Technical Report 705

An Evaluative Review of Hemispheric Learning Potential

Jules Davidoff
University College Swansea

John C. Marshall
Radcliffe Infirmary

J. Graham Beaumont
University of Leicester

Alan Beaton
University College Swansea

ARI Scientific Coordination Office, London
Basic Research Office

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U. S. Army

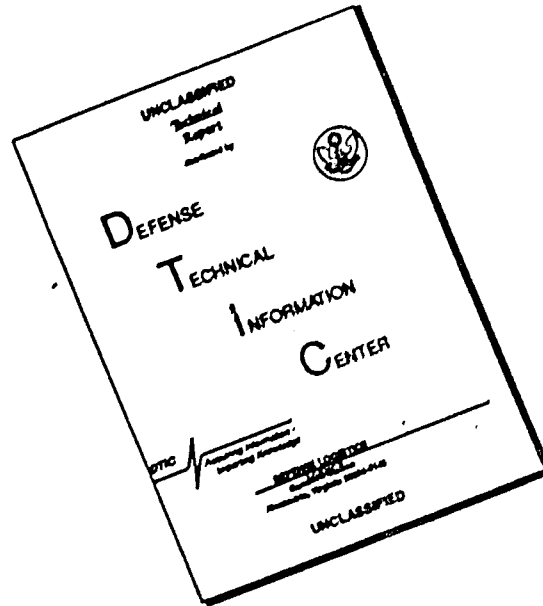Research Institute for the Behavioral and Social Sciences

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Technical review by

Milton S. Katz
George H. Lawrence

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This report reviews evidence from several sources that conclusively shows the two hemispheres of the human brain have different functional organizations for cognition. The notion of hemisphericity--that there is a way of thinking that relies on one half-brain--is critically considered. Despite the reasonability of the assumption, there is, as yet, no good evidence to show that any procedure based on hemisphericity principles enhances learning potential.

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Jules Davidoff
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Michael Kaplan, Chief

Basic Research Office
Milton S. Katz, Director

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FOREWORD

The Basic Research Office of the Army Research Institute for the Behavioral and Social Sciences has initiated a program to develop new technologies for enhancing human performance. An important part of this endeavor evaluates commercial claims based, in some cases rather loosely, on scientific observations originally made in psychological laboratories. Few recent phenomena have led to more such claims than the observations that the human cerebral hemispheres appear, to some degree, to have different specialized functions.

This review of the relevant literature provides the ground work for ongoing investigation of related phenomena and documents ARI's commitment to pursuing new means of enhancing soldier/unit performance.

EDGAR M. JOHNSON
Technical Director

AN EVALUATIVE REVIEW OF HEMISPHERIC LEARNING POTENTIAL

CONTENTS

AN EVALUATIVE REVIEW OF HEMISPHERIC LEARNING POTENTIAL

1. THE NOTION OF HEMISPHERICITY: AN INTRODUCTION

The current notion of hemisphericity encompasses a wide domain of empirical observation and theoretical interpretation. It begins with the undoubted fact that different areas of the human brain are specialized for different sensory, motor, and cognitive functions and ends with the claim that each cerebral hemisphere within the brain supports a "mind" that is largely independent of its paired "twin." As Wigan wrote in 1844: "The mind is essentially dual, like the organs by which it is exercised." Along this continuum scholarly opinion begins to diverge about the significance of modern brain and behavior research. At one end, there is reasonable consensus that the human brain is indeed characterized by considerable localization of function; at the other end, there is radical disagreement over the claim that such phenomena as consciousness, personality, and cognitive style may each be disjoint within a single individual. The review that follows attempts to disentangle fact from speculation in the key areas that are relevant to the learning capacities of the cerebral hemispheres. It is useful to begin, however, with a brief historical survey of how the issues came to be framed in their current form.

To casual inspection, the human brain (and the brain of other vertebrate species) appears to be bilaterally symmetrical at the level of the cerebral hemispheres. This apparent anatomic symmetry naturally leads to the supposition that the two hemispheres are functionally equivalent (as in the case with other paired organs, such as the eyes, ears, and kidneys). Yet the physicians who compiled the Hippocratic Corpus some two millenia ago observed that injury to one side of the head is often associated with paralysis or weakness of the opposite side of the body; they further noted that loss of speech and language (dysarthria and dysphasia) is usually associated with right hemiparesis. For modern scholars, the conclusion that the left hemisphere is dominant for language processing seems inescapable. Yet neither the Greek doctors nor the many later European neurologists who made similar observations drew this conclusion.

Localization of function in the cerebral cortex first assumed importance in the work of the phrenologist Franz Joseph Gall. The early 19th-century neurologists, inspired by the phrenological movement, succeeded in showing that localized brain damage could give rise to specific cognitive impairment (of language, spatial perception, and memory, e.g.). Yet in Gall's model of brain functioning the faculties responsible for these skills were duplicated in homologous locales in the two hemispheres. The effects of unilateral brain damage were thus interpreted as disorders consequent on perturbation of the symmetrical, simultaneous functioning of the two hemispheres. Each side of the brain was thus regarded as a complete cognitive organ. As Bouillard (1825) wrote: "We have a double intelligence: an intelligence on the right and an intelligence on the left."

This view did lead, however, to the speculation that the two minds associated respectively with the two hemispheres could become dissociated from each other. In particular, it was argued that one mind could become mad while the other remained sane. Split-personality thus became linked to the independent

functioning of the hemispheres. Wigan (1844) was the most forceful advocate of such a position. He argued that, normally, one hemisphere exercises control over the other (thus leading to the "illusion" of a unified self), but that in pathological circumstances each hemisphere can, as it were, pursue independent purposes.

This concept of dominance, or superiority, led irrevocably to socio-political interpretations of the relations between the hemispheres. The left hemisphere, motorically dominant, as expressed by the fact that most people are right-handed, was argued to be more "human" than the "animal" right hemisphere. The left was argued to be more intelligent and objective while the right was said to be more swayed by subjective emotions; the left was the seat of ration-ality, the right of madness. The left hemisphere was thought to be the source of male virtues, the right of female weaknesses. The left enthroned the supe-riority of white races, the right the inferiority of nonwhite races. All these concepts are still present in many current discussions of hemisphericity, al-though (partially) purged of their more obnoxious sexist and racist connotations.

These early 19th-century views nonetheless preserved the notion that each hemisphere had the same cognitive capacities, albeit with greater or lesser strength and effectiveness.

This overall picture changed when in the 1860s Paul Broca convinced the scientific community that "on parle avec l'hemisphere gauche." Broca finally saw the implications of the kind of observation that had been made by the Hip-pocratic physicians. He reported a series of autopsied cases of aphasia with relatively focal left-hemisphere lesions and argued that the (cognitive) domi-nance of the left half of the brain was expressed in its control of both lan-guage and (preferred) handedness.

What, then, was the cognitive function of the right hemisphere? Many 19th-century neurologists seem to have believed that the right hemisphere (of right-handers) was merely a spare, functionless entity that came into use only by taking over the functions of the left, should the latter hemisphere be dam-aged. This claim likewise came under attack when the English neurologist Hughlings Jackson (1876) speculated, on the basis of a case of unilateral right-hemisphere damage, that the right hemisphere plays the leading role in "visual ideation." Thus arose the modern notion of "complementary specializa-tion," in which each hemisphere is differentially specialized for the exercise of particular cognitive functions. We shall see, however, that aspects of all 19th-century conjectures recur in contemporary accounts of hemisphericity.

2. PSYCHOLOGICAL AND NEUROLOGICAL BACKGROUND TO COMPLEMENTARY HEMISPHERIC SPECIALIZATION

An intelligent organism must identify and locate the objects in its envi-ronment; it should plan and execute action appropriate to the situation. A constantly updated record of experience must be kept, a record that, in the human case, can be described in language. The first steps toward a neurobiol-ogy of cognition were taken in the late 19th century when it was discovered that many such higher mental functions could be selectively impaired by rela-tively focal brain lesions. Subsequent work has been devoted to obtaining a more detailed picture of possible behavioral fractionations and more precise

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anatomo-clinical correlations as assessed either by histology at autopsy or by computerized axial tomography (CT scan) in vivo. Current studies have also emphasized the desirability of interpreting pathology within the framework of computationally explicit models of normal performance. The virtues of data that converge from different sources are obvious, although the possibility both of brain reorganization after pathology and of strategic adaptation to deficit cannot be discounted when inferring theories of normal cognition from lesion studies. Nonetheless, single-case studies of selective deficit consequent upon brain lesion do seem to have provided privileged insight into the biological fractionation of mind.

One issue central to current inquiry concerns the specificity of the component mechanisms and processes involved in object recognition, spatial orientation, praxis, language production and comprehension, arithmetic calculation, music, and episodic memory. Is the functional architecture of mind such that general principles of perceptual and response organization, biological intelligence, and memory are applied to sensory analysis and motor execution across different cognitive tasks? Or is it rather the case that many special-purpose mental organs have evolved, each one committed to a restricted cognitive domain and instanciated in a specialized neuronal substrate? In brief, do humans have one brain, two brains, or many brains? Localization of function for elementary sensory and motor elements has not been at issue since the close of the 19th century, but argument about the nature of specialization within association cortex and the interpretation of high-level deficits is not yet fully resolved.

The basic concept of complementary specialization in which the left hemisphere plays the leading role in language processes and the right in visual ideation continues to receive qualified support. In the vast majority of right-handers, unilateral damage to the perisylvian region of the left hemisphere results in frank aphasia, which is not seen after comparable insult to the right hemisphere; there is some evidence for similar specialization at the level of the thalamus. Damage to the right hemisphere has been reported to produce disturbances of speech prosody, but not, typically, the gross impairments of sentence structure, word finding, segmental phonology, and language comprehension that are so common after left-hemisphere injury. Severe, yet isolated aphasias can be found in patients with well-preserved nonverbal intelligence, visuospatial skills, and nonverbal learning and memory functions. Attempts to reduce aphasic symptomatology to some more general processing deficit have met with very limited success. For example, the frequent co-occurrence of aphasia and apraxia might suggest a common system for the internal representation and control of moving body parts (both oral and branchial). Yet in individual cases there is full double dissociation of aphasia and (limb) apraxia, suggesting that the association of symptoms is due to involvement of contiguous anatomical areas that are respectively implicated in language and praxis. Severe Wernicke's aphasia (with word deafness) has been found, for example, in a pianist who could play melodies without difficulty, compose new melodies at the piano, and write them down accurately. Even more striking dissociations between aphasia and apraxia have been found in speakers of American Sign Language, who use the same peripheral musculature in the performance of both linguistic and nonlinguistic gestures. Such cases preclude the interpretation of language impairment as a generalized movement disorder, as does the frequently observed preservation of singing in patients with severe Broca's aphasia.

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The apraxias are usually defined as disorders in the execution of skilled purposive movements in the absence of significant motor weakness, incoordination, or sensory loss; when the patient is required to perform to verbal command, the presence of comprehension disorder must also be excluded. In severe cases, the manipulation of common objects is impaired; in milder cases, the patient may fail to pantomime the use of objects, and will often employ a body part as if it were the object (e.g., the fist will be used as a hammer). Different computational substages of the motor system are associated with the parietal cortex, cerebellum, motor cortex, and cortico-spinal pathways; patients who meet the exclusionary definition of apraxia typically have left-hemisphere lesions. In ideomotor apraxia, the spontaneous execution and execution to command of simple gestures and acts is intact, but a severe sequencing deficit is manifest when the patient, for example, attempts to make a cup of coffee. The patient may stir the cup before putting the coffee in it, pour the milk into the kettle, or put the plug of the kettle into the sugar rather than the electric socket. In such cases, the deficit is not restricted to motor execution; the patient may fail to distinguish between a random and a correctly ordered sequence of cards that illustrate the task. It would thus seem that supra-motor programs for learned acts have been lost. Although the programs for everyday acts are apparently located in the left hemisphere, specialized acts may be programed from other cortical organs. For example, severe apraxia (and global aphasia) has been reported from an infarct of the left middle cerebral artery in a conductor. Although there was gross apraxia for use of common objects (asked to demonstrate the use of a toothbrush, the patient moved it in front of his eyes, then passed it over cheeks and neck), the patient succeeded in conducting a performance of Verdi's Nabucco to the total satisfaction of Italian opera critics!

Posterior parts of the left hemisphere are also involved in arthmetic calculation, and there are now convincing reports of dissociation between the retrieval of number facts (e.g., 9 x 3 = 27) and the deployment of calculation procedures (as in long multiplication or division) in patients with left-posterior damage; selective deficits in the comprehension of operational signs (e.g., +, $\div$, - , x) have also been demonstrated with intact number understanding, arithmetic fact retrieval, and calculation procedures. By contrast, the cognitive processing of geometry draws more strongly on the intrinsic specialization of the right hemisphere. Studies of commissurotomy patients suggest an orderly progression in the relative competence of the hemispheres as one passes from Euclidean, through affine and projective, to topological geometry. The fewer opportunities for verbal encoding of the constraints and defining characteristics of projective and topological space are reflected in the right hemisphere's relative dominance for the apprehension of these forms.

Gross impairment of spatial orientation and topography can be seen after right-posterior damage in cases with preserved language skills, good verbal intelligence, and essentially normal figural perception. Visually guided maze-learning tasks are maximally impaired after injury to the right parietal area, as is the ability to perform mental rotation. In severe cases, patients cannot draw plans of their environment and frequently lose their way even in familiar surroundings when they cannot steer by landmarks. In cases of gross visual neglect it is overwhelmingly the case that injury is right-sided (and left-space neglected). Patients asked to draw a clock face may reproduce only the right-hand side and put in only the numbers from 1 to 6 (or cram all 12 numbers into the hemispace). The condition cannot be reduced to the effects

of hemianopia; most patients with field defects rapidly learn to compensate. Furthermore, left neglect has been found for central, memorial representations of space, when the patient is asked to describe from memory particular well-known locales. Whichever direction patients are asked to imagine themselves looking in, only the right side of space is described from that vantage point.

Such disorders of spatial cognition can be firmly dissociated from impairment of figural perception and object identification. Right-sided lesions, particularly in the occipito-temporal region, have a more deleterious effect on form perception (when the stimuli are visually degraded) than do comparable left-sided lesions. It would seem, however, that frank visual agnosia for objects (genuine three-dimensional objects, and their realistic representation in photographs and line drawings) is provoked only by bilateral lesions. Cases of visual agnosia cannot be reduced to a combination of sensory deficit, dementia, and aphasia. In some instances the patient who fails to recognize objects is able to draw from a model with sufficient accuracy to enable another observer to recognize the drawing. The patient may nonetheless fail to match two views of the same object. In other cases such matching can be performed successfully, and yet the patient still fails to identify the object. The impairment is not secondary to anomia; the patient can name appropriately to tactile palpation or verbal definition. Very restricted visual agnosias have been reported. The most striking is a selective deficit in the recognition of familiar faces (prosopagnosia). Faces are recognized as faces, but the unique identity of even close relatives and friends cannot be ascertained from vision alone; person identification is successful from a voice cue. There is some controversy about whether the deficit is specific to faces or rather to identification within a class of very similar members; cases have, however, been described with dissociations between, for example, flower recognition, human face recognition, and (in farmers) the recognition of specific animals within a species.

