

Hemisphere Differences in the Acquisition and Use of Descriptive Systems

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Differences in neuroanatomical organization of the cerebral hemispheres may account for two fundamental distinctions in processing: the right hemisphere has a greater ability to perform intermodal integration and to process novel stimuli; the left hemisphere is more capable of unimodal and motor processing as well as the storage of compact codes. In the process of acquisition of a new descriptive system, the right hemisphere plays a critical role in initial stages of acquisition, whereas the left hemisphere is superior at utilizing well-routinized codes. This leads to a right-to-left shift of hemisphere superiority as a function of increased competence with respect to a particular type of processing. This process is discussed in reference to various descriptive systems which are operative in normal cognition.

Differential neuroanatomical characteristics of the two hemispheres may lead to a wide range of specific consequences for cognition. For this reason, various views of the nature of hemispherical asymmetry need not be seen as mutually exclusive, but rather as examples of the entire set of consequences which stem from fundamental biological differences in hemispherical organization and function. "Linguistic-nonlinguistic," "sequential-simultaneous," and "analytic-gestalt" dichotomies have been commonly used to express these distinctions. We suggest an al-

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ternative dichotomy which appears to follow naturally from basic neuroanatomical differences, and has the capacity to account for a large body of experimental data. This distinction invokes the concept of task novelty with respect to the representational codes preexisting in a given subject's cognitive repertoire. In this review we will first consider relevant neuroanatomical evidence and then discuss the possible cognitive consequences of this evidence.

NEUROANATOMICAL SUBSTRATES: IMPLICATIONS FOR INFORMATIONAL COMPLEXITY AND MODALITY SPECIFICITY

Early reports (Kakeshita, 1925; Von Economo & Horn, 1930; Pfeiffer, 1936) indicated that the surface of the left temporal planum is larger than the surface of the right temporal planum. According to later estimates, the left planum is on the average one-third longer than the right planum (Geschwind & Levitsky, 1968). Moreover, Wada, Clarke, and Hamm (1975), and Witelson and Pallie (1973), have shown that a considerably larger left temporal planum is found not only in adults but in infants as well. Further investigation of the anatomy of the temporal planum has indicated that the posterior portion of the superior temporal gyrus (which is coincident with Brodmann's Area 22, a secondary division of auditory cortex) is the most markedly asymmetrical, with the left being some seven times larger than the right (Galaburda, LeMay, Kemper, & Geschwind, 1978). LeMay and Culebras (1972) reported a greater left-hemispherical representation of the parietal operculum (the inferior portion of the postcentral gyrus), which is known to control kinesthetic afferentation of the articulatory apparatus. Galaburda (1980) found a similar (pro-left-hemispherical) discrepancy for the pars opercularis of the inferior frontal gyrus. According to Polyakov (1966) this area together with the inferior portion of the precentral gyrus in the left hemisphere, constitutes Broca's area. Cytoarchitectonically, this area appears to be similar to the premotor area or Brodmann's Area 6 (Polyakov, 1966). It thus appears that the three cortical areas most intimately involved in processing of the linguistic signal (secondary auditory, oral-kinesthetic, and oral-kinetic) have greater representation in the left hemisphere.

Cortical asymmetries have been demonstrated outside the fundamental "speech zones" which make any attempt to account for hemispherical differences solely according to a linguistic-nonlinguistic dichotomy unreasonable. Galaburda et al. (1978) found that in right-handed subjects the left occipital lobe appears to be consistently wider than the right. In left-handers, this asymmetry is less pronounced and instances of a relatively wider right occipital area are more frequent (LeMay, 1976). Earlier studies by Cunningham (1892) and Connolly (1950) suggested that the postcentral gyrus is wider in the left hemisphere, and a similar finding was reported for the superior parietal area (Gurevitch & Knachaturian,

1960), which is known to be the secondary area of the somatosensory analyzer (Polyakov, 1966).

Thus, neuroanatomical measures suggest that hemispherical asymmetry in posterior cortex is not modality specific as has been previously implied (auditory versus visual), but rather is such that distinct modality-specific representations are more prominent in the left hemisphere, and this is true for all three main sensory modalities. The same body of findings suggests that the cortical areas of intermodal associative zones must be larger in the right hemisphere. This deduction is a consequence of the failure, so far, to demonstrate any conclusive interhemispherical differences regarding the overall area of posterior cortex (Von Bonin, 1962).

