■Special Lecture

New Thoughts on Functions of the Right Hemisphere

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I. Introduction: The Trap of Traditional Dogma

The major conclusion of this paper is the following: traditional anatomical models of brain-behavior relationships are yielding to a new understanding. Human behaviors are based on dynamic and complex interactions of chemical networks, called pharmacosystems. Cognitive function, sometimes labeled "higher cortical function", is constructed upon the interaction of semi-autonomous psychological networks called cognitive modules. Cognitive modules represent functional units of the brain. There is no point-to-point mapping of cognitive modules onto brain anatomy. Rather, brain-behavior relationships may be understood as a dynamic coupling between pharmacosystem networks and cognitive modules.

The concept of cerebral dominance, hence also "right hemisphere" functions, must be revised. Stated in its simplest, most concrete form, functions of the right hemisphere can only be understood in relation to functions of the left hemisphere, and to limbic system and reticular activating system function as well.

We have been led to a frozen, rigid, and ultimately incorrect conception of brain-behavior relationships because of our unyielding attachment to the dogmas of an earlier scientific technology. New methods of exploring the anatomy, physiology, and chemistry of the brain are yielding research results which challenge traditional concepts. We should respond to the challenge by breaking out of the rigid mold which constrains our thinking about brain-behavior relationships and by attempting to devise novel hypotheses which account for all available evidence, not just those pieces of the evidence which conform to traditional teachings.

This new approach to brain-behavior relationships states explicitly that cognitive functions, such as visuo-spatial manipulation or even language, cannot be "found" anywhere in the brain. Cognitive functions are constantly being created and re-created in ever-changing form by the integrated activity of the entire brain in response to everchanging external stimuli and internal need and capability.

I have divided the rest of this paper into three parts. In the first, I shall briefly review the traditional understanding of right hemisphere functions. In the second, I shall discuss some new research findings on right hemispheric function—mainly from research-

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ers at our Aphasia Research Center in Boston —which fit into the traditional stream of neurobehavioral studies, but which also start to point to the new conceptual approach. In the third, I shall present some neurobehavioral data, not exclusively related to the right hemisphere, which may be explained in a non-traditional way and which may serve as evidence in support of a new concept of brain-behavior relationships.

II. Functions of the Right Hemisphere: A Brief Review

A review of the entire history of right hemisphere functions would be beyond the scope of this paper. Instead, I would like to present a plan for organizing one's thinking about the right hemisphere. Studies of right hemisphere functions can be organized into two major categories; 1. syndromes resulting from right hemispheric damage; 2. neuropsychological mechanisms of normal right hemispheric activity. In many instances, hypotheses of normal right hemispheric activity were inferred from studies of deficits following brain damage.

1. *Neurobehavioral Syndromes due to Right Hemisphere Damage*

It is widely believed that studies of right hemisphere syndromes are relatively new in neuropsychology. That belief is only partly correct. Already in the 1890's scientists were describing pieces of the right hemisphere syndrome—without organizing them into a syndrome. For example, in 1890 Foerster described loss of orientation, loss of sense of place, and loss of memory for place. In 1893 Anton described anosognosia, i. e. denial of illness. In 1909 Balint described defective exploration of space due to a parietal lesion; and in 1914 Babinski (of the Babinski sign) related anosognosia (denial of hemiplegia) to a focal cortical lesion.

Thus the stage was set for the discovery of a right hemisphere syndrome. In 1922 Pierre Marie described two patients with "planotopokinesia", an inability to orient themselves in a two-dimensional plane. Russell Brain, in 1941, was the first to describe a true right hemisphere syndrome—he identified "dressing apraxia" as a syndrome related to right parietal lesions.

The first modern neuropsychological description, however, of the right hemisphere syndrome was provided by Henry Hécaen in 1956. He described "the syndrome of apractagnosia of the minor hemisphere". This syndrome consisted of disorders of the recognition and use of spatial information, including visuo-constructive deficits, spatial dyslexia, disorganization of spatial orientation, and unilateral spatial neglect. Virtually all subsequent studies of right hemispheric function are dependent on this original observation of Hécaen and his collaborators.