We are thus led to see cognition as a collection of special-purpose processing mechanisms, each with a proprietary knowledge base and instanciated in specialized neuronal circuitry. Learning and memory functions appear to be multiple in that they are linked to distinct cognitive domains and can be independently impaired; verbal learning is maximally impaired after left-temporal lobectomy, visual and spatial learning after right-temporal lobectomy. Even the amnesic syndrome, consequent upon bilateral damage of the medial temporal lobes, cannot be interpreted as a generalized disorder of learning and memory. The retrograde amnesia destroys neither language nor motor skills; the anterograde amnesia can spare the ability to learn perceptual motor skills, mirror reading, and some problem-solving tasks. The patients nonetheless live in a specious present, unable to bring episodes from their past into conscious recall. Yet this autobiographical capacity, so important for the development of personal identity and cultural achievement, seems quite distinct from the faculties employed in perceiving and describing the world and appropriately moving therein.

This work indicates that humans have at least two brains. That is, there are well-documented examples of cognitive functions that can be selectively impaired by lesions of one hemisphere (with essentially normal performance after comparable lesion of the other hemisphere). Further fractionation is observed in that within one hemisphere different lesions can provoke different patterns of cognitive impairment. Furthermore, for some functions (e.g., face recognition and episodic memory), gross deficit is seen primarily (or even

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solely) after bilateral lesions. It may nonetheless be the case that the mech-
anisms underlying different components of such complex tasks are located in dif-
ferent hemispheres. (Examples of selective cognitive deficit consequent upon
unilateral or bilateral injury can be found in Heilman and Valenstein, 1985.)

In some cases, there is evidence that behavior observations of hemispheric
specialization may be correlated with anatomical asymmetries. Although the two
cerebral hemispheres are grossly symmetrical, careful observation does show
quite striking anatomic asymmetries. Some of these structural differences are
present at birth, and some can be observed as early as 31 weeks of gestation.
Interest in the topic originally arose from the fact that anatomical left-right
asymmetries in the human brain are associated with some of the classical speech
areas where damage typically results in aphasia.

Thus the finding that seems most reliable and has occasioned most comment
is that the left-temporal plane (as part of auditory association cortex) is
generally bigger, sometimes substantially so, than the right-temporal plane.
However, it does not seem to be true that all the gross morphological asym-
metries in areas that form part of the neurological substrate for language show
greater development on the left side. It has been shown that the transverse
temporal gyri are on average larger or more numerous in the right hemisphere;
likewise, the superior temporal gyrus (on some accounts a part of Wernicke's
area) is larger in the right. There is also evidence that the retrosylvian
parietal region, which includes the angular gyrus, is usually larger in the
right. According to the classical lesion-derived model, all these areas are
involved in language functions. There are, however, serious problems involved
in measuring areas in objects whose landmarks are as complex and variable as
those of the human brain. Inferences from surface area to volume are similarly
fraught with difficulties. Gross morphological asymmetries must be correlated
with the extent of cytoarchitectonic regions. Some preliminary, albeit very
encouraging, results of such studies are reported in Geschwind and Galaburda
(1984), the most comprehensive account of the anatomical foundations of com-
plementary hemispheric specialization.

It is equally important, however, that anatomical studies be conducted
against a firm background of functional theory. One cannot specify where
functions are located without adequate psychological specification of what
functions are involved in human cognition.

Psychological theory has provided two main approaches to the mental rep-
resentation of objects. One of these--the dual-code theory--relates closely
to the critical notions of hemisphericity, which will be discussed later. The
other--the propositional theory--does not. A simple version of the dual-code
theory states that memories are tied to sensory modalities and that information
is represented as sensory or motor experiences. The two major senses (i.e.,
vision and audition) happen to be better dealt with by different hemispheres
and thus incidentally memory can be associated with hemispheric function. The
link to brain function has not been an important issue for the main proponents
of dual-code theory, though there has been some dabbling (Paivio & Ernest, 1971).
This lack of interest in hemisphericity is probably in part due to the diffi-
culty of running lateralized experiments involving memory of normal subjects.
Otherwise no doubt many more studies (but see the following section) would have
been carried out since the nature of the mental representation is one of the
core issues in memory research.

The necessity for dual coding in memory comes, as already noted, initially from research on clinical populations, but psychological research has added to the usefulness of the division. The evidence from normal subjects comes from at least five sources:

1. <u>Matching Studies</u>: It is much easier to judge that objects are the same than that they are different (Nickerson, 1967). Saying that objects are different is critically dependent on the number of features by which they differ; this is not the case for same judgments. If same judgments were performed by a feature-by-feature comparison, they should be very long. As they are short, we need to postulate another mechanism for same judgments, which Bamber has called an identity reporter and others a holistic processor.

The quickness of matching A to A compared with matching A to a clearly suggests that the name response (Aa) involves different mechanisms than the physically identical match (AA) (Posner & Mitchell, 1967). Furthermore, the large advantage for the identity match disappears if a couple of seconds elapse before presentation of the second stimulus. It would appear, as is reasonable, that the first letter is coded verbally because of the difficulty of maintaining an accurate visual representation. Smith and Nielson (1970) showed a similar effect for faces. The matching of two faces separated by a second is accomplished in the same time irrespective of the number of features making up the face, but this is not true for a 4-second delay. Definite limits cannot be given for the time for which a visual representation may be held. With subtle experimental designs visual representations can be shown to be intact several months later (Kolers, 1979). Specifically asking the observer to maintain the presented stimulus as an image appears to help maintain the holistic representation.

2. <u>Spatial Configuration Versus Linear Order for Stimulus Presentation</u>: The matching experiments hint at a verbal-visual dichotomy for memory representation. The experiment of Santa (1977) makes the point more clearly. Geometric shapes arranged in a face-like display were remembered better if tested using spatially similar arrays. When the shapes were replaced by their written names, assigning them to a particular configuration was unimportant. Indeed it was clear that observers recoded the words in a linear left-right order and that words were the test stimulus that promoted best recognition.

3. <u>Priming</u>: If memories are stored as both verbal and visual representations, then one would expect that a cue given verbally would preferentially prime the verbal store and that a visual cue would preferentially prime the visual store. Warren and Morton (1981) showed this was the case and that furthermore the first picture did not have to be identical to the second picture to facilitate recognition. The facilitation did not spread to the verbal representation of a picture and would not prime recognition of the written name of the object.

Although the two memory systems appear to have some independence, one must be able to contact the other. Given a name, a person can easily generate an image so there is clearly a mental connection. Thus, in the first part of an experiment, Tversky (1969) found that matching two names was quicker than matching a name to a face. In the second part of the experiment, Tversky found subjects given advance warning that the second stimulus was to be a face did not

exhibit the name pair advantage, presumably because they created the face image for comparison.

4. Specific Interference: In a similar vein to the effects of priming, we should expect a visual code to be impaired by performing another visual task and pari passu for a verbal code by a verbal task. Baddeley, Grant, Wight, and Thomson (1975) found that such specific interference does occur. The ability to track a moving light was impaired if subjects were asked to imagine an F and answer questions about it. The tracking was unimpaired if accompanied by a verbal memory task.

5. Semantic Decisions: The existence of two memory systems, according to Paivio (1975), explains the fact that it is easier to make judgments about the size of objects from pictures than from words. Paivio argued that perceptual attributes must be represented as pictures. However, the argument has been held suspect because intelligence judgments (e.g., are horses smarter than worms?) are also better done from pictures. Paivio, in fact, did not maintain that all semantic judgments are better performed from pictures. He found that judgments concerning the colors of objects are easier from words than pictures (TeLinde & Paivio, 1979) and inferred that object color is stored as a verbal label.

The Nature of the Visual Code

Given that there is at least prima facie evidence for a visual code, there is a need to know more about it. Some rather clever experiments have suggested some of the necessary properties. In one of these, Cooper and Shepherd (1973) found that the time taken to match a letter to a rotated version depended on the extent that the letter was rotated. To make the match subjects behave as if rotating the representation in order to verify the identity. In another study, which asked for judgments about animals, Kosslyn (1975) showed that judgments were carried out as if scanning an internal picture, a picture that could be of different sizes. He found that it was easier to agree that a rabbit has ears if it was imagined next to a fly than if it were next to an elephant.

The Nature of the Verbal Code

It is not clear that all proponents of a dual code for storing memories mean exactly the same thing when talking of a verbal code. Anderson (1980) put up somewhat of a straw man by giving the verbal code of Paivio no semantic content. He could then argue against the existence of a verbal code. For while it is clear that people do remember the particular voice with which information is given, for the most part they remember the meaning. Since meaning is the key to memory, a simple sensory version of verbal memory is clearly insufficient.

Propositional Code

In this view of mental representations of objects it is argued that memories are stored as neither a visual nor a verbal code but in an abstract propositional form. This view has had many variations (see, e.g., Anderson & Bower, 1973; Clark, 1974; Norman & Rumelhart, 1975; Pylyshyn, 1973). People certainly

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do remember the gist rather than the detail of both verbal and visual presentations. Indeed, on a task involving saying if two pictures are the same, meaning changes are more easily noticed than visual changes (Mandler & Ritchey, 1977). Propositional coding is easily fitted into computational theories of memory and attempts to create computer-based models of semantic networks; clearly the memory in a computer is neither visual nor verbal. One can then argue that a verbal or visual representation is created from the abstract propositional code in the same way that an output can be produced from the computer's memory in either an auditory or a visual form.

The evidence given above for the dual codes does resist the notion of a propositional code. To common sense and for a functional analysis, visual codes do have a reality as is illustrated by learning research. For example, memory performance is much enhanced by mnemonics; both verbal (key-word methods) and imagery techniques are effective in improving retention. Furthermore the evidence from lateralized stimulus presentations points to a functional reality for a distinction between visual and verbal codes; this evidence is considered in the next section.

3. EXPERIMENTAL RESEARCH ON NORMAL SUBJECTS WITH LATERALIZED STIMULI

Attempts to compare the relative effects of damage to the left and right sides of the brain are notoriously fraught with problems. Chief among these is ensuring that groups with left- and right-hemisphere damage are appropriately matched in extent and type of pathology as well as in locus of lesion. The effects of right-sided damage are likely to be less immediately troublesome than comparable damage on the left, which frequently causes some degree of aphasia. Therefore naturally occurring left-hemisphere lesions may well lead the patient to seek medical advice earlier in the disease process than would equal damage at the right side of the brain and hence would introduce a bias into the composition of groups with left- and right-sided brain damage. In the absence of postmortem verification of the site and size of the cerebral lesion, it is also difficult, despite recent advances in radiology, to be certain that the two groups are evenly matched in extent or severity of damage.

One group of Italian workers attempted to deal with the problem of ensuring equivalent left- and right-hemisphere damage in their two groups of patients by assessing simple reaction time to a visually presented stimulus. Reaction time has been found to be extended in cases of brain damage (Costa, 1962), and it may reasonably be thought that latency to respond is related to the degree of damage. By entering reaction time data in an analysis of covariance, De Renzi and his colleagues (Arrigoni & De Renzi, 1964; De Renzi & Faglioni, 1965) hoped to control for possible differences in extent to damage between left- and right-hemisphere groups. However, there is evidence that implicates the right hemisphere in the time taken to respond to a light flash (Benson & Barton, 1970; Howes & Boller, 1975; Nakamura & Taniguchi, 1977), so equivalent response times for left- and right-hemisphere groups may not in fact reflect equivalent damage at the two sides of the brain.

A second problem that besets the researcher investigating the effects of unilateral cerebral lesions is the possibility that the same functions may be organized in different ways in the left and right hemispheres (Semmes, 1968). If this is so, identically placed lesions at the two sides will not necessarily

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have equivalent effects even though each intact hemisphere may be as capable
as its fellow of subserving a given function. Furthermore, it is usually im-
possible to say whether the effects of a lesion in one hemisphere, in terms
of loss or impairment of a particular function, follow from the destruction of
the true neural locus of that function or instead reflect the influence of ab-
normal tissue on other brain areas that actually subserve the function in ques-
tion. To localize a region of dysfunction, therefore, is not to localize a
function, as pointed out by Hughlings Jackson in the 19th century.

A final difficulty is that there are almost always generalized as opposed
to specific effects of localized cerebral lesions. Because of the sort of
problems outlined earlier (for a more detailed account see Piercy, 1964), it
is desirable that the results of studies carried out on patients with brain dam-
age be confirmed, and if possible extended, among normal subjects. Within the
context of hemispheric asymmetry there are several means whereby this can be
achieved, and each of these is considered in the following discussion. (Refer-
ences to fuller reviews are made at appropriate points in the text.)

Tachistoscopic Visual Half-Field Studies

Directing visual input to a single hemisphere of the brain by flashing a
stimulus to one side of a central fixation point has been employed with normal
subjects, as well as with commissurotomized patients, although the presence of
intact mid-line commissures in normals means that visual information presumably
does not long remain lateralized to one hemisphere as it does in split-brain
patients.

The dependent variable in tachistoscopic visual field studies is usually
accuracy of recognition or recall or simple or discriminative reaction time.
Simple reaction time refers to a response, such as a key press, indicating
merely that the stimulus has been detected, whereas discriminative reaction
time refers to a response requiring some kind of discrimination between two
stimuli presented either simultaneously or successively. For example, subjects
are often required to decide whether two stimuli are the same or different and
then to respond on one key for "same" matches and on a second key for "differ-
ent" matches or else to respond to instances of one kind of match and withhold
responding to instances of the other kind (a GO/NO-GO discrimination).

In this review no particular effort has been made to distinguish between
the results obtained with different classes of response measure (accuracy or
reaction time) as the findings, by and large, are consistent with each other.
Speed versus accuracy trade-offs, for example, have rarely been reported.

The use of half-visual field presentations can be traced back at least to
Curtis and Foster (1915), co-workers of Dallenbach who in 1923 explicitly con-
nected the findings to hemispheric function. The research was largely ignored
during the behaviorist-dominated years of psychological research (1930-1950),
and the upsurge of recent interest in tachistoscopic laterality techniques can
be traced to an experiment conducted by Mishkin and Forgays in 1952. Although
these investigators were not specifically concerned with the notion of cerebral
asymmetry of function, their finding that bilingual subjects recognized English
words more accurately from the right of fixation but Yiddish words (which are
read from right to left) more accurately from the left of fixation (see also

Orbach, 1967) sparked off a number of experiments designed to uncover the relationship between visual field asymmetry and a range of procedural and subject variables. A crucial distinction turned out to be whether the stimuli are presented only to one side of fixation at a time or, as in the Mishkin and Forgays study, simultaneously to both sides. Heron (1957) found that unilaterally presented words were better recognized from the right visual field, but with bilateral presentation there was an advantage for words to the left of fixation. With bilateral stimulus presentation a tendency to scan or report the leftmost stimuli first (or rightmost for Yiddish) provides an explanation of the results (Ayres, 1966; Coltheart & Arthur, 1971; Dick & Mewhort, 1967; Wilkins & Stewart, 1974).

An alternative to the scanning hypothesis of laterality differences in tachistoscopic recognition is that, with unilateral stimulus presentation, words (Terrace, 1959), letters (Bryden, 1966), and material for which a verbal label is readily available (Bryden & Rainey, 1962; Wyke & Ettlinger, 1961) are more accurately recognized in the right visual field as a consequence of the more direct neural pathway from the right than from the left side of fixation of language areas of the left cerebral hemisphere. The cerebral dominance hypothesis is able to explain the results of an experiment by Barton, Goodglass, and Shai (1965), who presented three-letter words in a vertical orientation so as to minimize putative scanning mechanisms. These investigators found their unilaterally presented stimuli to be more accurately recalled from the right visual field both by American subjects viewing English words and by Israeli subjects seeing Yiddish words.

The early experiments have been reviewed by Bradshaw, Nettleton, and Taylor (1981), who argued that at least with single-syllable words exposed one at a time to left or right visual hemifields, artifacts due to directional scanning contribute little if anything to hemifield asymmetry. With nonword letter strings or multisyllabic words, the position is less clear.

