the superior parietal lobe is associated with orienting following the presentation of a cue (Corbetta & Shulman). The superior parietal lobe in humans is closely related to the lateral intraparietal area (LIP) in monkeys, which is involved in the production of eye movements (Andersen, 1989). When a target occurs at an uncued location and attention has to be disengaged and moved to a new location, there is activity in the temporal parietal junction (Corbetta & Shulman). Lesions of the parietal lobe and superior temporal lobe have been consistently related to difficulties in orienting (Karnath, Ferber, & Himmelbach, 2001).

Executive control of attention is often studied by tasks that involve conflict, such as various versions of the Stroop task. In the Stroop task, subjects must respond to the colour of ink (e.g., red) while ignoring the colour-word name (e.g., blue) (Bush, Luu, & Posner, 2000). Resolving conflict in the Stroop task activates midline frontal areas (anterior cingulate) and lateral prefrontal cortex (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). There is also evidence for the activation of this network in tasks involving conflict between a central target and surrounding flankers that may be congruent or incongruent with the target (Botvinick et al., 2001; Fan et al., 2003). Experimental tasks may provide a means of fractionating the contributions of different areas within the executive attention network (MacDonald, Cohen, Stenger, & Carter, 2000). Recent neuroimaging studies have provided evidence that the executive attention network is involved in self-regulation of positive and negative affect (Beauregard, Levesque, & Bourgouin, 2001; Ochsner et al., 2001) as well as a wide variety of cognitive tasks underlying intelligence (Duncan et al., 2000).

Individuality

Almost all studies of attention have been concerned with either the general abilities involved, or with effects of brain injury or pathology on attention. However, it is clear that normal individuals differ in their ability to attend to sensory events, and even more clearly in their ability to concentrate for long periods on internal trains of thought.

To study these individual differences, we have developed an attention network test (ANT) that examines the efficiency of the three brain networks described above (Fan et al., 2001). The data provide three scores that represent the efficiency of each individual in the alerting, orienting, and executive networks. In a sample of 40 normal persons, we found each of these scores to be reliable over repeated presentations. In addition, we found no correlation among the orienting, alerting, and executive scores.

The ability to measure differences in attention among adults raises the question of the degree to which attention is heritable. To explore this issue, the attention network test was used to study 26 pairs of monozygotic and 26 pairs of dyzygotic same-sex twins (Fan et al., 2001). We found strong correlations between the monozygotic twins' scores on the executive network leading to an estimate of heritability of the executive network of .89. Because of the small sample, the estimate of 95% confidence interval for heritabiltiy was between .3 and .9. Nonetheless, these data support a role for genes in executive attention.

We then used the association of the executive network with the neuromodulator dopamine (see Table 1) as a way of searching for candidate genes that might relate to the efficiency of the networks (Fossella et al., 2002). To do this, 200 persons performed the ANT and were genotyped to examine frequent polymorphisms in genes related to dopamine. We found significant association of two genes, the DRD4 and MAOA gene. We then conducted a neuroimaging experiment in which persons with different alleles of these two genes were compared while they performed the ANT (Fan et al., 2003). Groups with different alleles of these genes showed differences in performance on the ANT and also produced significantly different activations in the anterior cingulate, a major node of the executive attention network.

Hebb thought that most of the networks involved in higher functions were shaped primarily through experience. We now know that there is a great deal in common among humans in these high-level networks, and thus that they must have a basis within the human genome. It seems likely that the same genes that are related to individual differences in attention are also important in the development of the attentional networks that are in common among people. Some of these networks are also common to nonhuman animals. By examining these networks in animals, it should be possible to test this assumption further and to understand the role of the gene in shaping the network. We believe that this kind of genetic analysis of network development is becoming a very productive link between genes and psychological function.

Development

Every parent of more that one child recognizes that from birth, infants are individuals with their own distinct characteristics and dispositions. These include reactive traits such as activity level and orienting to sensory events and regulatory traits like attentional control. We believe that these early developing temperamental differences reflect the maturation of particular neural networks. We have studied individual differences in attention and related these differences to emotional and behavioral control (Rothbart & Rueda, in press; Ruff & Rothbart, 1996).