Since then, hundreds of books and papers have been published on syndromes of the right hemisphere. In the contemporary period, for example, Heilman et al have contributed considerably to our understanding of the neglect syndromes; and Mesulam has added to our knowledge by providing a theoretical model relating neglect syndromes to a cortical network for spatial distribution of attention, dependent on right hemispheric dominance.

Besides the disorders of space related to right hemispheric damage, disorders of control of melody and emotion are also related to right hemispheric damage. Ross has described syndromes of dysprosody; Gainotti and Heilman and others have described disorders of emotional expression and reception.

2. *Neuropsychological Mechanisms of Right Hemisphere Activity*

As soon as it was determined that a special syndrome could be related to right hemisphere damage (i. e. the apractagnosic syndrome described by Hécaen in 1956), neuropsychologists attempted relentlessly to discover the contrasting mechanisms of the two hemispheres. Integrated function of the whole brain has been relegated to the background (I shall return to a consideration of the integrated function of the whole brain in my concluding section). Rather than attempting to explain all available evidence, neuropsychologists have preferred to select bits and pieces of evidence which facilitate a dichotomous analysis between left and right hemispheric functions. The techniques of the scientific method have been subverterd to conform to a particular point of view. The frame of reference is this : asymmetry of function at the level of the hemisphere is the dominant or primary basis for brain-behavior relationships. (I do not believe that this dichotomy is necessarily the primary neural basis for cognition. I believe that more basic biological mechanisms than hemispheric asymmetry of function underlie human behavior. I discuss this alternative approach below).

The dichotomous approach to asymmetry of hemispheric function assumes that the two hemispheres are independent information processing units, with each unit having its own unique cognitive style (LeDoux). Thus, neuropsychologists talk about left hemisphere behaviors or right hemisphere behaviors. (Example : A workshop was held in the Boston area this spring by a psychiatrist and a social worker. The goal of the workshop was to improve family relationships and reduce marital problems. People who were unhappy in their marriages were participants. The program was designed to discover the "thinking preference" style of each husband and wife—right brain or left brain. Once the cognitive style was determined, the styles could be made to harmonize. If the husband had a right brain style and the wife a left brain style, the marriage could be improved by changing each others cognitive style).

Among researchers in the field, the first dichotomy of left brain vs right brain was, naturally, verbal vs non-verbal. Subsequent contrasts have all had some advocates, and each contrast has evidence to support it. (My belief is that the evidence exists, but was selected in a biased manner from the larger pool of evidence). Contrasts include :

Left hemisphere	Right hemisphere
verbal	non-verbal
analytic	synthetic
semantic	perceptual
sequential	non-sequential
detailed	holistic
realistic	impulsive
logical	intuitive
objective	subjective

From these contrasts have emerged the notion that the left hemisphere is the rational, verbal, systematic hemisphere, and the right hemisphere is the creative, artistic, spiritual, imaginative hemisphere. (Example : a two-page advertisement for Toyota in an American magazine showed simply a picture of the car on the left page and a long verbal description of the car on the right page. The title of the advertisement was "A Car for Both Sides of Your Brain").

Bogen ; Gazzaniga ; LeDoux, and others have demonstrated that these contrasting styles do not represent an accurate picture of brain function. There is more symmetry in the brain than asymmetry. Few contemporary theories of brain function take brain symmetries into account. The major emphasis is on asymmetry, and on dichotomy. I might ask why limit oneself to two brains? Why not three or more? (A perceptive article on the history of "duality of mind" by Harrington discusses this very point).

Nevertheless, there is what we might call the standard belief system. To summarize, if we combine the syndrome approach with the normal mechanisms approach, we could produce a fair statement of the principal role of the right hemisphere, as generally accepted (Hécaen and Albert : Mesulam) :

The right hemisphere is said to be specialized for

1. complex non-linguistic perceptual skills
2. the spatial distribution of attention
3. reception of spatial stimuli and manipulation of spatial activity
4. experience and expression of emotion
5. paralinguistic aspects of communication.

III. Language in the Right Hemisphere: Some Recent Research

In this section I do not intend to consider all contemporary research being done on the right hemisphere. Rather, I shall talk only about selected studies of language and the right hemisphere which have been carried out by my colleagues and me at the Aphasia Research Center in past few years.

Because this paper is not intended to be a research report, but rather a synthesis and formulation of ideas (i. e. a statement of theory and of principle), I will not review the experimental methodologies, but will only comment on the major conclusions. If we could convincingly demonstrate a major, on-going or potential contribution of the right hemisphere to language, we could argue that the traditional concept of cerebral dominance has to be revised.