Davidoff (1982) reviewed the tachistoscopic studies of lateralized nonverbal stimuli from the viewpoint of stimulus rather than task demands. Visual field advantages have been found for extremely simple displays and invariably indicate right-hemisphere superiority. These studies have asked subjects to make brightness judgments (Dallenbach, 1923; Davidoff, 1975), discriminate colors (Davidoff, 1976; Hannay, 1979; Pennal, 1977), estimate aftereffects (Meyer, 1976), judge depth (Durnford & Kimura, 1971), detect motion (Bertolini, Anzola, Buchtel, & Rizzolatti, 1978), estimate the duration of visual stimuli (Koch, Polzella, & DaPolito, 1980), localize dots (Kimura, 1969; Levy & Reid, 1976), count dots (Kimura, 1966; McGlone & Davidson, 1973), or estimate orientation (Hatta, 1978; Umilta et al., 1974). However, many of the elementary perceptual abilities that have been shown to give right-hemisphere advantages have been shown by others not to do so. Davidoff (1982) concluded that discrimination difficulty is usually present when right-hemisphere advantages are found.

The perception of shape has also been shown to be more accurate (Fontenot, 1973; Hellige, 1978) and quicker (Beaumont & Dimond, 1975; Gross, 1972) in the left visual field. Discrimination difficulty again appears to be an important variable as is verbalizability of the shape (Umilta et al., 1974), especially if the shape is to be named (Paivio & Ernest, 1971; Wyke & Ettlinger, 1961). Faces seem particularly likely to give a left visual field and hence right-hemisphere advantage (Berlucchi, Brizzolara, Marzi, Rizzolatti, & Umilta,

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1974; Geffen, Bradshaw, & Wallace, 1971; Hilliard, 1973; Zocollotti & Oltman, 1978).

Dichotic Listening

One of the techniques now employed in many laboratories to assess differences in function between the two halves of the brain entails simultaneous presentation of competing information to the left and right ears. Pairs of stimuli are aligned on two tracks of a magnetic tape such that the onset and offset of one stimulus coincide exactly with the onset and offset of the second stimulus. Intensity of the two stimuli is also carefully balanced. The tape is played over a pair of stereo headphones to the subject, who hears one member of the stimulus pair at one ear and the second member of the pair at the opposite ear; this procedure, referred to as dichotic presentation, has its origins in experiments on selective attention carried out by Broadbent (1954, 1958). However, the rapid development of interest in dichotic listening as a tool for the investigation of hemispheric asymmetry stems largely from the work of Kimura in the early 1960s.

Following publication of Kimura's (1961) paper, dichotic listening was taken up enthusiastically as a means of assessing language laterality in normal subjects. Her finding of a mean right-ear advantage in the recall of dichotically presented material has been replicated by many investigators (see Berlin & McNeill, 1976; Studdert-Kennedy, 1975) and is now a firmly established phenomenon. However, Kimura's interpretation of this finding as related to hemispheric functioning has not gone unchallenged.

When digits are presented in pairs to left and right ears, there is an almost universal tendency for subjects to report all the items presented to one ear before reporting those items presented to the other ear (Broadbent, 1954). Inglis (1965) summarized data that showed that among individuals with memory defects only the number of items recalled from the second ear differed from the number recalled by normal control subjects, whereas recall from the initial ear was similar for both groups. Inglis argued that his result supported an interpretation of the right-ear advantage in terms of memory rather than sensory competition. He suggested that a tendency to report first the material entering the right ear might allow information from the left ear to decay in short-term memory and thus give rise to the observed superiority of the right ear. An order-of-report interpretation was not considered a sufficient explanation by Bryden (1967), who continued to find a right-ear advantage even when analyzing responses given from the ear reported first, but such an explanation continues to surface from time to time (e.g., Friedes, 1977).

Notwithstanding Bryden's (1967) results, it may happen that subjects primarily attend to, as opposed to recall, information presented to the right ear in the absence of constraints to do otherwise (Haydon & Spellacy, 1973; Levy & Bowers, 1974; Simon, 1967). Perhaps that is why sounds are recognized more accurately to the right of a subject and appear louder than sounds of equal intensity heard on the subject's left (Kellar, 1978; Wexler & Halwes, 1981). However, an attentional hypothesis cannot explain the finding of a right-ear advantage when subjects are asked to attend to the input presented to the left ear (Bryden, 1969). Furthermore, Kallman (1978) found a right-ear superiority

for words and a trend toward a left-ear advantage for music in a target detection task in which the two types of stimuli were randomly interspersed.

Few, if any, workers would deny that a superiority for the right ear has, other things being equal, something to do with the fact that the left hemisphere is more efficient at verbal tasks generally. Yet the nature of this "something" varies with different stimuli, tasks, and subjects. Not all dichotic listening experiments tap the same psychological operations, and these operations may well differ in the extent of their underlying cerebral lateralization. As a general rule stimuli that are heard within, or form part of, a linguistic context give rise to an advantage for the right ear, whereas stimuli heard within a nonlinguistic context are more likely to show a superiority favoring the left ear. Other nonverbal tasks to give a left-ear advantage include discriminating or recognizing pitch (Curry, 1968; Halperin, Nachshon, & Carmon, 1973; Kallman & Corballis, 1975; Oscar-Berman, Goodglass, & Donnenfeld, 1974; Schulhoff & Goodglass, 1969), identifying environmental noises (Carmon & Nachshon, 1973; Curry, 1967; Knox & Kimura, 1972), discriminating between clicks (Murphy & Venables, 1970), and detecting square-wave patterns (Sidtis, 1980).

Musical stimuli have been employed in a number of dichotic listening experiments. Kimura (1964) first reported an ear difference in the perception of dichotically presented melodies. The same subjects who showed an advantage for the right ear with pairs of digits gave a left-ear advantage for melody detection. Similarly Bartholemeus (1974) presented dichotic pairs of letter sequences sung as melodies. Using the same stimulus tapes but different subjects for each task, she found that recognition of the melodies gave a significant left-ear advantage; the letter sequences yielded a significant right-ear superiority. These findings support Milner (1962), who found that right brain-damaged subjects were more impaired than patients with left-sided damage on certain items of the Seashore test of musical abilities. Subsequently Shankweiler (1966) found right-temporal lobectomized patients to be inferior to left-temporal patients on a dichotic melodies test. Together with Kimura's work this evidence strongly implicates the right temporal lobe in certain aspects of music perception (see also Shapiro, Grossman, & Gardner, 1981).

In an attempt to identify the musical dimensions that determine the left-ear effect, Gordon (1970) presented competing melodies matched for rhythm and pitch to experienced musical subjects. In a second condition single chords were heard at each ear. No asymmetry was found on the melody task, but a significant left-ear advantage emerged for the chords. Gordon suggested that the failure to find a left-ear superiority for melodies, in contrast to Kimura's (1964) results, might have been due to differences in the rhythm and/or pitch of the stimuli employed by himself and by Kimura. He subsequently found (Gordon, 1978) that these two features gave different laterality patterns, pitch yielding no ear difference and rhythm an advantage for the right ear. Robinson and Solomon (1974), Natale (1977), and Gates and Bradshaw (1977a) also obtained a right-ear advantage in recognition of rhythm, but dichotic pitch perception has yielded contradictory results. For a fuller review, see Craig (1979).

Gates and Bradshaw (1977b) reviewed the literature concerning music and the cerebral hemispheres and cautioned against regarding one particular hemisphere as dominant for musical functions. Each half of the brain may make its own contribution toward different aspects of musical expression or appreciation.

Reliability and Validity of Dichotic Listening Asymmetry

Much of the motivation in dichotic listening research lies in identifying the hemisphere responsible for speech or other functions. However, as with the tachistoscopic paradigm, left-right ear differences in dichotic listening scores are far more labile than one would expect if ear asymmetry is an index of some fixed structural attribute (Blumstein, Goodglass, & Tartter, 1975; Teng, 1981). In one study as many as 30% of subjects exhibited a change in the side of the superior ear when retested within a period of 1 month (Pizzamiglio, Pascalis, & Vignati, 1974). Even within a single testing session the magnitude or direction of asymmetry may change, perhaps due to changing strategies utilized by the subject (Kallman & Corballis, 1975; Perl & Haggard, 1975; Sidtis & Bryden, 1978). Over a number of sessions the proportion of subjects showing a right-ear preference for verbal stimuli tends to increase due to the greater probability of change among subjects showing an initial left-ear advantage (Blumstein et al., 1975; Shankweiler & Studdert-Kennedy, 1975).

The stimuli and tasks used in dichotic listening research have been almost as varied as the number of investigations undertaken, with little or no attempt at proper validation. An exception to this criticism is found in the work of Geffen, who together with her colleagues has devised a dichotic monitoring test. Subjects hear words in left and right ears and are required to make a manual response on detecting a specified target word in either ear. A greater number of detections in one ear than the other is said to reflect speech dominance of the hemisphere opposite the more accurate ear. The technique has proved reliable (Geffen & Caudrey, 1981) and has been validated against the assessment of language laterality by means of unilateral ECT (Geffen, Traub, & Stierman, 1978) and, in four cases, against the Wada sodium amytal test (Wale & Geffen, 1981).

Tactile Perception

Although hemispheric specialization of function has been studied mainly through the visual and auditory modalities, there has been some work carried out with regard to the sense of touch. The fact that the sensory and motor functions of each hand are represented predominantly in the contralateral cerebral cortex means that information available to one hand alone is processed largely in the opposite hemisphere. Thus the abilities of left and right hemispheres on tactile tasks can be assessed by comparing the performance of the right and left hands. Although a tendency toward greater tactile sensitivity of the left compared with the right hand has been reported for right-handed adults (Semmes, Weinstein, Ghent, & Geuber, 1960), a sensitivity difference between the hands is probably not important in tasks employing suprathreshold stimulation.

Benton and his colleagues used an electromechanical device to stimulate the back of the hand. Three points lying in a straight line were stimulated in quick succession, and the subject's task was to indicate from among four alternatives the orientation of the line in which the stimuli had been presented. More accurate perception of orientation was found for the left than for the right hand, at least among right-handers (Benton, Levin, & Varney, 1973; Benton, Varney, & De Hamsher, 1978; Varney & Benton, 1975). Earlier Carmon and Benton (1969) and Fontenot and Benton (1971) had found that patients

with lesions in the left hemisphere were impaired on this task only on the right hand, whereas patients with right-sided lesions were impaired on both hands. This pattern is the reverse of results found for purely somatasensory defects (Semmes et al., 1960). These findings together with those for normal subjects therefore suggest that the right hemisphere plays an important role in mediating tactile perception of direction, which would explain why right brain-damaged patients perform poorly in learning a tactual maze (Corkin, 1965).

With regard to neurologically intact subjects, Witelson (1974) devised a dichotomous tactile task that revealed a left-hand superiority in perceiving meaningless, three-dimensional forms. Similar findings have been reported by others (Dotts, 1978; Gardner et al., 1977; Klein & Rosenfeld, 1980; Kleineman & Cloninger, 1973). Thus it does appear that in normal subjects the right hemisphere bears particular responsibility in the tactile perception of shape.

A superiority in either the perception of shape or the perception of direction, if in fact these functions are dissociable, can account for the left-hand advantage in Braille reading found for both experienced blind subjects (Hermelin & O'Connor, 1971) and blindfolded normal subjects (Harriman & Castell, 1979; Smith, Chu, & Edmonton, 1977) taught to read Braille. These findings are particularly interesting in view of the fact that reading is a verbal process and might therefore be expected to yield a superiority for the right hand. Oscar-Berman, Rehbein, Porfert, and Goodglass (1978) obtained a right-hand superiority in recognition of letters traced on the palm of the hand but a left-hand advantage in discriminating the orientation of lines. Conceivably, the degree of difficulty in discrimination determines whether the spatial or verbal aspects of Braille dominate performance on the task, thereby determining the direction of asymmetry.

Electrophysiological Studies

It is impossible from purely behavioral experiments conducted with neurologically intact subjects to specify with any accuracy the locus within the hemisphere of any functional advantage. Therefore some researchers have turned to recording the electrical activity of the brain while tasks are being performed.

The electrical wave forms recorded from the scalp can be broadly classified into two types. One type consists of event-related potentials, the other of ongoing electroencephalographic (EEG) activity (Hillyard & Woods, 1979). Event-related potentials, as the term implies, are the changes brought about when a subject is presented with a particular stimulus. When the event precipitating the change is a visual or auditory stimulus under experimental control, the resulting activity is referred to as the visual or auditory evoked potential. The broad classification of EEG activity into ongoing and event-related activity is purely arbitrary since, as Hillyard and Woods (1979) pointed out, even ongoing EEG activity might be considered event related if only the event concerned could be specified. By definition, event-related potentials are time-locked to some stimulus or other specificable event. As these changes in electrical potential may be very small in relation to fluctuations in ongoing EEG activity, the usual procedure is to use a computer to sum the potentials during the half second or so following each presentation of the evoking stimulus so as to produce an average value. The principle here is that if particular

changes in activity bear a constant relationship to the reference event, they will show up against fluctuations of the ongoing EEG, which, being "random," should cancel out to zero when averaged over successive trials by the computer.

Despite the EEG's appearance of probing the machinery of the brain, electroencephalography is a relatively gross technique that tells only that a population of neural units is active rather than quiescent. It is difficult to localize with more than a fair degree of accuracy the spatial locus of this activity. Because the brain is a three-dimensional structure, very precise localization of the activity picked up by surface electrodes is rarely possible. It is also worth pointing out that EEG recording is technically difficult and fraught with potential artifacts due to muscle movement (Grabow & Elliott, 1974), eye movement (Anderson, 1977), and possible left-right differences in skull or brain mass underlying the electrodes (Rubens, 1977).

While not denying the clinical value of the EEG as a noninvasive technique, it is probably fair to conclude that electro-physiological research has so far not contributed anything new to the knowledge of cerebral asymmetry but rather has corroborated findings from other areas of investigation. However, there are situations in which the EEG may disclose lateralized phenomena which, because of their very nature, may not have been suspected on other grounds. Morgan, MacDonald, and Hilgard (1974), for instance, related hypnosis to mediation by the right hemisphere, and Cohen, Rosen, and Goldstein (1976) claimed to show that sexual orgasm in humans is associated with increased amplitude of the wave form over the right but not the left hemisphere.

Dual-Task Experiments

The final method of investigating hemispheric functional asymmetry in neurologically intact subjects involves having the subject simultaneously do two tasks that putatively involve both hemispheres. Cremer and Ashton (1981), for example, required subjects to alternately tap with a rod two small metal targets. A concurrent verbal task interfered with the speed and consistency of tapping by the right hand, while a visuospatial task interfered more with left-hand performance. Reducing the size and increasing the distance apart of the targets did not remove these lateralized effects even though greater accuracy was required in hitting the targets.

The effect of increasing task difficulty may be confined to one hand or affect both hands. Hicks, Provenzano, and Ribstein (1975) found that as subjects rehearsed increasingly difficult lists of words a deficit on a typing-like task showed up first on the right hand and then spread to the left hand. Comparable results have been reported by other authors (Bowers, Heilman, Satz, & Altman, 1978; McFarland & Ashton, 1978). However, Hicks, Bradshaw, Kinsbourne, and Feigin (1978) found that concurrent verbalization increased response times for both hands on a typing task but more so for the right hand. The magnitude of this asymmetrical effect increased with the difficulty of the typing task. The effect of task difficulty in terms of whether a purely lateralized effect or a bilateral effect (symmetrical or asymmetrical with respect to the two hands) is observed thus appears to depend on the nature of the two competing tasks.