A major advantage of viewing attention as an organ system is to trace the ability of children and adults to regulate their thoughts and feelings. Over the early years of life, the regulation of emotion is a major issue of development. The ability of attention to control distress can be traced to early infancy (Harmon, Rothbart, & Posner, 1997). During early infancy, most regulation depends on the caregiver providing ways to control infant reactions. In our study, for example, we first induced a mild level of distress, and then showed how attentional orienting calms that distress while the infant remains engaged with the object. When the orienting is broken, distress returns to the level present prior to the introduction of the object. It is likely that the distress remains present and is held by networks in the amygdala. Parents often use manipulation of the infants' orienting to control distress, and the infant also exhibits coping behaviors that involve orienting to form the basis for self-regulation (Rothbart, Ziaie, & O'Boyle, 1992).

We have found that the developmental changes in executive attention found during the third year of life are correlated with parent reports of temperamental effortful control (Gerardi-Caulton, 2000). Effortful control includes the ability to inhibit a dominant response in order to produce a subdominant response, and to detect and correct errors. Because children of this age do not read, location and identity rather than word meaning and ink color served as the dimensions in a spatial conflict task. Children sat in front of two response keys, one located to the child's left and one to the right. Each key displayed a picture, and on every trial, a picture identical to one of the pair appeared on either the left or right side of the screen. Children were rewarded for responding to the identity of the stimulus, regardless of the spatial compatibility between the stimulus and the matching response key (Gerardi-Caulton). Reduced accuracy and slowed reaction times for spatially incompatible trials relative to spatially compatible trials reflected the effort required to resist the dominant response and to resolve conflict between these two competing dimensions. Performance on this task produced a clear interference effect in adults and activated the anterior cingulate (Fan et al., 2003). Children 24

TABLE 2
Data on Development of Conflict-Related Network in the ANT Flanker Taks for Children: Behavioural Results

Congruent 

Incongruent 

Age	Overall RT	Overall % errors	Conflict effect RT (ms)	Conflict effect % errors
4.4	1,443	6.8	273	8.9
6	930	13	95	15.6
7	835	5.6	70	0.5
8	811	4.8	70	-0.2
9	740	2.4	67	1.6
10	643	2.2	72	2.1
Adults	492	1.2	63	1.6

months of age tended to perseverate on a single response, while 36-month-old children performed at high accuracy levels, but like adults, responded more slowly and with reduced accuracy to incompatible trials.

We have traced the development of executive attention beyond the preschool period (Rueda et al., 2004) by using a version of the ANT adapted for children (see Table 2). In some respects, results were remarkably similar to those found for adults. The reaction times for the children are much longer, but they showed similar independence among the three networks. Children have much larger scores for alerting and conflict, suggesting that they have trouble in maintaining the alert state when not warned of the new target, and in resolving conflict. Rather surprisingly, the ability to resolve conflict in the flanker task, as measured by the ANT, remains about the same from age seven to adulthood (see Table 2).

There is considerable evidence that the executive attention network is of great importance in the acquisition of school subjects such as literacy (McCandliss et al., 2003), and in a wide variety of other subjects that draw upon general intelligence (Duncan et al., 2000). It has been widely believed by psychologists that training involves only specific domains, and that more general training of the mind, for example, by formal disciplines like mathematics or Latin, does not generalize beyond the specific domain trained (Simon, 1969; Thorndike, 1899). However, attention may be an exception to this idea. It is a domain that involves specific brain mechanisms, as we have seen, but its function is to influence the operation of other brain networks (Posner & Fan, in press; Posner & Petersen, 1990). Anatomically, the network involving resolution of conflict overlaps with brain areas related to general intelligence (Duncan et al., 2000). Training of attention either explicitly or implicitly is also often a part of the school curriculum (Mills & Mills, 2002) but little research is available to determine exactly how and when attention training can best be accomplished.

Socialization and Culture

Cognitive measures of conflict resolution have been linked to aspects of children's self-control in naturalistic settings. Children who are relatively less affected by spatial conflict also received higher parental ratings of temperamental effortful control and higher scores on laboratory measures of inhibitory control (Gerardi-Caulton, 2000).

Questionnaires have shown that the effortful control factor, defined in terms of scales measuring attentional focusing, inhibitory control, low intensity pleasure, and perceptual sensitivity (Rothbart & Rueda, in press) is inversely related to negative affect. This relation is in keeping with the notion that attentional skill may help attenuate negative affect, while also serving to constrain impulsive approach tendencies.