The neuroanatomy of anterior cortex reveals a somewhat similar picture. Galaburda et al. (1978) reported that the right frontal lobe is consistently wider than the left in right handers. Although no distinction was made in their discussion between motor/premotor and associative prefrontal areas, further differentiation is made possible by other data. LeMay (1976) reported a greater extension of the right compared to the left frontal pole. Wada et al. (1975) found that the combined area of pars opercularis and the posterior part of pars triangularis of the inferior frontal gyrus is greater in the right hemisphere in both adults and infants. Together with the findings of Galaburda (1980) regarding the greater area of pars opercularis alone in the left hemisphere, it allows the conclusion that there is a larger right hemispherical representation of pars triangularis, which is the portion of the frontal lobe extending anterior to the classical Broca's Area, and is a part of associative prefrontal cortex by cytoarchitectonic measures (Polyakov, 1966). It thus appears that the left hemisphere is characterized by greater area for the premotor zone in its inferior extension and the right hemisphere by a greater representation of associative prefrontal areas. These conclusions are tentative given the reservations of Wada et al. (1975) with respect to the imprecision of areal measurements in what they term the "frontal operculum."

The CT studies reported by LeMay (1976, p. 363), commonly show "the left occipital pole longer and often extending across the midline toward the right and a wider right hemisphere in its central and frontal portions and frequent forward protrusion of the right frontal pole. This is found also in newborns." LeMay further points out that the anatomical findings are in agreement with studies of impressions on the vaults (petalia) resulting from local protuberances of the brain. The pattern most frequently found is left occipital petalia associated with right prefrontal and right temporoparietal petalia (Hadžiselimović & Cus, 1966; Hadžiselimović & Ruždić, 1966). When right occipital petalia were observed, left frontal and left temporoparietal petalia were present. Measures of ventricular size (McRae, Branch, & Milner, 1968) and arteriographic studies (Hochberg & LeMay, 1975; LeMay & Culebras, 1972)

are generally consistent with the discussed findings regarding cortical surfaces.

It thus appears that the areas of sensory and motor-specific representations are greater in the left hemisphere, while the right hemisphere is characterized by greater areas of associative cortex (temporoparietal and prefrontal). The latter two areas are implicated in the most complex levels of processing and decision-making (Luria, 1966; Pribram, 1973) and are heavily interconnected forming one functional system (Graybiel, 1974).

In her review, LeMay (1976) concluded that in man a larger volume of the left compared to the right lateral ventricle is usually found, and a heavier right compared to left hemisphere. These two findings led Whitaker and Ojemann (1977) to suggest that there is more tissue in the right hemisphere. If this is true, then the recent study by Gur, Packer, Hungerbuhler, Reivich, Obrist, Amarnek, and Sackeim (1980) may provide clarification of this asymmetry. Gur et al. demonstrated that the grey-to-white ratio is higher in the left than in the right hemisphere. If considered in light of LeMay's study, the findings of Gur et al. may be seen as the reflection of relatively more white matter (long myelinated fibers) rather than relatively less grey matter (neuronal mass and short nonmyelinated fibers) in the right hemisphere.

Inspection of the results of Gur et al. (1980) reveals that in each hemisphere motor areas and areas of unimodal sensory representations appear to show greater grey-to-white ratios than do, respectively, prefrontal and posterior associative zones. Interhemispherical comparison of these associative areas reveals, however, that while grey-to-white ratio is higher in the left hemisphere for prefrontal, it is higher in the right hemisphere for posterior areas.

These conclusions are interesting in several respects. Intrahemispherical comparisons suggest an inverse relationship between the presumed complexity of information processing controlled by a given area and the grey-to-white ratio that characterizes this area. This is at least an indication that the grey-to-white ratio cannot be used as a direct index of the functional capacity of a network, and that the "connectivity" of an area with other structures may well be as important a determinant of this capacity as is the amount of neuronal mass. By the same token, this finding supports the proposition of Gur et al. that grey-to-white ratio can be used as a marker of the prevailing organizational feature of a structure in reference to intra- as opposed to interregional integration.