It may be helpful to distinguish between two possible sources of inter-
ference between concurrent tasks. One source is competition for the same neu-
ral mechanisms of motor (including verbal) output. The other is competition
between two tasks for attention or cognitive processing capacity (see Lomas,
1980). Hellige and Longstreth (1981) asked subjects to tap with either the
left or right index finger. Concurrent reading reduced the rate of tapping
more for the right than for the left finger; the effect was greater for read-
ing aloud than for silent reading and larger again for subjects who were led
to expect a test on what they had read. It was therefore concluded that lat-
eralization effects are mediated by both motor and cognitive aspects of the
tasks. Similar results were reported by Bowers et al. (1978), who observed a
bilateral but asymmetrical impairment on finger tapping when subjects merely
had to listen to a story knowing that they would susequently be asked to re-
call its contents.

Kinsbourne (1975) argued that "both hemispheres draw upon and often com-
pete for a finite amount of attention invested in the organism as a whole."
Consequently attention may be distributed asymmetrically between the two hemi-
spheres. The effect of this, according to Kinsbourne, is that there is a bias
in responding to the side of space contralateral to the hemisphere that has
the greater share of attention. Part of Kinsbourne's evidence for this view
is that on tachistoscopic tasks for which no left-right hemifield asymmetry is
normally observed, concurrent verbalization can induce a left-right difference
in favor of the right visual hemifield.

On a task requiring the subject to detect and respond to a small gap in
one of the sides of a square, Kinsbourne (1973) found concurrent verbalization
led to a right-hemifield superiority and humming to a superiority in detecting
gaps in the left visual hemifield. Other authors, however, have failed to
replicate these findings (Boles, 1979; Gardner & Branski, 1976). Nonetheless
there is sufficient evidence to suggest that concurrent performance of certain
cognitive tasks can in some circumstances alter left-right perceptual asymme-
tries (Allard & Bryden, 1979; Beaumont & Colley, 1980; Hellige, Cox, & Litvac,
1979; Kinsbourne, 1970, 1973; Rizzolatti, Bertolini, & Buchtel, 1979). The
problem is that the additional task has sometimes been found to facilitate per-
formance in the visual field opposite the supposedly activated hemisphere and
in other cases has been found to impair performance. Cases of facilitation are
"attributable to the beneficial effect on performance of increase in arousal
when this is moderate in degree," according to Kinsbourne and Hicks (1978).
When the effect of an additional task is to disrupt rather than facilitate per-
formance, the two tasks are said to compete for the same "functional space"
within the hemispheres. As Cohen (1979) pointed out, Kinsbourne's theory has
"too much explanatory power and too little predictive power." It is impossi-
ble to predict whether a particular task will help or hinder performance on a
second task.

Theoretical Interpretations of Laterality Effects

Although this review of the normal literature has concentrated on those
findings that reveal most clearly opposite hemisphere superiority for verbal
and nonverbal stimuli, it is impossible for anyone familiar with the work not
to be struck by the lability of the laterality effects reported (see Cohen,
1982). Failures to replicate results are common. If a superiority of one

half field or ear derives from some fixed advantage of the contralateral cerebral hemisphere for the stimulus material in question, then comparatively minor procedural differences should have little or no influence on the outcome of an experiment. As it is, the magnitude and direction of laterality effects vary not only between different subjects and different experiments but also within the same subject at different stages within an experiment (see, e.g., Hellige, 1976).

Structural models of hemisphere specialization that posit that perceptual asymmetries arise because the brain structures that deal with a particular class of stimuli are lateralized exclusively or predominantly to one hemisphere rather than the other cannot cope with variability produced by small changes in task demands or stimulus parameters. Accounts such as those of Kinsbourne (1970, 1973, 1975), which stress dynamic as opposed to structural determinants of perceptual laterality effects, do not have this problem. In Kinsbourne's attentional model, shifts in the magnitude or direction of a visual field difference are due to changes in the relative activation of one hemisphere as compared with the other. Such a theory predicts that an increase in advantage for a particular visual hemifield should be accompanied by an equivalent decrease in performance for the other hemifield. However, this does not appear to be the case (Hellige & Cox, 1976).

Models of hemisphere specialization have been critically reviewed by Cohen (1982). She distinguished between those models that treat hemisphere specialization as absolute, according to which a given cognitive function can be performed only by a particular hemisphere, and those that regard specialization as relative. According to the relative specialization models, both hemispheres can perform a given function but one is faster or more efficient than the other. These models therefore differ in the degree to which specialization for a particular function is thought to exist. In her review Cohen argued that there is little evidence in favor of the absolute specialization model. As regards the relative nature of hemispheric specialization, differences between the two halves of the brain have been conceptualized in terms of specialization for different types of material, specialization for different processes, and specialization for different stages of processing; for our future concern with hemisphericity, differences in modes of processing are the most important to consider.

Information-Processing Asymmetry

In recent years a growing sophistication, especially in tachistoscopic half-field investigations, has derived from a conceptual and methodological framework known as information-processing theory. The basis of this approach is the belief that the response a subject makes is not an immediate outcome of sensory stimulation but results from a number of processes that occur over time, stimulation of the sensory receptor being only the first stage in a series of events. Information-processing theorists attempt to define these stages and the order in which they occur.

Models of human information processing have been developed by a number of theorists of this persuasion (Atkinson & Shiffrin, 1968; Broadbent, 1958; Neisser, 1967; Turvey, 1973). Common to all models is the view that stimulation of sensory receptors sets up neural activity that outlasts the duration

of the physical stimulus; this persistence is referred to as visual (iconic) or auditory (echoic) storage and is believed to last up to about one quarter of a second (Sperling, 1963). During this time various encoding operations may be performed on the stored information, which enables some representation of the stimulus to be held in a short-term memory store after which it either drops out or is transferred into some other more durable store. Thus the simplest information-processing models distinguish between three distinct stages: registration, coding, and retrieval. Hemispheric differences at registration have been commonly reported but are labile; coding differences are the critical findings to examine.

Both clinical (Jones-Gotman & Milner, 1978; Whitehouse, 1981) and experimental evidence link the verbal and nonverbal codes to the left and right hemispheres, respectively. Cohen (1972) presented the Posner task (see the previous discussion of dual-coding strategies) to the left or right visual field and found a left-hemisphere superiority for name matches and a right-hemisphere superiority for physical identity matches. Geffen, Bradshaw, & Nettleton (1972) have replicated the results. Thus it is not so much the ostensible nature of the stimuli that is crucial in determining any difference between the visual fields as the kind of cognitive processing that the subject undertakes (but see Simion, Bagnara, Bisiacchi, Roncato, & Umilta, 1980). This conclusion is supported most dramatically by the results of studies in which, using exactly the same stimulus material, opposite field advantages have been obtained according to the task requirements (Niederbuhl & Springer, 1979; Robertshaw & Sheldon, 1976; Seamon & Gazzaniga, 1973).

That a stimulus can be processed either verbally or nonverbally helps explain those otherwise anomalous findings in which verbal stimuli give rise to a right-hemisphere superiority (Gibson, Dimond, & Gazzaniga, 1972; Hellige, 1976; Jonides, 1979; Martin, 1978; Niederbuhl & Springer, 1979; Schmidt & Davis, 1974; Wilkins & Stewart, 1974) and nonverbal stimuli such as faces (Marzi & Berlucchi, 1977; Patterson & Bradshaw, 1975; Umilta, Brizzolara, Tabossi, & Fairweather, 1978), colors (Malone & Hannay, 1978), or pictures (Wyke & Ettlinger, 1961) produce an advantage for the left hemisphere. Even within the same series of experimental trials, opposite field superiorities may be obtained for similar stimuli processed in different ways. For example, Umilta et al. (1974) required subjects to judge the orientation of a single line. Those lines that were oriented so as to be readily named (e.g., vertical, horizontal, diagonal) gave a left-hemisphere superiority in reaction time whereas the remaining orientations favored the right hamisphere. This finding explains the results of White (1971), who presented lines only in horizontal, vertical, and diagonal orientations and found a left-hemisphere superiority.

A preference for using one code rather than the other could explain differences between individual subjects in the direction of hemifield asymmetry for different tasks (Kroll & Madden, 1978). However, there is a risk of becoming circular in accounting in this way for any particular visual field difference that is observed. What is required is independent evidence that a particular code--as reflected in a mode of processing--is in fact being used.

Modes of Processing. Information-processing theorists distinguish between serial and parallel processing. Serial processing refers to cognitive operations carried out successively whereas parallel processing is carried out simultaneously. Attempts have been made to map these two modes of processing onto

the left and right hemispheres respectively, where they are referred to as analytic and gestalt processing.

The view that the left hemisphere has a sequential mode of operation has held great currency and has been used, for example, by Gordon (1978) to sort out ear advantages for music. His research showed that rhythm was processed better by the left hemisphere and tone discrimination by the right hemisphere. The left-hemisphere superiority for dealing with sequences of auditory material does not, therefore, apply only to speech. Nor is it said to apply only to the auditory modality, as more accurate left-hemisphere judgments of sequences have been found for the tactile modality (Nachshon & Carmon, 1975).

Kimura and Vanderwolf (1970) regarded their finding of a left-hemisphere superiority for motor sequencing as related to the anatomical proximity of the motor and speech areas in the left hemisphere. However, it is an oversimplification to regard language as simply sequencing behavior (Poeck & Huber, 1977) and, while the evidence for preferential left-hemisphere involvement for sequencing is considerable, it is not sufficient for a task to have a sequential element to produce a left-hemisphere superiority. The right hemisphere is preferred for velocity discrimination (Bertolini et al., 1978), Braille reading (Hermelin & O'Connor, 1971), and the Corsi span, which is the spatial equivalent of the digit span (Kim, Roger, Bonstelle, & Boller, 1980). The left-hemisphere preference for sequencing is, however, built on firmer evidence than the supposed gestalt or holistic processing mode of the right hemisphere.

Recourse to the clinical literature shows that right-hemisphere damage leaves the patient capable of a perceptual analysis only by detail (Hecaen & Angelergues, 1962) and that patients with left- or right-hemisphere lesions carry out constructional tasks differently from each other (Piercy, Hecaen, & de Ajuriaguerra, 1960). Levy (1974) postulated an holistic strategy for the right hemisphere from such evidence. However, if the hemispheres have different absolute specializations, unilateral brain lesions will force the patient to rely on only certain aspects of the input. Similarly, a superiority shown by normal subjects when dealing with information presented to a hemisphere for which it is better suited does not need the explanation of a preferred processing mode. If attention is directed toward certain attributes of a stimulus, it should not surprise if lateral advantages are altered. Linguistic training, for example, reverses an existing left-ear advantage for identifying intonation contours of words (Blumstein & Cooper, 1974), an unremarkable finding if the subject is trying to discriminate linguistic features. It is generally harder to force subjects to attend to nonverbal aspects of stimuli but, in any case, the evidence offered by Webster and Thurber (1978) that a so-called gestalt training strategy improved right-hemisphere performance was, to say the least, slight. It depended on transforming the raw scores for the dichaptic data and on ignoring the monohaptic results.

If the style of processing of the right hemisphere is referred to as holistic or gestalt, it is essential to clarify what is meant by a gestalt. A gestalt must be distinguished from the findings of Gestalt psychology, which indicate both right (Jasper & Raney, 1937, for the phi phenomenon) and left visual field advantages (Nebes, 1973, for proximity). Only too often a gestalt has meant what any particular author decided it meant. Gestalt processing is claimed by Bryden (1976) because more false alarms occurred in the left visual field, by Clem and Pollack (1975) because the Muller-Lyer illusion was stronger

in the left visual field only if parts of the figure appeared simultaneously, and by McKeever and Huling (1970) because a left visual field advantage was obtained for dot figures, but not for outline figures. Gestalt processing is even claimed for the right hemisphere because the left visual field is better at detecting mismatches of words and pictures (Tomlinson-Keasey, Kelley, & Burton, 1978). Most, if not all, of these results could be explained more parsimoniously by a right hemisphere that extracts visual information more quickly than the left hemisphere.

Clinical studies have been even vaguer in their use of the term gestalt processing. For example, a right hemisphere that operates on a gestalt basis is concluded because, in the judgment of the similarity of rectangles, form is overweighted compared to area (Bisiach & Capitani, 1976). Gardner et al. (1977) even claimed disturbed right-hemisphere function because patients were unable to deal with the supposedly gestalt associations of high versus low musical notes corresponding to red versus blue, and loud versus soft notes corresponding to filled versus open circles.

A gestalt is talked of in some instances as being the formation of a unified percept, and it is this right-hemisphere function that is lost when objects cannot be identified (De Renzi & Spinnler, 1966). Martin (1979) argued that if the right hemisphere was really specialized for dealing with the whole shape (global processing) rather than portions of the shape (local processing), then hemifield presentations of a letter constituted from smaller letters would exhibit a left visual field advantage for the whole, but not the local shapes. There was little evidence for such global processing in the right hemisphere. Indeed, the shape of a word, which could be misconstrued as a gestalt, has been found to be better detected by the left hemisphere (Bradshaw, Gates, & Nettleton, 1977).

A gestalt, in its more proper meaning of a whole processed more efficiently than its constituent parts, applies to verbal as well as to nonverbal stimuli. Reicher (1969), for example, showed that a word can take less time to process than its constituent letters; this word-superiority effect has been tested for hemifield differences and is accompanied like the majority of verbal stimuli by a right visual field advantage (i.e., left-hemisphere advantage) (Krueger, 1975).

Fortunately, the work of Cohen (1973) provides, at least, a testable statement of holistic processing. Gestalt processing (the mode of operation of the right hemisphere) is taken to mean parallel processing (i.e., it takes the same processing time to deal with many stimuli as it does for a single stimulus). The left hemisphere is taken to process stimuli sequentially and the right hemisphere in parallel; this view has face validity, as parallel processing is known to be confined to matching on the basis of physical identity (Neisser & Beller, 1965) and simple dimensions like size and brightness (Biederman & Checkosky, 1970).

Cohen (1973) obtained RTs for judgments of whether all the stimuli in a display were the same. The number of stimuli varied from two to five. The effect of set size for right visual field displays was, unfortunately, not always the predicted increase in RT as set size increased. Also, parallel processing was not consistently shown for the left visual field or even seen for the right visual field. A replication of Cohen's study by White and White (1975) using a

better design found parallel processing for both hemispheres. To further complicate matters, a replication by Polich (1980) tended to show serial processing for both visual fields. So while set-size effects appear variable, there is little supportive evidence for Cohen's hypothesis. The argument that the right hemisphere can act only as a parallel processor is certainly denied. Gross (1972) found a left visual field advantage for judging the similarity of two arrays of black and white squares. Reaction time increased with the number of black squares (the critical features), implying that the arrays were being processed in a serial fashion. Similarly, Umilta, Salmaso, Bagnara, & Simion (1979) found a right-hemisphere advantage for dot detection with a serial search from fixation outward.

It is a pity that the clearest definition of holistic processing with respect to hemispheric involvement has been found lacking in empirical validation. The extension by neuropsychologists of serial (analytic) versus parallel (holistic) processing differences to correspond to left versus right hemispheres is therefore empirically uncertain but nevertheless has had widespread currency on the fringes of academia.