Empathy is strongly related to effortful control, with children high in effortful control showing greater empathy. To display empathy towards others requires that we interpret their signals of distress or pleasure. Imaging work in normals shows that sad faces activate the amygdala. As sadness increases, this activation is accompanied by activity in the anterior cingulate as part of the attention network (Blair, Morris, Frith, Perrett, & Dolan, 1999). It seems likely that the cingulate activity represents the basis for our attention to the distress of others.

Developmental studies find two routes to successful socialization. A strongly reactive amygdala would provide the signals of distress that would easily allow empathic feelings toward others and a hesitancy to perform behaviors that might cause harm. These children are relatively easy to socialize. In the absence of this form of control, development of the cingulate would allow appropriate attention to the signals that are provided by amygdala activity. Consistent with its influence on empathy, effortful control also appears to play a role in the development of conscience. The internalization of moral principles appears to be facilitated in fearful preschool-aged children, especially when their mothers use gentle discipline (Kochanska, 1995). In addition, internalized conscience is facilitated for children high in effortful control (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). Two separable control systems, one reactive (fear) and one self-regulative (effortful control) appear to regulate the development of conscience.

Individual differences in effortful control are also related to some aspects of metacognitive knowledge, such as theory of mind, knowing that people's behavior is guided by their beliefs, desires, and other mental states (Carlson & Moses, 2001). Tasks that require the inhibition of a prepotent response correlate with theory of mind tasks even when other factors, such as age, intelligence, and working memory are factored out (Carlson & Moses). Inhibitory control and theory of mind share a similar developmental time-course, with advances in both areas between the ages of 2 and 5.

Emotion, thought, and behaviour form a cluster of processes associated in specific situations as experienced by the child. Single and repeated life experiences will thus shape connections between elicited emotion, conceptual understanding of events, and use of coping strategies to deal with these events. Several theorists have made contributions to this approach (e.g., Epstein, 1998; Mischel & Ayduk, 2004), but the overall framework is in keeping with the idea of Hebbian learning through network activation. Mischel and his colleagues have recently developed a cognitive affective personality (CAP) theory, making use of Cognitive Affective Units (CAUs) seen to operate within a connectionist network (Mischel & Ayduk). In their model, CAUs are variables encoding features of situations, which include environmental effects as well as self-initiated thoughts.

When repeatedly exercised, temporally linked clusters of thoughts, emotions, and action tendencies to a particular situation will become highly likely to reoccur and difficult to change; some of the processes may be conscious and others unconscious; in most cases the thoughts about affectively significant material will be self-referent. Research on the distinction between conscious and unconscious processes has shown that special networks are active only when items are conscious (Dehaene et al., 2004). Studies of self-reference have also suggested activation of specific networks of neural areas (Gusnard, Akbudak, Shulman, & Raichle, 2001).

In applying this approach to control of distress, one basic question is how to weaken the mental connection between the situation and its component reactions. In the Eastern tradition, this is done partly through meditation, when ideas can be brought up in a context of calmness and safety, and partly through changing the view of the self so that situations will become less threatening. Links between thoughts and emotions or action tendencies are also weakened. Western therapy similarly works through the client's patterns of reaction, attempting to rework previously consolidated patterns and to provide new frameworks for meaning. From a developmental view, one would wish to give the child the kinds of experiences that will form favourable and noninjurious mental habits.

These clusters of reaction are also based on individual differences in personality, including emotions, expectancies, beliefs, values, goals, self-evaluations, appraisals, and thoughts about the situation and/or others. Individuals differ in the "ease of accessibility" of CAUs as well as in the organization among them. CAUs will be influenced by temperamental predispositions, but they will also be influenced by socialization and experience. Coping and the application of effortful control will operate when "the subjective meaning of the situation, including its self-relevance and personal importance, are appraised. The appraisal itself activates a cascade of other cognitive-affective representations within the system – expectations and beliefs, affective reactions, values and goals" (Mischel & Ayduk, 2004, p. 105).

Different coping strategies will follow, and may be consolidated or rejected in the future depending in part on their consequences. To develop this idea, Mischel and Ayduk, 2004, give the example of individual differences in rejection sensitivity (RS), which they interpret from the CAU perspective.