Three sets of studies can contribute to our understanding of the role of the right hemisphere in language. One set of studies is the work that Loraine Obler and I did on bilingualism. We found more crossed aphasia in bilinguals than in unilinguals, suggesting that the presence of a second language engages the right hemisphere more in language function. We also found that certain specific languages may engage the right hemisphere more than others, Hebrew, for example.

We have proposed the "stage hypothesis" for learning a second language. According to this hypothesis, the right hemisphere is engaged in the first stages of learning a second language. Gradually, dominance for the second language shifts to the left hemisphere as fluency develops.

The implication of this hypothesis is that the right hemisphere has the potential for language throughout life.

A second set of studies of language in the right hemisphere from our department is by Hiram Brownell, Howard Gardner, and Edgar Zurif. These studies relate to the paralingusitic aspects of communication. They have demonstrated that patients with right brain damage have lost the ability to make logical inferences—they fail in inferring what is *likely* to happen in a given context. They have no difficulty with the denotative aspects of language, but have lost the full sense of the connotative aspects of language. They have great difficulty in arriving at the overall point or theme of a text. And, especially, they have lost the *metaphoric* content of language. It is these disabilities, it seems, which contribute to the apparent impression that patients with right brain damage have lost emotional receptivity.

A third, and quite remarkable set of studies, is by Davis Howes. He has evidence to support his dramatic hypothesis that a full and complete vocabulary exists in the right hemisphere. In other words, he is claiming that in patients with severe aphasia, by using the proper techniques, we can discover a complete storehouse of information about the meanings of words together with the algorithms for retrieving information about these words—all in the right hemisphere.

His technique of investigation is original—he conducts his analysis by *mathematical parameter*, which separates processes which are intact from processes which are defective in individual patients ; and by *computerized sequential testing*. He uses hundreds of tests, which vary only slightly from one to another, to build up a complete range of possibilities. Most neuropsychological testing dces spot checking, like a customs agent. He fills in the full picture, and by this means, has discovered capabilities in brain damaged patients that many of us never even dreamed of.

These three sets of studies which have tested different subject populations (bilinguals, right brain damaged, left brain damaged) and which apply different experimental methodologies, all point to the same conclusion : the right hemisphere plays an active role in the daily use of language ; and it has a potential role much larger than had previously been considered.

IV. Brain-Behavior Relations : Building Blocks and Pharmacosystems

Using "functions of the right hemisphere" as my point of departure, I am trying to build a case in favor of a new theory of brain-behavior relations : Cognitive functions are not localized in a particular part of the brain, but are constructed from building blocks which are located anatomically in many different parts of the brain and which are linked by networks—anatomical and chemical networks. To make my point, I have been looking mainly at language, but the same argument holds for other cognitive functions as well.

In this section I want to add to my argument from a different point of view. Suppose we asked—what if there were no such thing as "visuospatial knowledge" ? What if there were no such thing as "language" ? Suppose we argued that language is an epiphenomenon. If language were an epiphenomenon, then aphasia would be an epiphenomenon. And we could then ask—an epiphenomenon of what ?

During the past three years my colleague Jennifer Sandson and I have been looking at the problem of perseveration. (This is a problem on which Dr. Yamadori has done some important research). I want to discuss perseveration briefly, and then indicate how perseveration is related to aphasia and to right hemisphere function, and how the study of perseveration can change the way we think about brain-behavior relations.

We have described three different forms of perseveration : stuck-in-set, which is the inappropriate maintenance of a category or framework of activity ; recurrent, which is the repetition of a previous response to a subsequent stimulus ; and continuous, which is the abnormal prolongation of a current activity.

We devised a battery of tests of perseveration, and administered this battery to different subject groups : dementia of the Alzheimer type, aphasics, right brain dama-

Correlates of Perseveration

	Types of perseveration		
	Recurrent	Continuous	Stuck-in-Set
Cognitive Dysfunction	Disorders of Language	Disorders of Visuo-spatial Manipulation	Disorders of Integration of Multiple Inputs
Cognitive Process	Failure to Access Specific Information in Semantic Memory	?Disorder of Attention	Disorders of Executive Function
Anatomic Correlate	Left Hemisphere, temporoparietal	Right Hemisphere	Fronto-subcortical, mesolimbic
Chemical Correlate	Cholinergic	Noradrenergic	Dopaminergic

ged, frontal system damaged, and normal controls.