4. INDIVIDUAL DIFFERENCES THAT COULD AFFECT HEMISPHERICITY

Personality

Until relatively recently, laterality researchers have focused on trying to understand the characteristics of cerebral lateralization as they relate to some idealized typical individual, with some attention also directed to the effects of handedness, sex, or other organismic variables, such as eye or foot dominance. For the most part, variations among right-handers in the degree and direction of ear asymmetries on dichotic tests or visual field asymmetries on tachistoscopic tests have rarely been considered except when various pathological or learning-disabled populations have been compared with normal controls. For normal right-handers homogeneous with respect to sex, individual differences in behavioral asymmetries are often so little noted that tables and figures depicting data may show only measures cf central tendency, with no indication of variance. Even when both means and measures of variation are given, it is unusual for authors to describe frequency distributions of subjects. Quite probably, this tendency to ignore variation has derived from the belief that there is no way to decide whether the observed variance was due to random error of measurement or to real individual differences in the underlying dimension of interest and that there is no way to surmount the problem of choosing a laterality index (Marshall, Caplan, & Holmes, 1975) giving an appropriate ordering of subjects with respect to asymmetric functioning of the brain. Yet research has shown that real differences do exist among right-handers in both the direction and degree of hemispheric engagement and that these differences are predictive of personality and cognitive characteristics.

The role of the two hemispheres in emotional-personality function is currently a matter of debate. One view is that the right hemisphere plays a special role in the experience, expression, and discrimination of all emotion. Thus, in normal right-handed subjects, the majority display a left-ear advantage for discrimination of the emotional tone of voice (Safer & Leventhal, 1977), a left visual field advantage in recognizing facial expressions (Buchtel, Campari, De Risio, & Rota, 1978; Heller & Levy, 1981; Safer, 1981), and an asymmetry in

favor of the left side of the face in the production of expressions (Campbell, 1978; Chaurasia & Goswami, 1975; Heller & Levy, 1981; Sackeim & Gur, 1978).

In clinical investigations, right-hemisphere damage impairs story recall for stories with emotional content (Wechsler, 1973), produces a specific deficit in judging the emotional mood of the speaker when listening to spoken sentences (Heilman, Scholes, & Watson, 1975), is associated with disabilities in comprehending emotional expression on faces, over and above any general impairment in facial recognition (Cicone, Wapner, & Gardner, 1980), and causes difficulties in expressing emotion through tonal inflections in speech (Ross & Mesulam, 1979). Under this model of hemispheric differentiation of emotion, variations in emotional-personality characteristics of normal right-handers would arise from differences in the affective tone and related characteristics of the right hemisphere. Thus, persons with the critical, depressive, inward-looking, a d untrusting attitudes of introverts would have their right hemisphere "tuned" to sadness. Persons with the uncritical, optimistic, outward-looking, and trusting attitudes of extraverts would have a right hemisphere "tuned" to happiness (see, e.g., Eysenck's, 1967, characterization of these polar personality types).

An alternative view holds that the two hemispheres play equal roles in emotion but that the emotional valence of each side differs. The earliest suggestions of differential hemispheric involvement in emotion can be found in the observations of clinicians such as Goldstein who noted that following damage to the left side of the brain patients commonly showed an emotional reaction he described as "catastrophic" (Goldstein, 1939). This reaction was a response of exaggerated despair to the situation in which the patients found themselves. The opposite reaction of "indifference," often seen in patients with right-hemisphere damage, was also described in the neurological literature of this period (Denny-Brown, Meyer, & Horenstein, 1952; Hacaen, de Ajuriaguerra, & Massonet, 1951). Sackeim et al. (1982) based their approach on such findings and proposed that the left hemisphere tends toward happiness and the right hemisphere toward sadness. However, Tucker (1981) proposed the reverse (i.e., that the right hemisphere tends toward happiness and the left hemisphere toward sadness).

Sackeim's interpretation was that damage to one or the other side results in disinhibition of the intact hemisphere, so that the pathological emotion displayed characterizes the emotional valence of the undamaged side. Tucker (1981) interpreted these same data in a different way. He suggested that cortical damage results in disinhibition of ipsilateral limbic regions, with brain damage exaggerating the emotional tone of the damaged hemisphere. He pointed out that the emotional effects of unilateral hemispheric inactivation are not observed when anesthesia is complete, but rather only when patients are recovering, that is, during that time when it is reasonable to suppose that the subcortical regions have regained function but prior to cortical recovery.

Both lateralized valence models conflict, however, with Levy's proposal that the right hemisphere predominates in all emotions. One possibility that could reconcile the various findings incorporates both the idea that arousal relations between hemispheres are reciprocally inhibitory and the idea that cortical regions exercise a modulatory and inhibitory influence over ipsilateral subcortical areas, while also holding that the right hemisphere is crucial for the regulation of all emotion. The central hypothesis of Levy's model is

that the arousal level of the right hemisphere determines the nature of its affective tone: When arousal is high, affect tends toward happiness, and when arousal is low, affect tends toward sadness. Thus the model predicts that variations in personality-emotional dimensions are associated with differences in arousal relationships between hemispheres, that higher right-hemisphere arousal correlates with positive affect and higher left-hemisphere arousal correlates with negative affect.

Considering individual variation in basic emotional state, Tucker's model predicts that a highly aroused left hemisphere would manifest sadness in people with a gloomy outlook, while Levy's model predicts that the right hemisphere in such people would manifest sadness and the left hemisphere displays neutral affect. Both models predict that the highly aroused right hemisphere in people with a sunny outlook displays happiness, and both yield predictions that are opposed to those derived from Sackeim et al. (1982). None of these models have been more than tentatively tested, but they do have important implications for personality differences and hemispheric functioning.

Individual Differences in Personality and Hemispheric Function: Experimental Investigations. Tucker, Antes, Stenlie, and Barnhardt (1978) examined performance of high-anxious and low-anxious subjects on lateralized tachistoscopic tests of verbal and nonverbal function and on perception of loudness of tones played to the left and right ears. High-anxious subjects showed a specific deficit in performance on both tachistoscopic and auditory tasks indicating overarousal of the left hemisphere in high-anxious subjects sufficient to interfere with performance. This result is consistent with Tucker's proposal that the left hemisphere has negative affect, as well as with the arousal model that attributes the high anxiety to the low arousal level of the right hemisphere, which fails to inhibit negative experience. However, a previous study of Tucker quoted in the same article appears to give contradictory results.

Another characteristic said to be related to the difference between the introversion-pessimism-critical personality and the extraversion-optimism-uncritical personality is hypnotic susceptibility. Hypnosis entails subjects' ability for an imaginative involvement in external events, trust of the hypnotist, reduced testing of reality, and uncritical acceptance of suggested ideas (Hilgard, 1970), all of which contrast with the personality traits of introverts but conform to the attitudes of extraverts. Bakan (1969) and Gur and Gur (1974) found that subjects who predominantly moved their eyes to the left (i.e., had an active right hemisphere) were more susceptible to hypnosis than right-movers. Frumkin, Ripley, and Cox (1979) investigated linguistic asymmetry of the two ears on a dichotic listening test in relation to hypnotic susceptibility and the effects of hypnotic induction. The right-ear advantage was significantly reduced during hypnosis, as compared to pretest and posttest conditions, and a significant correlation was found between the laterality scores obtained during all three conditions and hypnotic susceptibility. The greater the hypnontic susceptibility, the smaller the linguistic advantage of the right ear.

The experimental investigations seem to offer support for the view that individuals who tend toward introversion (i.e., who are characterized by anxiety, depression, critical evaluations of self and others, and a generally pessimistic outlook) are biased toward left-hemisphere reliance. Individuals

who tend toward low anxiety, absence of depression, uncritical evaluations of self and others, and a generally optimistic outlook are biased toward right-hemisphere reliance. This conclusion may support Tucker's (1981) hypothesis that the right hemisphere has a positive affective tone and the left hemisphere has a negative affective tone. However, it could equally well be that differential reliance on the left hemisphere reflects asymmetrically low right-hemisphere arousal and that the sadness results form this low right-hemisphere arousal.

Task Performance and Personality. What effect might personality have on task performance? Levy proposed that, among right-handers, the degree of right-hemisphere or left-hemisphere engagement on either verbal or nonverbal tasks is closely related to the level of task performance: Asymmetric right-hemisphere engagement diminishes tachistoscopic verbal performance and enhances tachisto-scopic face recognition, and the opposite relations hold for persons with asymmetric left-hemisphere engagement. This prediction is consistent with findings from other researchers. Rapaczynski and Ehrlichman (1979) tested 24 females who had been classified as field dependent or field independent (field independence is the name given by Witkin to an analytical view of the world) for their lateralization and ability on a tachistoscopic face-recognition test. For upright faces, field-independent subjects showed an advantage for the right hemisphere. In a previous, similar study Oltman, Ehrlichman, and Cox (1977) investigated perceptual asymmetries for the comparison of a normal face to two symmetric face composites, one composed of two right-half faces and one composed of two left-half faces. Subjects were asked to judge which composite looked more like the original. A significant correlation was found between field independence and a leftward asymmetry, consistent with the relationship observed by Rapaczynski and Ehrlichman. However, field dependence is so complicated that it is hard to see how it would fit neatly to hemispheric functioning. Moreover, why do analytic, field-independent persons show right-hemisphere engagement?

The possibility of individual differences in cognition (cognitive style) relating to hemispheric function would have relevance to instruction. If such differences are reliable, the learning task would have to be tailored to the individual. However, at the moment, research has not provided a theoretical framework sufficiently certain to suggest a course of action.

Handedness

In many societies, left-handers are felt to be different from right-handers in ways that go beyond the trivial fact that they prefer to use their left hands for tasks on which the majority of the population use their right hands. "Difference" is then taken to imply inferiority in left-handers, who constitute some 10% to 15% of the population at large in Western societies. Confirmation of this purported inferiority might seem to be implied by the undoubted fact that left-handers are overrepresented in many pathological populations. For example: among subjects with epilepsy, mental retardation, learning disability, or developmental dyslexia, the incidence of left-handedness significantly exceeds that found in the general population. However, if one selects members of the general population (right- and left-handed) and tests their level of cognitive functioning, significant handedness differences favoring the right-handed are

rarely found. Among university populations (both faculty and students), for example, there is no selective underrepresentation of left-handers.

The resolution of this seeming paradox is as follows: Handedness has an inherited component favoring right-handedness, but overt manifest handedness can be changed by early (perinatal) brain damage. It follows that the number of pathological left-handers (who should genetically be right-handers) will be greater than the number of pathological right-handers (who should genetically have been left-handers). Thus in populations that have suffered early brain damage leading both to changed handedness and cognitive deficits, left-handers will be overrepresented. The questions, then, are whether normal left-handedness (not consequent upon cerebral damage) has any cognitive implications and whether there are structural anatomic correlates of "left-handed cognition."

When complementary hemispheric specialization was initially discovered in right-handers, it was assumed that cerebral organization in the left-handed is the mirror image of the right-handed brain, that is, that left-handers have language in the right hemisphere and visuospatial skills in the left. This is not true for the left-handed population as a whole. The incidence rates of aphasia following unilateral lesions in left-handers indicate that the majority of these subjects have definite left-hemisphere language. Nonetheless, the incidence of aphasia after right-hemisphere injury in left-handers is significantly higher than in right-handers. Furthermore, results from sodium amytal testing and unilateral ECT studies suggest that some 20% of left-handers have an appreciable degree of bilateral representation for language. It is likely that bilateral language representation is most common in familial left-handers, and also in right-handers who have close relatives who are left-handed. There is some evidence that these two groups show better recovery from aphasia than do right-handers without left-handed family.

It is found fairly reliably in nonclinical poulations of left-handers that the right-ear advantage and right visual field advantage for verbal material is smaller in magnitude (or reverses more frequently) than in right-handers. A tendency toward bilateral or right-hemisphere language representation is thus an established characteristic of a significant proportion of the left-handed population. As far as is known, however, there are no reliable differences in verbal ability associated with these forms of neuronal organization.

It has, however, been argued (see Marshall, 1973, for discussion) that bilateral language representation interferes with the right-hemisphere mechanisms that underly visuospatial skill. Thus it was hypothesized that normal left-handers (or mixed handers, depending on the investigator's categorization of that part of the population that is not fully right-handed) would perform more poorly on nonverbal intelligence tests and on specific visuospatial tasks known to be right-hemisphere dependent. Although a few studies with very small groups of right- and left-handed subjects did show the predicted discrepancy, numerous large-scale studies have signally failed to confirm the finding. There is at the moment no evidence for a selective visuospatial deficit in normal left-handers. Indeed, recent studies (so far unreplicated) have suggested that left-handers are overrepresented in the architectural profession. (One's interpretation of this finding is dependent on one's attitude to modern architecture.) Further, there is at least an average (and perhaps an above-average) representation of left-handers among professional cricketers, baseball players,

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and tennis players, groups not deficient in visuospatial ability or visuomotor coordination (see Geschwind & Galaburda, 1984).

In short, left-handers are both cognitively and neurologically a very heterogeneous group. Attempts to regard them as a homogeneous population who are functionally distinct from right-handers should be firmly discouraged.

Sex

The population of sex differences in cognitive capacity has a long and somewhat dubious history. Western societies have had a strong tendency to stress the superior intelligence of men and dismiss women as frail, subjective, and intuitive creatures. In the past, neurologists have rarely hesitated to ascribe women's purported inferiority to the relative delicacy of their nerve fibers. When cerebral dominance (for language) was discovered in the 19th century and interpreted as a biological index of man's superiority over the animals, it became popular to ascribe female inferiority to a failure to develop fully the complementary hemispheric specialization that was characteristic of the male brain. Yet it was simultaneously popular to argue that men were superior in visuospatial skill and women superior in linguistic skill. It was, of course, easy to argue that this purported discrepancy reflected an evolutionary specialization in which man was the hunter while woman remained in the cave to talk to baby, and to use this story to justify current social practices. Consistent adoption of this latter lateralization hypothesis would lead to the conclusion that (left) cerebral dominance for language was more pronounced in women than men, but (right) cerebral dominance for visuospatial skills more pronounced in men.

There is little evidence to support the first of these conclusions. And indeed it has been reported that there is a higher incidence of aphasia after left-hemisphere damage in males than in females. If this is so, then one possible conclusion is that speech and language functions are more bilaterally organized in women than in men. Kimura uand Harshman (1984) argued, on the contrary, that the finding reflects an intrahemispheric difference in language organization between the sexes. Their claim was that "in females, speech appears to be critically dependent on the left anterior cerebral region, with left posterior damage rarely producing aphasia." By contrast, they claimed that "aphasia in males is produced equally often from anterior or posterior damage." They did, however, find that impairment of vocabulary scores (on the Wechsler Adult Intelligence Scale) is found after right-hemisphere damage in women but not in men. Yet vocabulary impairment is approximately equal in both sexes after left-hemisphere damage. There is thus no simple inference to bilateral representation of vocabulary in women.

In normal subjects assessments by dichotic listening and split visual field presentation provide some evidence to suggest that the right-ear advantage and the right-field advantage for verbal material is more pronounced in men than women. The standard interpretation of this finding is that language is more bilaterally represented in women than in men (McGlone, 1980). Whether this difference confers any significant overall verbal advantage on women is unknown.

It is likely that higher visuospatial functions are more bilaterally represented in both men and women than is language. In clinical populations with acquired brain damage, there is no reliable evidence to indicate sex differences in the relative contributions of the hemispheres to visuospatial performance, although it has been suggested that women may try to solve visuospatial tasks in a more verbal fashion than men.

In normal populations, it has been claimed that perceptual asymmetries are more striking in men than women, and vice versa. However, on the kind of tasks that are typically employed in lateralization studies, there is little evidence for male superiority. There are no significant sex differences in overall level of performance on dot location tasks; similarly, there are no relative sex differences on embedded figures tests. Women are as good as men on the Street Gestalt completion test. In general, the evidence for biologically determined sex differences in visuospatial ability in normal human subjects is far from conclusive. Similarly, with lateralized stimulus presentation, there are few if any reliable sex differences in the magnitude of hemifield advantages.