When persons are particularly prepared to perceive rejection, attention is likely to be narrowly focused on this possibility, and defensive behaviors such as anger or preventative rejection of the other, may serve to fend off rejection. It has been demonstrated that rejection by a social group can influence areas of the anterior cingulate related to executive attention and pain (Eisenberger, Lieberman, & Williams, 2003). These strategies in turn can also provide further support for the idea that the self is unworthy of positive social relationships. Different levels of generality of CAU are possible. Rejection sensitivity, for example, might extend to a wide range of human relationships, but the sensitivity may also be more specific, so that only rejection by the child's peers but not by adults is sensitized. The reaction may in fact be limited to a single person in a single kind of situation, in which a particular person but not other persons, elicits rejection sensitivity.

Socialization in Western cultures strongly emphasizes the fate of the individual, thereby promoting the pursuit of individual security, satisfaction of individual desires, and achievement of a positive self-concept. In other cultures, the shaping of the child's CAUs can be quite different. Mascolo, Fischer, and Li (2003) suggest, for example, that the biological systems on which pride and shame are based are the same across cultures, yet the responses can be shaped in quite different directions. In the U.S., pride reactions develop as parents and others praise the child's accomplishments; shame reactions occur when there is self-referent failure. In China, however, parents downplay or criticize children's performance while other adults praise it, leading to more moderate prideful affect. Shame, on the other hand, is directly encouraged by parents and others when children are seen not to fulfill their obligations to family.

The biological equipment that underlies temperament is similar across cultures, but the mental habits and representation of self created as a result of the child's actions varies from culture to culture (Ahadi, Rothbart, & Ye, 1993). There is flexibility in the shaping of what is rewarding and what is punishing, so that by the time a child is a well-socialized member of the society, more biologically based responses will have been shaped into a set of values, goals, and representations of the self and others that specify what is good and bad for the person. Even for the child who is not well-socialized, parts of cultural socialization may have had an effect. The child in the U.S., for example, may continue to pursue a positive self-concept, even though the goals and values followed to achieve it may not be socially acceptable ones.

Plasticity

Much of modern psychology is involved in the diagnosis and treatment of mental illness or disturbance, and the network framework may be an ideal one for incorporating ideas related to clinical remediation. An excellent example of this approach has been in the recent studies of Mayberg (2003) on clinical interventions for depression based upon a neural network model. Treatments involved drugs or cognitive behavioral therapy. Both forms of therapy were about equally effective based on percentages of persons showing improvement. Imaging data, however, indicated that the two therapies involved very different brain networks. The drugs remediated a largely subcortical network of brain areas that might be difficult to control voluntarily. The cognitive-behavioral therapy affected cortical networks, including areas involved in attention that would be more easily subject to voluntary control. These findings show how important network approaches are likely to be in evaluating the outcome of clinical trials.

A similar story may emerge in the study of dyslexia. Many forms of dyslexia involve difficulty in phonological processing that can be remediated by an intervention that targets the ability to convert visual letters to sound (McCandliss et al., 2003). Following remediation, there is normal activation of a brain region at the boundary between the temporal and parietal lobes related to phonology. However, while these students can now decode words, they do not show fluent reading. This may require development of the visual word form system, which involves an extrastriate visual region (fusiform gyrus) quite distinct from the phonological areas (McCandliss, Cohen, & Dehaene, 2003). It is likely that time spent reading is one way to develop this brain area, but it may also be possible to create special training exercises that target this area, as has been done for phonological intervention.

The possibility that aspects of brain networks involved in depression and dyslexia might be remediated by therapies based on training illustrates the close connection between therapeutic interventions designed to correct deficits and education designed to improve the performance of people in general. From the perspective of improving neural networks through specific training, therapy and education can represent similar approaches to improving network efficiency.

A central aspect of the executive attention network is the ability to deal with conflict. We used this feature to design a set of exercises adapted from efforts to train monkeys to perform tasks during space missions (Rumbaugh & Washburn, 1995). These exercises resulted in training monkeys to resolve conflict in a Stroop-like task (Washburn, 1994).

Our exercises began with training the child to control the movement of a cat on a computer screen by using a joystick, as well as prediction of where an object would move on the screen, given its initial trajectory. Other exercises emphasized the use of working memory to retain information for a matching to sample task and the resolution of conflict.