We found that stuck-in-set perseveration was linked to frontal system damage, recurrent perseveration was linked to left brain damage with aphasia, and continuous perseveration was linked to right brain damage.

We also found correlates of perseveration with specific neurobehavioral deficits and with specific pharmacosystem abnormalities, as indicated in the table. For example, we found perseveration to be one of the fundamental causes of paraphasias, a problem which had previously been thought to be strictly linguistic. In other words, we found an aphasic defect to be built upon the building block of another, more fundamental defect.

The strongest point of my argument comes next: Together with Nancy Helm-Estabrooks we treated an aphasic patient by "perseveration deblocking". We did not use aphasia therapy, we used perseveration therapy. As we caused the perseveration to decrease, the paraphasias decreased also. But even more importantly, as we treated the perseveration, naming ability returned as well. Naming, which is considered to be a strictly linguistic phenomenon, was dependent on mechanisms of perseveration.

We have found that visuoconstructive deficits due to right brain damage are linked to continuous perseveration. And the treatment of perseveration in those cases could ameliorate the so-called right hemisphere disorder.

Basing our work on the principles described in this paper, we have even begun treating specific neurobehavioral symptoms with pharmacotherapy—with some startling early results.

V. Conclusions: Cognitive Modules, Networks, and Cake

As I approach my conclusions, I would like make clear the focus of my argument. I have been using the topic "the functions of the right hemisphere" to make a new point: it may be that there is no such thing as "the functions of the right hemisphere", as we have understood that term in traditional neuropsychology.

I would like to repeat a point which I made earlier: Cerebral functions cannot be localized anywhere in the brain. "Higher cortical functions" emerge from the mathematical combination of their building blocks, but they don't look anything like the building blocks, and they can't be found by trying to find the building blocks. Consider the following analogy. A specific behavioral function, such as the ability to dress oneself, or topographic memory, or visuo-constructive skills, or language, could be compared with a cake. A cake is made up of butter, eggs, milk, sugar, and flour. Each of these components of the cake has its own chemistry. Each could be studied in its own right. Each is independent of the other, although there is some overlap. (Butter and milk, for example, have points in common.) When you mix these several independent components together and bake them, you produce a cake. The cake, as a cake, has very little in common with any one of its ingredients. The combination of the building blocks of the cake produces something new and different in structure and function. Furthermore, you cannot find butter, eggs, or milk, etc., in the cake. They have disappeared. Their combination transforms them into something else.

So it is for cognitive functions.

A principal difference between constructing a cognitive module and baking a cake is the factor of dynamics. Cognitive functions are constantly being created. From instant to instant language, perception, gnosis change in response to everchanging external stimuli and internal needs and capabilities. The factor of *constant change* must be included in any comprehensive theory of cognitive function.

The principal conclusions I would like to draw are these :

1. We must move away from a strictly anatomical approach to brain-behavior relations. This approach was based on the best technology we had at one time : clinicopathological correlation. Technological advances, however, allow us new ways to study brain function, and we must discard our static conceptions of brain activity.

2. The brain is plastic and dynamic at all ages, not just in childhood. Cognitive functions are constantly being created, from moment to moment. A useful theory of cognition must not only attempt to capture the mechanisms underlying a behavior at a given moment, but also must capture the meaning inherent in the process of change itself. The dynamics of brain activity are as much a part of cognitive functions as the structure of the brain.

3. Cognitive functions cannot be found somewhere in the brain. Functions of the right hemisphere must be understood in relation to left hemispheric activity, and limbic system and reticular activating system activity as well. Cognitive functions emerge from their building blocks. The building blocks can probably be linked to specific anatomical and chemical networks, but the complex function which emerges will be more difficult to localize. There is no one-to-one correspondence between cognitive functions and brain anatomy. The relation between behavior and the brain is a dynamic coupling between cognitive modules and pharmacosystem networks.

4. This approach to brain-behavior relations not only provides a new way of understanding behavioral function but also leads directly to specific new approaches to therapy of neurobehavioral disorders.