These results do not mean that reliable and significant effects will not eventually be found, and the entire question has recently been reopened on the basis of Geschwind's hypothesis that the developmental course of hemispheric dominance is under the control of the sex hormone testosterone (see Geschwind & Galaburda, 1984). Nonetheless, for the moment, the Scottish verdict of "not proven" seems appropriate with respect to both sex differences in ability and sex differences in the anatomical substrate for higher mental functions. Whatever group differences may exist, they are likely to be small in comparison with the differences in ability that exist within either the male or female population.

Age

The overall result of most aging research is that mental functioning shows very little evidence of a generalized decline until quite an advanced age. Benton, Eslinger, and Damasio (1981) studied a sample of normal, well-educated, healthy, older subjects and found no evidence for any real decline below the age of 80 years. Even at ages of 80 to 84 years, the average failure rate on the standard neuropsychological tests was only 14%. However, performance on the tests was not uniform. Five tests showed very little decrement: temporal orientation, digit span, word association, logical memory, and paired-associate learning. The tests that were more sensitive to aging were digit sequence learning, visual retention, facial recognition, and, to a limited extent, line orientation (i.e., those tasks that contained considerable visuospatial processing).

In contrast, Cantone, Orsini, and Grossi (1978) reported that normal aging does not affect memory for visuospatial information more than memory for verbal information. But other large-scale studies on normal subjects (Arenberg, 1978; Poitrenand & Clement, 1965) and demented subjects (Miller, 1977) did find a much greater decline for short-term visual memory, so it is an idea to take seriously. As the visual-verbal dichotomy can be fitted to the right-left split, it is not surprising to find that it has been postulated (Klisz, 1978) that the right hemisphere ages more quickly than the left hemisphere.

Systematic analysis of the question of differential hemisphere aging requires a little skepticism about Klisz' suggestions. The study by Benton et al. did not find that judgment of line direction—the task most suscepti- ble to unilateral right-hemisphere lesions, in Benton's view—declined most with age. In a much larger study, Goldstein and Shelly (1981) also found that very few of their standard right-hemisphere tasks declined with age. There was no particular decline for functions such as spatial relations, except for solving psychomotor problems with the left hand. Goldstein and Shelly based their analysis on a comparison of normal performance with neuropsychological profiles found after unilateral brain damage; the main finding was that aging was reflected more as a decline of both hemispheric functions than as a de- cline of the right more than the left. Nevertheless, there was a significant tendency for aged normal subjects to show profiles similar tc right brain- damaged patients.

There are other consistencies in the pattern of decline of mental func- tion with age. It is generally known that the ability to gather information from briefly presented material does indeed decline. It is probably this property, rather than any other, that underlies failure, when it occurs, in visual memory tasks even when the memory component appears to be small. There is some evidence that the ability to integrate visual material is related to right-hemisphere function (Newcombe, 1969), which may be the case especially for brief presentations (Davidoff, 1984). It is for this ability that a cor- related age factor might be found. The right-hemisphere tasks that do not seem to show a decline with age are more of the problem-solving variety. However, in the absence of a clearer notion of what constitutes a pure right- hemisphere task, there is really no point in speculating on hemispheric mech- anisms that could be differentially impaired with age.

5. HEMISPHERIC LEARNING AND LEARNING POTENTIAL

In considering the role of the two cerebral hemispheres in learning, it is important to keep a number of questions quite distinct. These are:

- What has been directly demonstrated about lateralization of learning processes in the brain?

- Are there general characteristics of human performance that can be related to the organization of the brain?

- Do these general characteristics have implications for learning poten- tial or training methods?

- If there are such implications, do they arise from the underlying as- sociation with lateralized brain processes?

This review attempts to disentangle these issues, which are frequently confused in discussions of hemispheric function, hemisphericity, right- and left-brain cognitive style, and learning or creativity.

The first issue is to identify what experimental and clinical neuropsy- chological studies have directly demonstrated about the lateralization of learning processes in the brain. In the case of experimental neuropsychology,

laboratory studies assess human performance following presentation of stimuli that are directed solely to one hemisphere of the brain, as well as record certain physiological variables. Clinical studies attempt to associate focal damage to the cortex of the brain with functional deficits, thereby providing information about the cerebral organization of the impaired functions. In neither case is the observation of brain function and its relation to cognitive functions strictly direct, but the inferences drawn are reasonably short. Scholars can be confident that the brain-behavior relations so deduced are valid (Beaumont, 1983c). (For general reviews of experimental neuropsychology, see Bradshaw & Nettleton, 1984; Bryden, 1982; Springer & Deutsch, 1985; for reviews of clinical neuropsychology, see Beaumont, 1983b; Heilman & Valenstein, 1979; Kolb & Whishaw, 1985; Walsh, 1978).

Split-Brain Studies

The stimulus to the upsurge of interest in cerebral lateralization over the past two decades was the work on split-brain patients carried out by Sperry and Gazzaniga from 1960. Most of the split-brain research in recent years has concentrated on the linguistic and visuospatial abilities of the two hemispheres. However, it is generally accepted that the two hemispheres have more or less independent capacities to perceive, remember, and learn. Unfortunately, direct studies of learning ability have been rare.

Gazzaniga and Johnson (Gazzaniga, 1970, 1972; Johnson & Gazzaniga, 1969) found some evidence for the lateralization of learning to the hemisphere in which it was originally established. However, they also found that it was possible for responses to be mediated by information about the extent of vertical eye movements (moving over the extent of the long or short bars used as stimuli). This information was transferred subcortically (because of the low-level systems subserving eye movements), so providing an alternative route that allowed bilateralization of learning. These results illustrate the kind of difficulty encountered in designing rigorous experiments in this area.

Bilateral motor learning established before the operation has been found to be preserved (Preilowski, 1975), but patients were unable to learn normally a novel bimanual coordination task. Again the interpretation of the data is complicated by the fact that there is some ipsilateral innervation (from one hemisphere to the same side of the body) for all but fine motor control of the fingers.

An idea that developed out of the early research was that if the hemispheres could operate relatively independently, then a task could be assigned to each, so perhaps doubling the mental capacity of the split-brain patient. Franco (1977), among others, did show that the two disconnected hemispheres were capable of concurrently processing entirely unreleated information, which would be subject to mutual interference if processed in the same hemisphere. This finding has been confirmed, although it has been shown to operate only within certain limits imposed by the overall allocation of processing resources (Holtzman & Gazzaniga, 1982; Kinsbourne, 1980).

In one sense, then, it appears as though the mental capacity of the split-brain patient can be extended, if not entirely doubled. It is, however, essential to realize that although the performance of these patients can be

extended under artificial laboratory conditions, it is not necessarily sensible to expect that the same could be achieved by normal, intact subjects. Apart from the active contributions of intact commissures, the level of performance of the commissurotomy patients is so far below the level of performance of normal subjects on the tasks under study that even the doubling of performance leaves the result well below the competence of normal individuals.

Although there is evidence form other areas of study (see the following discussion) for lateralization of memory functions, split-brain patients appear to suffer a general impairment of memory after commissurotomy. This fact suggests that the commissures play a role in both encoding and retrieving memories (by providing links between the hemispheres) (Zaidel & Sperry, 1974).

Brain Damage

Historically, the most important way of establishing the functions of the cerebral cortex has been through the study of the effects of focal damage to the brain. After a century of scientific investigation, the principal conclusion seems to be that many different areas of the brain are involved in learning.

One area of debate has been the degree to which any function is localized. The supporters of mass action theories have argued that the brain cannot be regarded as a collection of independent processing modules, and have pointed to research (mostly in animals) showing that it is the amount of tissue affected rather than its exact location that determines the degree to which general cognitive ability—particularly learning—is disrupted. Although these views are not currently dominant, they are a reminder that, with certain specific exceptions, damage to many distinct parts of the brain may impair learning. Although the currently dominant approach of relative regional localization has assigned many functions to areas of the cortex, with the exception of certain primary sensory and motor functions, there is an uncomfortable lack of precision in the localization proposed.

An early view was that "biological intelligence," which involved adaptive learning behavior and was in part founded on "abstract attitude," was specifically associated with the frontal lobes of the brain. This view was, however, discounted by the demonstration that frontal lobe-injured patients had, on average, large lesions, and that the lesion size was the critical factor (Chapman & Wolff, 1959). Modern studies of the war-injured do not support the idea that intelligence and learning can be associated specifically with the frontal lobes (Black, 1976). It is also the case that dementing illnesses (notably dementia of the Alzheimer type), which cause general diffuse pathology in the cortex of the brain, interfere with general learning abilities.

There is, however, some evidence of a specific contribution of the temporal lobes to aspects of learning and memory. The dense anterograde amnesia produced by bilateral medial temporal lesions, in the form of the amnesic syndrome, is produced either by a failure to properly encode information into memory or else by a severe inability to retrieve it. The classic case is HM (Milner, Corkin, & Teuber, 1968), who remembered almost nothing that had happened to him and learned little or no new information since surgery in 1956. A similar effect can be seen in patients with Korsakoff's psychosis associated with chronic alcoholism. However, although such patients require no

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episodic learning, they are able to learn motor tasks with almost normal facility.

Such illnesses, which affect both sides of the brain, produce quite global effects on learning. Unilateral temporal lesions have, however, been shown to selectively affect verbal long-term memory if on the left side and spatioperceptual long-term memory if on the right side. Learning of verbal paired associates, whether presented in the visual or the auditory modality, has also been shown to be deficient after damage to the left temporal lobe of the brain (Black, 1973; Blakemore, 1969; Jones-Gotman & Milner, 1978).

With the exception of these relatively isolated reports of the lateralization of delayed recall of information, there is little other evidence for the lateralization of learning processes from the study of patients with damage to the brain. Clinical neuropsychological studies indicate that in most learning tasks large areas of the brain, on both sides, are involved. This involvement might be because of the importance of involving substantial masses of cortical tissue, or it might be because learning involves so many independent component functions that contribute to the high-level ability as it is observed. In either case, there is no evidence that one hemisphere contributes significantly more than the other to the process.

Neuropsychological Rehabilitation

Can anything be gleaned about the brain and learning from current approaches to retraining and rehabilitation? Answering this question requires considering both the process of recovery and the training methods currently employed.

There is still considerable controversy about the exact nature of the processes that underlie recovery of function. It is clear that although the sprouting of neurons around the region of damage may play some part, there is no significant contribution from the actual regrowth of tissue in the human central nervous system. The recovery that occurs must result from one or more of four processes:

- Acute reduction in the disturbance that results from swelling of tissue and other secondary effects of the lesion--Undoubtedly, these disturbances do resolve and lead to some short-term recovery.

- Duplication of functions in the brain, with activation of the previously silent reserve areas--This process seems unlikely to be a major factor from a biological point of view, because it would be wasteful to have so many systems reduplicated, and the resulting recovery ought to be more effective.

- Establishment of new learning in a remaining intact region of the brain so that functions are relocated--This process is a possibility, but it has been hard to demonstrate that it actually occurs in adults.

- Functional compensation and adjustment--This is the process currently most favored by writers in this area. The idea is that high-level intelligent functions are based on a complex network of lower functions,

only some of which are actually damaged. Recovery depends on re-
organizing the remaining intact functional units to restore perfor-
mance. This process is more or less successful depending on the
range of functional units remaining and the opportunity to develop
new cognitive strategies that may evade the areas in which the spe-
cific problems lie. If this process is responsible for the (limited)
recovery seen in adults, attention should be directed to the cogni-
tive organization of the cortex, not its anatomical architecture (of
which lateralization is a feature).

Specific procedures for retraining brain-damaged patients are as yet lit-
tle researched. Other than appropriate practice and rehearsal, little has
been formally developed, although considerable interest is now turned in this
direction. One obvious idea is to build upon naturally occurring processes,
aiding patients to make optimum use of remaining functional units by giving
them opportunities for relearning experiences in an appropriate context.

Almost the only way in which cerebral lateralization has been implicated
is in the retraining of aphasics (who have severe speech and language impair-
ment, usually resulting from left-hemisphere lesions). This work has suggested
that intact right-hemisphere mechanisms such as singing (melodic intonation
therapy) or the use of visual tokens for communication (as used with "linguis-
tic apes") could educe recovery of function. The widespread success of these
methods has not been clearly established.

The work on rehabilitation suggests that it is the cognitive psychologi-
cal parameters of the patient's deficit that determine the scope of recovery
and whether recovery can be enhanced. The neuropsychological organization of
the cortex, in terms of left-right hemisphere relationships, is probably of
limited importance except in the general way in which it sheds light on how
the brain achieves its functions.

Reviews of recovery and rehabilitation can be found in Brooks (1984),
Finger and Stein (1982), Golden (1981), Miller (1984), Perecman (1983), and
Powell (1981).

Studies in Animals

There is a vast literature on the neuropsychology of learning in animals;
studies have involved the ablation of selected areas of the cortex and split-
brain experiments. There are no general and integrated reviews available that
cover the topic of laterality and learning, although Denenberg (1981) expertly
reviewed animal studies of hemispheric laterality and the effects of early ex-
perience. Also, Geschwind and Galaburda (1984) presented state-of-the-art re-
views on a number of relevant current areas of research.

In artificial laboratory preparations, it can be shown that learning can
be established in a single hemisphere of the brain. If the cerebral commissures
are intact, then learning leads to bilateral engrams being established. How-
ever, if the commissures are unable to function during the period of training,
then unilateral engrams may be laid down. Subsequently, although the commis-
sures (principally the corpus callosum) may transfer complex information, they
apparently cannot normally transfer an already establish.' engram from one

hemisphere to the other (see, for example, Gaston, 1980, on chicks; Gulliksen & Voneida, 1975, on cats; Rose & Plotkin, 1977, on rats).

The picture is, however, a little complicated by the role of reward systems in these studies. It may be that the failure to demonstrate performance in the untrained hemisphere is a function of a reduced motivational level rather than an essential failure to learn the contingencies that operate in the experimental task. If nothing else, the experiments that lead to this conclusion underline the importance of not treating learning as if it can be simply located within the brain. The external contingencies associated with training may well in part determine the apparent specificity of function inferred from a particular experimental paradigm (Gazzaniga & LeDoux, 1978).

Nevertheless, certain aspects of both learned and innate behavior have been shown to be lateralized in animals. Nottebohm (1984) showed most elegantly that birdsong depends on lateralized processes that are in part innate and in part learned (see Rogers, 1980).

Studies of the chicken have also demonstrated that there are not only cortical lateralized processes but also subcortical biochemical systems that provide evidence of lateral differentiation (see Glick & Shapiro, 1984; Rogers & Anson, 1979). It has also been reported that following training of one hemisphere (with one eye sutured), subsequent testing with both eyes open results in differential blood velocity within the two hemispheres (Bondy & Harrington, 1978). This effect appears, however, only when the chick is reexposed to the discrimination stimuli, in which case the flow through the untrained hemisphere is greater than through the trained hemisphere.

An analogous effect has been reported for electrophysiological activity in the monkey (Greenwald & Miller, 1980). Following training on auditory and visual GO/NO-GO tasks, systematic changes were reported in right-left relationships of EEG amplitude as learning occurred. Such findings from technically demanding research, however, warrant independent validation from other laboratories. It has been difficult to establish unequivocally similar effects in human studies (Donchin, 1984; Thatcher & John, 1977).

Although it is possible to demonstrate lateralization of learning in carefully controlled laboratory paradigms, there is no reason to infer that in normal learning contexts there is significant lateralization of learning processes for humans. As with lateralization in the songbird, the involvement of particular mediators (in humans, speech) may invoke lateralized contributions, as may the impetus of specific motivational systems. There is, however, no evidence that suggests that in humans learning per se might be considered to be simply either a left- or a right-hemisphere process.