We have tested the efficacy of a very brief five days of attention training with groups of four-year-old children. The children were brought to the laboratory for seven days for sessions lasting about 40 minutes. These sessions were conducted over a two- to three-week period. The first and last days involved assessment of the effects of training by use of the attention network test (ANT), a general test of intelligence (the K-BIT, Kaufman & Kaufman, 1990), and a temperament scale (the Children's Behavior Questionnaire or CBQ, Rothbart, Ahadi, Hershey, & Fisher, 2001). During the administration of the ANT, we recorded 128 channels of EEG to observe the amplitude and time course of activation of brain areas associated with executive attention in adult studies (Rueda, Fan, & Posner, 2003).

During our first experiment, we compared 12 children who underwent our training procedure with 12 who were randomly selected and took no training, but came in twice for assessment. In our second experiment, we again used four-year-olds, but the control group came in seven times and saw videos that required an occasional response on their part to keep them playing. All of the children seemed to enjoy the experience and their caregivers were quite supportive of the effort.

Of course, five days is a minimal amount of training to influence the development of networks that develop for many years. Nonetheless, we found a general improvement in intelligence in the experimental group as measured by the K-BIT. This is due to improvement of the experimental group in performance on the nonverbal portion of the IQ test. We also discovered that the reaction time (RT) measures registered with the ANT were highly unstable and of low reliability in children of the age we were testing; thus we were not able to obtain significant improvement in the measures of the various networks, although overall RT did improve. We did not observe changes in temperament over the course of the training. Our preliminary analysis of the brain networks using EEG recording suggested that the component most closely related to the anterior cingulate in prior adult studies could be seen in the four-year-olds (Rueda, Posner, Rothbart, & Davis-Stober, in press), and the component became apparent at a lower latency in the trained children. Because of the variability of RT in the four-year-old children, we are currently replicating our study with six-year-olds. We have also begun studying the early acquisition of word knowledge, using a program called word building (McCandliss et al., 2003) in samples of children who have previously undergone attention training and control children.

As the number of children who undergo our training increases, we can examine aspects of their temperament and genotype to help us understand who might benefit from attention training. To this end we are currently genotyping all of the children in an effort to examine the candidate genes found previously to be related to the efficacy of the executive attention networks.

We are also beginning to examine the precursors of executive attention in even younger children, with the goal of determining whether there is a sensitive period during which interventions might prove most effective. There is already some evidence in the literature with older children who suffer from attention deficit hyperactivity disorder (ADHD) that using attention training methods can produce improvement in the ability to concentrate and in general intelligence (Kerns, Esso, & Thompson, 1999; Klingberg, Forssberg, & Westerberg, 2002; Shavlev, Tsal, & Mevorach, 2003). As a result, we are also working with other groups to carry out attention training in children with learning-related problems such as ADHD and autism. These projects will test whether the programs are efficacious with children who have special difficulties with attention as part of their disorder. We also hope to have some preschools adopt attention training as a specific part of their preschool curriculum. This would allow training over more extensive time periods, and testing of other forms of training such as those that could occur in social groups (Mills & Mills, 2002).

While we do not yet know whether our specific program is effective, much less optimal, we believe that the evidence we have obtained for the development of specific brain networks during early childhood provides a strong rationale for sustained efforts to see if we can improve the attentional abilities of children. In addition, it will be possible to determine how well such methods might generalize to the learning of the wide variety of skills that must be acquired during school.

The Future

Hebb provided a basis for viewing brain activity in terms of networks that could compute the various functions underlying human thoughts and feelings. He also attempted to treat all the issues that would normally be included in elementary psychology textbooks in terms of this common framework. With the addition of new methods, we believe that the task of integrating all aspects of scientific psychology in a common framework seems even more possible than when Hebb undertook it.

Fifteen years of cognitive studies using neuroimaging have laid out large-scale networks underlying many cognitive and emotional tasks (Posner, 2004a). The distinction between conscious and unconscious processes so central to psychological thinking has also shown that special networks are active only when items are conscious (Dehaene et al., 2004). Studies of self-reference have also suggested activation of specific networks of neural areas when the self is the object of thought (Gusnard et al., 2001). It seems clear that most, if not all, topics of psychology can be explored at the neurosystems level when psychological tasks come together with neuroimaging. The depth and breadth of these links will grow in the years to come.