Interhemispherical comparisons of prefrontal and posterior associative cortex may reflect their differential patterns of organization as seen in both cytoarchitectonic (Von Economo, 1929) and functional (Luria, 1966) descriptions: prefrontal regions influence the entire cortical surface via major fasciculi (increasing the proportion of myelinated fibers), while

posterior associative regions provide for integration within a more limited cortical domain (increasing the proportion of nonmyelinated fibers). If this is so, then both prefrontal and posterior associative cortices have their prevailing organizational characteristics more pronounced in the right hemisphere.

It appears that there is relatively greater emphasis on interregional integration inherent in the neuronal organization of the right hemisphere, and on intraregional integration in the left hemisphere.

A composite picture of hemispherical asymmetries emerges with two basic features: (1) areas of sensory and motor representations are greater in the left hemisphere, while the right hemisphere is characterized by greater areas of associative cortex; and (2) the left hemisphere displays a predominantly intraregional pattern of connectivity while the right hemisphere displays a predominantly interregional pattern of connections.

Notwithstanding the caveats of making functional inferences on the basis of structural characteristics, the review of the differential neuroanatomy of the two hemispheres makes two hypothetical cognitive consequences plausible:

1. The right hemisphere has a greater neuronal capacity to deal with informational complexity.

2. The right hemisphere has a greater ability to process many modes of representation within a single cognitive task, while the left hemisphere is superior in tasks which require fixation upon a single mode of representation or execution.

One source of indirect support for the viewpoint that the right hemisphere has an increased capacity for dealing with complexity can be found in data concerned with the differential ability of each of the two hemispheres to perform the functions of both.

It was suggested that after severe infantile damage to the left hemisphere, language can develop in the right hemisphere (Milner, 1974, Rasmussen & Milner, 1977). Right-hemisphere damage, on the other hand, would produce a severe impairment of nonverbal skills. According to Milner (1974) the left hemisphere will not be able to "take over." The unequal ability of each hemisphere to take over functions of the other was also pointed out by Kohn and Dennis (1974). This is consistent with Lenneberg's (1967) observations of early brain plasticity in language acquisition, and Smith's (1976) observations of some language recovery after left hemispherectomy in adults.

The suggestion that the right hemisphere is relatively better able to subserve the functions of both hemispheres would be further strengthened by findings of higher full-scale IQ in left (relative to right)-hemispherectomized patients. Smith (1976) found that while the full-scale I.Q. is lowered in both groups, it is consistently higher in left- than in right-hemispherectomized patients. Kohn and Dennis (1974), in a small sample

of early hemidecorticates, found no statistically reliable differences between the IQ's of the two groups, yet the trend was clearly such that full-scale IQ is higher in left than in right hemidecorticates.

Behavioral observations tend also to indicate that the two hemispheres differ in their ability to deal with one as opposed to many modes of representation.

Chapanis (1977) found that on tasks involving cross-modal integration the patients with right-hemisphere lesions performed significantly worse than patients with left-hemisphere lesions. This effect was found for all sensory modality combinations. Semmes (1968) found a similar discrepancy between unimodal and intermodal representations in the two hemispheres. Butters, Barton, and Brody (1970) reported, to the contrary, that lesions of the left parietal areas affect cross-modal integration more severely than do lesions of the right parietal areas.

Conversely, unimodal processes were demonstrated to be associated with a left-hemispherical advantage. Lower right-ear threshold for auditory stimulation, (Turkewitz, Birch, Moreau, Levi, & Cornwell, 1966a; Hammer & Turkewitz, 1974), greater reliability of response to tactile stimulation on the right side of the body (Siqueland, 1964; Turkewitz, Gordon, & Birch, 1965; Hammer & Turkewitz, 1974) have been demonstrated in infants. Wickelgren (1967) reported greater tendency to attend to visual stimuli presented to the right visual field.

Alternative explanations of these phenomena in terms of asymmetric head position (Turkewitz, 1977b) or asymmetric muscle tone due to posture (Turkewitz, Moreau, Davis, & Birch, 1969) are difficult to support in light of demonstrations that these psychophysical asymmetries persist after postural asymmetries have been eliminated (Turkewitz, Moreau, & Birch, 1966b; Turkewitz, et al., 1969; Hammer & Turkewitz, 1974). It was concluded that in spite of contributing factors unrelated to hemispherical asymmetries, there is enough evidence to suggest initial left-hemispherical superiority in responsiveness to simple, unimodal stimuli (Turkewitz, 1977a).