Lateralized Presentation

Most studies have relied on presentation in the visual modality (divided visual field studies) or in the auditory modality (dichotic listening studies). As already discussed, there is now a very sizable literature derived from these techniques, although relatively little of it directly concerns learning. When learning has been studied within this paradigm, retention has been required only over very short intervals. However, some early studies did examine

paired-associated learning (of vowel-consonant duograms) and incidential learning, but found no differences associated with the visual field of presentation of the task material; no lateral hemisphere differences were inferred (Bimond & Beaumont, 1974a, 1974b). These workers did, however, find a left-hemisphere superiority for paired-associate learning of digits paired with key symbols. LeFebvre and Kubose (1975) also found a left-hemisphere advantage for reversal learning, but no lateral difference for verbal learning in a discrimination learning paradigm. These studies depend on a model of hemisphere differences that assumes stable structural asymmetries in the cognitive functional architecture of the hemispheres.

More recent studies in a similar vein have been carried out by an Italian group (Berrini, Della Sala, Spinnler, Sterzi, & Vallar, 1982; Berrini, Capitani, Della Sala, & Spinnler, 1984). They presented a matrix of stimuli to be remembered, which might be verbal (letters) or nonverbal (stars). The target and subsequent probe stimuli were presented in either the left or right visual field. They concluded that the initial stage of stimulus coding may play a more important role in determining lateral asymmetries than the stage of recognition. This interpretation, however, runs counter to other findings that have emphasized retrieval rather than encoding (Kirsner & Brown, 1981). They also found that with letter stimuli, the condition in which target and probe went to different hemispheres produced superior performance. They suggested that this result occurred because the right hemisphere, but not the left, can add specific mnestic resources to the initial stage of letter processing.

More recent studies have also taken into account not only structural factors but also attentional variables and strategy effects (Bryden, 1978). These have all been shown to play a significant role in lateral performance asymmetries. Seamon (1974) showed that an imagery strategy could generate a right-hemisphere lateral advantage, whether the probes were words or pictures (although Metzger & Antes, 1976, failed to find this effect). Hannay, Dee, Burns, and Hasek (1981) showed that a right-hemisphere advantage for processing irregular shapes could be transformed into a left-hemisphere advantage by having the subjects learn a verbal label for each shape. Even the acquisition of the label, although not its use, appeared to attenuate the right-hemisphere advantage (although this study has been critically attacked by Sergent, 1982a).

Other workers have found similar effects of inducing particular encoding strategies (Bersted, 1983; Edwards & Venables, 1982; Galluscio, 1984), even if the effects have not always been strongly evident. Practice has also been found to modify the pattern of lateral asymmetries, showing that experience of the stimuli and of the task can modify the cerebral organization as expressed in performance (see Beaumont, 1982a).

Alternative approaches have emphasized the flexible allocation of resources (Herdman & Friedman, 1985; Polich, 1982; Sergen , 1982b). Herdman and Friedman employed a dual-task approach demanding retention of both visual verbal items and auditory tones. Subjects were told to emphasize one of the two tasks and were found to be able to trade off task performance with right-ear tones, but not left-ear tones. This result supports an assumption that the processing resources of each hemisphere are relatively independent, but their allocation is governed by task and other processing demands.

These illustrations have all been drawn from the visual modality, but parallel results are to be found in dichotic listening (e.g., Bohannon & Baker-Ward, 1981).

The essential point about the studies is that they show that lateral cerebral organization depends not just on predetermined neurological structural asymmetries in which particular material, tasks, or responses are associated with the specialization of one of the hemispheres. Rather, the studies show that the expression of cerebral function is partly determined by dynamic cognitive processes. Some of these may be related to the nature of the stimulus material; some may be related to the functional demands of the task. Some, however, are determined by individual differences and by contextual factors, and suggest not fixed lateral differentiation, but a reactive, dynamic, and flexible arrangement that responds to cognitive demands in a complex way.

Specifically with respect to learning, the studies have not extensively explored the general parameters of learning abilities, and many of the experimental paradigms might be better described as involving memory rather than learning. Nevertheless, in tightly controlled experimental paradigms allowing dependable inferences to brain-behavior relationships, there is no reason to consider learning abilities to be lateralized in terms of the specialization of one of the hemispheres. Processes that relate to the encoding of information may be associated with one or the other of the hemispheres (although in a relatively complex way). There is, at present, no clear general experimental evidence that learning would be significantly more successful either if the material were presented to only a single hemisphere or if one hemisphere were to be invoked as the principal mediator of the learning processes involved.

Lateral Orientation

The experimental neuropsychological research that has focused on learning seems rather disappointing. Good techniques for establishing the cerebral lateralization of functions are available, and yet despite two decades of research nothing very informative seems to have been found.

There is one further aspect of this work that is relevant and may be exploitable in the future. This is the effect not of lateralized presentation, but of lateral personal orientation.

The effect is really the corollary of the discovery that conjugate lateral eye movements may be associated with lateralized cerebral functions (Kinsbourne, 1972). The hypothesis is that cognitive activity associated with a particular hemisphere produces greater activation in that hemisphere. This activation results in a lateral shift of gaze to the opposite side of space. The phenomenon is usually linked to attentional models of cerebral lateralization. (The validity of this explanation of lateral eye movements will be discussed later.)

As early as 1974, Hines and Martindale tried to see if inducing lateral eye movements would also influence hemisphere activation and hence cognitive performance. They found partial support for their hypothesis. They were able to demonstrate enhanced creativity on one task and improved performance on spatial relations in another, although only for male subjects. Gross, Franko, and Lewin (1978) also found a bias to a nonsemantic cognitive mode when subjects

gazed to the left rather than to the right. This group also found that better estimates of verticality were made on the Rod-and-Frame Test when gaze was directed to the right (even though this is not the expected result).

Casey (1981) presented verbal and spatial problems 20 degrees to the subject's left or right, not 20 degrees to the left or right of fixation; gaze is free to move. The hypothesis was that with gaze to the right, performance on the verbal problems would be better; with gaze to the left, spatial problems would be performed more successfully. Only partial support for the hypothesis was found. Similarly, LaTorre and LaTorre (1981), studying children, found that spatial intelligence test items were performed more poorly during rightward gaze, although there was no effect for verbal items. Complementary effects on verbal and spatial problems, with opposite directions of fixation, have nevertheless been found in adults (Walker, Wade, & Walkman, 1982). Lempert and Kinsbourne (1982) found better recall for sentences with head and eyes turned to the right. The effect has been extended to visuotactual and kinesthetic effects (Bradshaw, Nettleton, Nathan, & Wilson, 1983) and to dichotic listening (Hiscock, Hampson, Wong, & Kinsbourne, 1985).

An obvious extension of this work would be to see whether students who sit at one side of a classroom are more successful than those who sit at the other. No doubt such an effect would be hard to detect among all the other factors involved, but it was examined indirectly by Schuller and Grabl (1981), who found an association between handedness and seating position. This result is sufficiently intriguing to warrant further investigation.

Another intriguing result has been reported by Drake (1984a), who found that familiarity and liking for individuals were associated when subjects oriented themselves toward the right, but not toward the left. He also reported effects for personal optimism, which increased with right orientation, as did riskier decision taking, although subjects were also less persuasible (1984b, 1985; Drake & Bingham, 1985).

None of these reports can be considered firm demonstrations in support of the hypothesis that inducing lateral gaze influences cognitive abilities, including learning potential. However, it is a matter still open to empirical investigation. If the effect were more firmly established, the appropriate technology would be easy to develop. It is far from certain that any benefits would be significant in practical terms, but the issue deserves further investigation.

Hemisphericity: The Concept

The evidence relating to the question of what has been directly demonstrated of the lateralization of learning processes in the brain has essentially just been presented. The discussion now turns to the question of whether general characteristics of performance associated with brain laterality have been demonstrated. Leaving handedness apart, in the cognitive domain this means hemisphericity. The concept of hemisphericity has been the subject of a recent extensive review by Beaumont, Young, and McManus (1984). The discussion here summarizes and updates that review (see also Beaumont, 1983a).

Hemisphericity refers to the notion that a person may rely on a preferred mode of cognitive processing that may be linked to the activity of the left or right cerebral hemisphere. In view of the amount of research based on this concept, it is surprising that there have been so few attempts to directly demonstrate the existence of hemisphericity by the methods of experimental and clinical neuropsychology outlined. There have been occasional studies (Arndt & Berger, 1978; Caplan & Kinsbourne, 1981, 1982; Charman, 1981; Zoccolotti & Oltman, 1978), but no clear, unequivocal demonstration of the existence of cognitive styles that could be directly attributed to lateral cerebral function.

Four different paradigms have been used to measure hemisphericity: lateral eye movements, electrophysiology, cognitive tests, and questionnaires. They are best considered separately.

Lateral eye movements have already been referred to. Although their measurement requires care, there seems to be agreement that the phenomenon of lateral eye movements is a relatively stable one. Subjects do exhibit characteristic lateral gaze shifts when engaged in cognitive activity. However, the thorough review of Ehrlichman and Weinberger (1978) concluded that lateral eye movements are not necessarily related to hemispheric asymmetry. No evidence that would substantially alter this conclusion has subsequently appeared (see Beaumont et al., 1984; Owens & Limber, 1983). Although many studies refer to Ehrlichman and Weinberger's review and then proceed to treat lateral eye movements as if they were a valid index of cerebral activation, there is no good reason to do so. In the absence of independent validation that lateral eye movements directly index lateral cerebral activity, they cannot be used as a valid measure of hemisphericity.

The demands of electrophysiological research are considerable. The methodological difficulties have been highlighted most clearly by Gevins et al. (1979a, 1979b; see also Beaumont, 1982b, and Rugg, 1982). In particular the underlying anatomical asymmetry of the cortex (LeMay, 1984) seems an intractable problem. Although there may well be laterality effects to be discovered in the EEG, no experimental paradigm has yet been established that would enable a reliable index of lateral hemisphere function to be derived from EEG or evoked potential recordings. Hemisphericity cannot yet be validated with reference to electrophysiological techniques.

Cognitive tests that have been directly validated against patients with focal brain damage seem to provide a sensible and promising approach to indexing hemisphericity. Again, however, as Beaumont et al. (1984) showed, many writers have been content to assume the validity of the cognitive tests they employ, without presenting the required evidence. The one exception is the promising work from the team associated with Gordon (Bentin & Gordon, 1979; Gordon, 1980, 1983; Gordon, Frooman, & Lavie, 1982; Gordon, Silverberg-Shalev, & Czernilas, 1982). This work relies on a battery of tests (the Cognitive Laterality Battery) that have been directly studied in brain-damaged patients, although the battery is still in the process of development. Other approaches, however, especially those simply based on a dichotomy of verbal and nonverbal tasks, cannot be considered sound measures of hemisphericity (Dumbrower, Favero, Michael, & Cooper, 1981).

The final paradigm has been the use of questionnaires. Particularly widely used has been the "Your Style of Learning and Thinking" (YSLT) of Torrance, 1982;

Torrance, & Reynolds, 1980). This questionnaire, and others like it, was heavily criticized not only by Beaumont et al. (1984) but also by Fitzgerald and Hattie (1983). The instruments have weak theoretical bases, are psychometrically poorly constructed, and lack concurrent validity. Often, the questionnaires have been validated on the claim that creativity is a property of the right hemisphere of the brain. This claim has certainly not been established. However, questionnaires continue to be the most widely used instruments to measure hemisphericity. As is discussed in the following sections, a number of associations have been claimed between hemisphericity and a variety of aspects of learning and training. Whether or not these claims are valid (or useful), there is no clear evidence to support the belief that hemisphericity as measured by questionnaires like the YSLT has any connection with lateralized cerebral cognitive processes.

There is no reason, as yet, to modify the conclusion of Beaumont et al. (1984) that

> it would seem prudent to abandon the notion of hemisphericity, at least in so far as it claims to make any reference to the lateral function of the cerebral hemispheres. Such a claim cannot be supported by current scientific studies of the cognitive functions of the cerebral hemispheres . . . . (p. 206)

Leaving the question of the validity of the concept of hemisphericity aside for the moment, let us consider how the concept has been linked to creativity and to education and learning.

Hemisphericity and Creativity

Modern interest in the association between lateral specialization of the brain and creativity was sparked off by papers by Bogen (1969) and Bogen and Bogen (1969), which came out of their involvement with split-brain studies. They proposed a dichotomy between the left hemisphere as propositional and the right hemisphere as appositional. In later studies, it was suggested that the balance between predominantly propositional and appositional thought might be a general characteristic of individuals, or even of social cultures. The term hemisphericity was generated to describe this balance (Bogen, DeZure, TenHouten, & Marsh, 1972).

These ideas, together with others, were popularized by Ornstein in The Psychology of Consciousness (1972). Ornstein emphasized the dichotomy between Western and Eastern styles of thought, which, he proposed, could be associated with the left and right hemispheres, respectively. The left hemisphere represented analysis, reason, order, and logic; the right, imagination, intuition, synthesis, and creativity.

At this stage the hypotheses were to some extent derived from experimental work carried out with split-brain patients and with normal subjects using the new laboratory techniques of lateralized presentation and EEG recording. Although the theories went well beyond the evidence (which was actually concerned with the speed and accuracy of the recognition and matching of letters, simple words, random shapes, and everyday objects), they did refer to these investigations to establish their legitimacy. The current position with regard to this evidence has already been summarized.

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However, the introduction of dichotomies to characterize the nature of the two hemispheres seemed to encourage descriptions that went increasingly beyond the scientific evidence. Many reviewers have collated lists of these dichotomies, but as Corballis and Beale (1983) pointed out

> Just as it is difficult to find objects in the real world which are neither male or female sex symbols (in the Freudian sense), so it is difficult to discover distinctions that cannot be grafted onto the two cerebral hemispheres. (p. 165)

The difficulty of assessing the growing work on hemisphericity and creativity, from a scientific standpoint, is that this work has gone beyond the point at which it is supported by scientific evidence. It was the introduction of questionnaires, such as the YSLT, that was responsible for this shift. As mentioned, basing the validity of these instruments in neuropsychological processes is extremely dubious. The approach is based entirely on Torrance and Reynolds' (1980) belief that "the essence of creativity is a specialized function of the right cerebral hemisphere" (p. 2). In subsequent research, this instrument has been used as the primary measure of creativity; the validity of the conclusions of this research depends entirely on the questionable validity of Torrance and Reynolds' belief.

Examination of the items contained in the various versions of the YSLT shows that many items have much in common with other questionnaires that claim to measure creativity. It is therefore not surprising that correlations between these two types of questionnaire have been reported (Torrance & Mourad, 1978, 1979). Such correlations cannot be said to add much to the validity of the concept of hemisphericity.

Similarly, evidence about the trainability of hemisphericity and benefits of training for creativity is suspect to a degree. In the study by Reynolds and Torrance (1978), the training procedures involved specific discussion of the topics addressed by the YSLT questions (preferred ways of tackling problems, preferred activities, mental associations). As the hemisphericity questionnaire employs self-report and carries obvious face validity (i.e., the respondents know what the questionnaire is assessing), it seems quite surprising that there was a change in the nature of the answers given, in the direction of the mental processes urged by the course. It would certainly be rash to assume that a significant change had occurred in the subjects' cognitive performance, and foolish to think that their brains had in any pertinent way been modified by the training.

Despite these difficulties, the area has continued to attract a considerable amount of attention. Work that, on the basis of various questionnaires, links hemisphericity and creativity has continued to appear (Black, 1984; Gorovitz, 1982; Okabayashi & Torrance, 1984; Raina & Vats, 1983; Torrance & Frasier, 1983; Torrance & Horng, 1980). Kane (1984), in reviewing the potential for enhancement activities, discussed the impressive range of "input, organization, output, communication, auditory-visual-motor processing, thinking, affect, laterality, right and left space, reading, maths, and content areas" (p. 527).