Attentional networks have been among the most studied of all topics. The existence of attentional networks has been documented and many psychological studies have aimed to explore their development in infancy and childhood (Ruff & Rothbart, 1996). Attention has been unique in the range of its coordination between neurosystems studies and studies at the cellular and molecular levels (Posner, 2004b).

It seems clear that many other topics of emotion and cognition for which there can be reasonable animal models will be undergoing a similar development. Animal studies have already begun to yield clues as to the evolution of cognition and emotion at both the behavioral and molecular level. Enhanced links between human and animal studies are sure to develop in the years ahead.

The important developments that have taken place in computational network models provide a degree of integration between many behavioral studies and gives promise of increasing the usefulness of connections between brain systems and behavior (McClelland & Siegler, 2001).

The study of human and animal genetics is also illuminating the basis for individuality. A view of brain networks developing under combined genetic and experiential control provides a systematic basis for understanding how common networks can be linked through the study of genetic polymorphisms and socialization to an examination of individual differences. By relating task performance to self and other reported questionnaires as we have done in our work (Gerardi-Caulton, 2000; Rothbart & Rueda, in press), it is possible to examine the role of cultural and other social processes in the development of these networks (Ahadi et al., 1993).

The finding that different treatments with common behavioral results (Mayberg, 2003) can influence different brain areas indicates how a network approach may aid the design of clinical and educational interventions.

At a scientific level, Hebb's dream of an integrated psychology is coming about. In their important chapter and book, Sternberg and Grigorenko (2002; in press) lay out the many politicial and social impediments that any effort at an integrated psychology faces. These factors may unfortunately lead to a failure to realize the old dream of an integrated science, but the opportunities are clearly there. Hebb has led the way.

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Résumé

Dans un article paru récemment et dans un ouvrage à paraître, l'ancien président de l'American Psychological Association, Robert Sternberg, fait valoir la nécessité de déployer les efforts nécessaires pour réintégrer la psychologie en tant que science (Sternberg, sous presse; Sternberg & Grigorenko, 2001). Dans le présent article, nous soutenons que D. O. Hebb a, en publiant son volume technique en 1949 et, par la suite, une série de manuels d'introduction, présenté de manière convaincante la base d'une telle intégration. Le fondement de cette intégration repose sur la compréhension du rôle des gènes et de l'expérience dans le façonnement du réseau neuronal sous-jacent de la pensée, des sentiments et des gestes chez l'être humain.

Pourquoi ne reconnaît-on pas d'emblée le rôle des réalisations de D. O. Hebb dans cette intégration si nécessaire à la psychologie? Nous avançons que les méthodes dont disposait Hebb – des activités de recherche sur les animaux et des expériences sur le comportement humain pour la plupart – n'étaient pas suffisantes pour produire des méthodes empiriques qui auraient pu relier son système nerveux conceptuel à des activités réelles du cerveau humain. Cette méthodologie est aujourd'hui appuyée par la neuroimagerie. Bien que Hebb ait lui aussi reconnu l'importance d'étudier les différences individuelles qui caractérisent l'intelligence et l'affect, il n'existait, à son époque, aucune méthode permettant d'étudier à fond les gènes qui étaient à l'origine de ces différences. Le projet du génome humain a fourni des nouvelles méthodes d'analyse de cette question. L'idée fondamentale chez Hebb, de même que les nouveaux outils méthodologiques et les nouvelles disciplines (p. ex., la neuroscience cognitive, affective et sociale) qui se fondent toutes sur le réseau neuronal, fournit des preuves abondantes de la valeur du recours à la stratégie des opérations convergentes mise de l'avant par Sternberg et Grigorenko (2001).

Il importe que la psychologie reconnaisse la nécessité d'intégrer la neuroscience cognitive, affective et sociale avec la psychologie, car plusieurs des questions théoriques que doivent aborder la neuroimagerie et la génétique sont en tout point les mêmes que celles que se posaient, il y a un siècle, les psychologues. L'approche de la neuroscience fournit des contraintes critiques qui alimentent les théories psychologiques mais elle offre aussi un contact plus étroit avec le niveau d'analyse de la psychologie.

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