Not only reports of studies, but various books have promoted the idea that enhancing the contribution of the right hemisphere and its associated cognitive

style can lead to positive gains in imagination and creativity. Wuzdener's (1983) Right Brain Experience: An Intimate Program to Free the Powers of Your Imagination and Downey's (1984) Right Brain--Write On: Overcoming Writer's Block--Achieving Your Creative Potential are typical examples. Ehrenwald (1984) presented a series of case studies of genius that show how the relative contributions of both hemispheres, but especially the right, can generate the spark of genius. His pantheon included Beethoven, Nietzche, Leonardo, Freud, Jung, Mozart, Einstein, Picasso, Kafka, and Eileen Garrett. Cortes and Montezuma are also opposed as the contrast of two hemisphere styles.

Moore (1984) integrated such ideas into a more complex theory of personality and, incidentally, appended a list of 131 attributes for the left hemisphere and 128 for the right.

Corballis and Beale were probably correct in explaining the appeal of these ideas in terms of contemporary social and political folklore. There is a sense in which both contemporary concerns and the modern expression of long-standing cultural themes are encapsulated in the opposition of two poles: from good and evil, to masculine and feminine, to political left and right. The current scientific interest in neuroscience has simply become an arena for the expression of these general human concerns. That the legitimacy of science could be borrowed to enhance the prestige of the conception is simply an added bonus.

It may be that there is some connection between the activities of the right hemisphere and creativity. It cannot, however, be said that this connection has been demonstrated scientifically. It is more likely that there is a real relationship between the overt performance measures of hemisphericity and creativity as studied in this work. This relationship may exist quite independently of any actual reference to the hemispheres of the brain. Whether the relationship is significant or useful in a psychological sense has yet to be clearly established.

Hemisphericity and Learning Potential

Can whatever links there are between hemisphericity and human attainment be exploited through education and training?

Once again, a great deal has been written but not much clear evidence has been gathered to answer the question of whether there are any significant educational gains to be made. Much of the work discusses exploiting right-hemisphere potential, either as a laudable goal or as an attainable proposition, without examining its conceptual validity. Very few studies present firm evidence of the benefits expected or assumed. This makes a scientific evaluation particularly difficult.

The focus of attention has been either on the development of neglected right-hemisphere abilities--neglected because of the dominant left-hemisphere character of the Western educational system--or on the equal development of the hemispheres, with compensatory training for the right hemisphere. It is predicted that such training will expand human potential, enrich human lives, and speed cultural development. Price (1978) provided a typical example of the methods suggested: the use of musical backgrounds to verbal presentations, with the music occasionally becoming dominant over the spoken words; the use of guessing games; prohibition of the word no (because "the right hemisphere

has no equivalent of 'no'"). Other scholars have proposed the use of particular texts for developing the right hemisphere (e.g., Shuman, 1978, recommended Shakespeare's Hamlet; and see Rotalo, 1982). Recent papers on the application to education include the work of Bame and Gatewood (1983), Brooks (1980), Dunn et al. (1982), Elliott (1980), Hatcher (1983), Herrmann (1981), Sinatra (1983), Staley (1980), Torrance (1981), and Youngblood (1983).

Beaumont (1983a) reviewed the concept of hemisphericity with respect to education (many further references can be found in his article) and concluded that while different cognitive styles may well be of relevance to education, there is no reason to think that this should be based on a strictly neuropsychological interpretation of hemisphericity. There was also no substantial evidence that hemisphericity--again, as a neuropsychological or neuroanatomical entity--is trainable. There is no doubt that cognitive systems may well be modified through experience, which may include specific pedagogical intervention, but there is little evidence that neurological systems can be modified in any significant way by such interventions.

Other writers have been equally critical of the application of hemisphericity to education, among them Corballis (1980), Hardyck and Haapanen (1979), and Sandoval and Haapanen (1981). These last writers concluded that there is "no scientific basis" to any proposal to selectively educate the left or right sides of the brain. Even McCallum and Glynn (1979), while advocating specific procedures for the acquisition of left- and right-hemisphere skills, were clearly critical of the experimental bases on which such ideas are founded.

Despite these cautions, reports continue to appear. Some have simply been reviews of the impact or potential impact of hemisphericity in education. Airhart (1984) examined the implementation of the concepts in nursing education, while Ogorek (1982) examined curricula more generally. Several reviews have made specific proposals about ways of facilitating "holistic education" (Lockavitch, 1982; Sonnier, 1982; Webb, 1983). Some papers have been more specialized, such as Fertziger's (1983) contribution: "a holistic death education format proposed based on the synthesis of 2 oppositional styles."

Other workers have continued to explore the relationships between questionnaires and other measures in the areas of high ability (Code, 1983; Shannon & Rice, 1982), math (Grow & Johnson, 1983), classroom behavior (Stellern, Marlow, & Cossairt, 1984), and general learning styles (Way, 1982).

However, there have been certain instances of performance gains in association with hemisphericity. Zenhausern and Nickel (1979) showed that the ability to learn a finger maze was linked to individual differences in hemisphericity, right-dominant individuals being superior.

Markman (1983) taught subjects a cognitive strategy that was either congruent or incongruent with their general cognitive styles. The task was recall of word pairs. A significant interaction of cognitive style, strategy employed, and pretraining versus posttraining test was found, indicating that a match between cognitive style and strategy adopted produced enhanced learning.

However, in a rather similar study, Leps (1980) had found that matching instructional strategy to the degree of appositionality had no effect on success with a tape-slide presentation that could either be nonlinear and multiimagery

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in style or else linear, sequential, and visual. Matching style and format of presentation did not in this case lead to better learning.

Creative writing performance was studied by Reedy (1981) using a survey form to measure hemispheric dominance. No correlation was found between lateral brain dominance and lateral brain performance (as inferred from the writing produced), although the educational program introduced did have the planned effects.

These partially positive results must be set against some negative findings. Technical drawing was assessed after training periods in techniques of imagery designed to utilize only right-hemisphere functions (Fancher, 1982). The training had no effect, and there were no differences attributable to hemisphere styles. Brog (1985) looked at the relationship between hemisphericity (the Learning Style Questionnaire, not the same as YSLT), locus of control, and grade point average. There was a significant relationship (of limited practical significance) only between grade point average and locus of control, although there were differences in hemisphericity between grades. Within grades, hemisphericity did not relate to grade point average.

These studies have, at least, the merit of recognizing the importance of a scientific approach to the role of hemisphericity in training. By contrast, some training methods have gone well beyond any contact with the scientific literature, well into the realm of neuromythology and neurophrenology.

Although the training of individuals with learning disabilities has been otherwise excluded from this review, it is interesting to note that certain remedial methods in that field have claimed links with lateral cerebral development. Yellin (1983), for instance, discussed the application of a variety of techniques, including biofeedback, yoga, and the Lozanov method (suggestopedia: a "stress-freed method" using suggestion and music to accelerate the learning of, initially, languages and now used more widely). The Lozanov method combines music, drama, physical exercises, and mental relaxation techniques as prelearning preapration. It is proposed that this preparation frees the mind for the expression of the abilities of both the hemispheres. Specific learning gains on standardized tests have been reported.

Neurolinguistic programing is a technique that sounds as though it might be closely derived from models of cerebral cognitive processes (Dilts, Grinder, Bandler, Bandler, & DeLozier, 1980). This is, however, not the case. The technique is, in fact, based on an analysis of effective styles in a form of psychotherapy derived from the approach of Erikson (Haley, 1967). Particularly effective and charismatic therapists were studied, and their success attributed to the rapport they were able to build with their patients. Their success was apparently achieved by matching their communications to the expectations of the clients. However, the technique seems to extend beyond the cognitive domain, because it encompasses rhythms of the body and of speech and the perceptual analysis of sensory information. The idea is that the therapist, by observing signs in the client's face, body, voice, speech, and breathing, should be able to tell whether auditory, visual, or kinesthetic memory data are being accessed. There seems to have been no scientific test of whether this skill can actually be achieved.

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Learners can establish and make use of their dominant sensory mode--visual, auditory, or kinesthetic. This technique is linked with other humanistic techniques such as suggestopedia, the Alexander technique (to achieve poised movement and posture), and yoga. Together, these methods are proposed to "tap the mental powers of learners and engage the right brain hemisphere in the learning process" (promotional material of the Society for Effective Affective Learning). Some of the applications are to strictly cognitive areas, particularly to language teaching, but the methods also are directed to personal development. Limitations, it is claimed, will be transformed into possibilities; problems into creative opportunities (U.K. Training Centre broadsheet). Neurolinguistic programing can even be employed to enhance the intimacy of male-female relationships, it is claimed.

Similar claims are made by the organization Inner Track Learning. Its methods also draw on suggestopedia and neurolinguistic programing, together with yoga. Inner Track Learning suggests that

> Recent research has shown that most people use only a very small part of their full brain potential. Some psychologists put it as low as 1%. The key to unlocking these reserve powers lies in the activation of the right hemisphere of the brain. This is the seat of the subconscious, of memory, intuition, imagination and creativity. It is this part of the brain which is able to grasp concepts "holistically" and which provides inspiration, affective involvement and motivation to study. (promotional material)

The benefits claimed are better memory, a more harmonious mind, creative and effective thinking and writing, and the ability to pass exams and to learn more rapidly.

A similar approach is advertised by Futurehealth Inc. (see Psychology Today, March 1985, e.g.), whose Advanced Subliminal Technology, based on the work of Budzynski, offers "four ways to reprogram your best future." The particular feature of this method is the presentation of subliminal prompts and suggestions (positive to the left hemisphere; negative to the right) through stereo headphones. This concept is not far removed from the (equally unfounded) idea that material can be learned if played to the student while asleep.

None of these claims can be substantiated by reference to rigorous investigations. It is clear from this review that there is no evidence to support either the neuropsychological models employed or the gains in learning expected. Even with respect to the purely affective aspects of these therapies, there is no supportive evidence from studies of neuropsychological lateralization (Heilman & Satz, 1983). It appears that the implication of the right hemisphere, or of bilateral hemispheric integration, is simply a reflection of the current prestige of the neurosciences. These constructs are easy to include in a bundle of other loosely related conceptual frameworks, and can subsequently be used to bolster the legitimacy of a number of pragmatically derived techniques of unestablished practical value.

Conclusion

This section opened with four questions that can not be answered. First, rather little has actually been directly demonstrated about lateralization of learning processes in the brain. Research has clarified quite a lot about language, visuospatial skills, perception, and identification and matching, but relatively little is known about the neurobiology of human learning. From the scientific evidence there is no reason to think that, in general terms, learning is the exclusive property of one or the other cerebral hemisphere. There is evidence to suggest, however, that certain aspects of memory processes for verbal and visuospatial material are lateralized and associated with the left and right temporal lobes of the brain.

Beyond these limited findings, it is clear that many areas of the brain contribute to learning. Outside the peculiar arrangements of the psychology laboratory, it is a mistake to think of the two hemispheres as independent entities. Although each hemisphere may have its preferred specializations, in normal performance the two act as an integrated and cooperating system of components. The hemispheres interact, exchange information, and support mutual processes. Although the split-brain research and the experimental neuropsychological studies that spring from it have revealed much about the brain, an undesirable result has been the overemphasis on the importance of relative lateral specialization and the dichotomy of function between the hemispheres.

The second question was whether there are general characteristics of human performance that can be related to brain organization. Laying handedness aside, this is probably the most contentious of the questions. If strict scientific criteria are adopted, the conclusion must be that no such characteristics have yet been demonstrated. This is not to say that the idea of such general characteristics must entirely be abandoned (although perhaps the term hemisphericity should be abandoned as unhelpful and misleading). It may well yet prove possible to demonstrate and measure such general characteristics, but claims that hemisphericity exists and can be measured go beyond the scientific evidence now available.

Whether the phenomena measured by instruments assessing hemisphericity or lateral cognitive style are actually related to learning or learning potential is an independent question. Although it must be said that on strict methodological grounds, the evidence is a little thin, there is evidence of a correlation between, for example, the YSLT and questionnaires of creativity. There is also some evidence, although it is not unanimous, that the phenomenon may be relevant to performance in learning situations. Given that these various measures share a great deal of their content with the form of the outcome assessment, it would be surprising if some relationship were not found.

It would also be surprising if hemisphericity were not trainable. There is undoubtedly scope for the teaching of specific techniques that will result in improvement on measures of creativity or expressive writing, and that will reduce anxiety and boost confidence so that academic performance improves. There is no need to refer to neuropsychological concepts to predict that presenting material in a variety of formats, and encouraging the use of varied approaches to problem solving, will result in higher attainment. This is all that is actually observed in studies of educational performance and lateral brain function.

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However, it is a mistake to accept that such effects as may be observed are attributable to lateralization of the brain, to the involvement of right-brain potential, or to the harmonious development of the two hemispheres. There is simply no evidence to support such an idea. There is nothing radical about this conclusion; it has been reached repeatedly by the more sober members of the psychological community (see, e.g., Kinsbourne, 1982). It has, however, been ignored by many who have sought to apply neuropsychological work to education. Neuropsychological lateralization has been unreasonably exploited by the more extreme therapies. There is no scientific basis for their claims with respect to either the processes they invoke or the benefits they achieve.

6. CONCLUSION AND RECOMMENDATIONS

The evidence for both inter- and intrahemispheric specialization of function in the human brain is now very strong indeed. This evidence comes both from patients who have suffered localized brain damage and from normal individuals in whom lateralized cognitive processing can be studied by relatively simple noninvasive techniques.

In brain-damaged persons, distinct patterns of impaired and preserved cognitive performance are seen consequent upon the locus of injury. These differences are particularly striking as a consequence of the side of the injury (left or right hemisphere), but the varied response to damage to different loci within a hemisphere should not be minimized. Nor should it be forgotten that some functions (such as the ability to recognize objects or faces or to remember episodes from the past) are only grossly compromised in cases of bilateral damage.

In general, the evidence from pathology for differential hemispheric specialization for language and visuospatial skills is consistent with that obtained from normal subjects with fully intact brains. In broad outline, there is considerable scientific agreement about the basic facts of complementary cerebral specialization and differential localization of function within the human brain. It is also not in dispute that there is a sense in which the brain nonetheless functions as a unified whole. Most real-life tasks draw on a complex of skills. Even if the separate components of these skills have different anatomical substrates, it must nonetheless be the case that the underlying brain mechanisms must cooperate in an integrated fashion to produce the relevant behavior.

With respect to individual differences in cognitive capacity and skilled performance, it is an article of faith that this variability rests on differences in the efficacy of underlying brain mechanisms. But, except in cases of demonstrable brain pathology, the neurosciences are not yet in a position to specify the anatomic correlates of differences in ability for higher mental functions. When there is a higher probability of atypical brain organization in one group (left-handers, e.g.), it is as yet unclear whether the unusual pattern of hemispheric specialization correlates with any aspect of greater or lesser cognitive ability.

With respect to the more general notion of hemisphericity, there are few (if any) reliable scientific generalizations to be currently drawn from categorizing people along some kind of hemisphericity dimension. Future research

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may validate a hemisphericity index as a reliable and practically pertinent measure of individual differences in higher mental functioning. But there is little evidence now to support adoption of such measures when assessing variation in human ability.

Nonetheless, an already substantial literature on hemisphericity in educational practice and in the selection and training of personnel continues to grow at an alarming rate. We can only recommend what so far seems to have been little considered: namely, that all the purported benefits of selecting and training people in accordance with the principles of hemisphericity should be rigorously assessed in well-validated experimental designs that have proved their value in medical and industrial research.

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