Similar observations have been made in adults. In a vigilance task, left hemispherical superiority was found for visual signal detection (Dimond & Beaumont, 1974). In the motor system, Semmes (1968) reported a more discrete left hemisphere representation of both contra- and ipsilateral hands.

Comparable data can be found in the body of electrophysiological literature. Wada (1977) has reported that infants demonstrate a greater occipitotemporal coherency of evoked potentials in the right hemisphere for flashes and in the left hemisphere for clicks. Analysis of individual power spectra of the evoked potentials indicates, however, that responses to clicks or flashes are greater respectively in temporal and occipital

areas of the left than of the right hemisphere. It is clear that if response power is summed over areas within each hemisphere, the superiority of the left hemisphere would be still more apparent for both types of stimuli.

On the other hand, indices and tasks on which the right hemisphere out-performs the left hemisphere are unrelated to any single modality and reflect composite involvement of the whole hemisphere. Alpha rhythm develops earlier and is better expressed in the right hemisphere than in the left (Giannitrapani, 1967; Schenkenberg, Dustman, & Beck, 1971). The right hemisphere shows developmentally earlier signs of sensitivity to photic driving (Crowell, Jones, Kapunia, & Nakagawa, 1973) earlier development of main gyri (Chi, Dooling, & Gilles, 1977), and a greater blood volume (Carmon, Harishanu, Lowinger, & Lavy, 1972). These findings make the hypothesis of the left-to-right maturational gradient proposed by Corballis and Morgan (1978) less than entirely convincing.

It can be predicted that following initially limited unilateral stimulation the hemisphere with greater interregional connectivity will excite larger areas ipsilaterally and will subsequently influence broader areas of homologous cortex via the corpus callosum and commissures. This pattern would obtain both in the cases of initially ipsilateral and contralateral stimulation due to callosal and commissural transfer. These considerations lead to the conclusion that the right hemisphere is better able to activate the entire cortex than is the left. This process may be comparable to what Heilman and Van Den Abell (1979, 1980) have termed a right hemispherical dominance for cortical activation.

Heilman and Van Den Abell generated this hypothesis on the basis of studies which measured parietal EEG desynchronization following lateralized visual stimuli (1980); and reductions of reaction time to centrally located stimuli as a function of lateralized "warning" stimuli (1979). Close inspection of the results of these studies indicates that least EEG desynchronization was recorded from the left parietal area following left sided warning stimuli, with the other three hemifield/recording-site combinations showing greater and roughly equivalent amounts of desynchronization. Similarly, at a 1-sec foreperiod the greatest reaction time reduction was found for the left-hemifield-warning/right-hand-response condition, with the other three hemifield-hand combinations showing smaller and roughly equivalent reductions. It appears that a more complete interpretation of these findings may be offered by considering the properties of both hemispheres *en ensemble*. In both cases, the effect seems to be a function of the interaction between the hemispherical role in "global arousal" versus local "input" processing or "output" execution. It can be suggested that the findings of Heilman and Van Den Abell (1979, 1980) reflect the combined effect of complementary hem-

ispherical characteristics; greater interregional connectivity in the right hemisphere, and an advantage in the processing of simple, unimodal stimuli and execution of discrete motor acts in the left hemisphere.

HEMISPHERAL ROLES IN THE DEVELOPMENT OF COGNITIVE STRATEGIES

Differences in neuroanatomical organization between the hemispheres and some of the functional implications of these differences have been considered. We shall now discuss the relevance of these asymmetries to the differential roles of the hemispheres during the acquisition and use of cognitive strategies.

It was proposed earlier that a multiplicity of codes or descriptive systems are operative in normal cognition (Posner, 1972, 1978; Goldberg, Vaughan, & Gerstman, 1978). A descriptive system implies any set of discrete units of encoding or rules of transformation which can be successfully applied to the processing of a certain class of stimuli. It is implied that descriptive systems constitute superstructures imposed on elementary "feature detection" mechanisms (Hubel, 1963; Mountcastle, 1957; Maturana, Lettvin, McCulloch, & Pitts, 1960). To use a computer analogy, descriptive systems are related to feature detectors in the way that a compiler is related to machine language.

There may be several types of descriptive systems with respect to individual-culture interaction. Natural language constitutes a representational system with the strongest invariance across the members of a given linguistic domain, but even within that domain, certain specialized classes exist which are not shared by all language users (e.g., scientific terminology and conceptual systems.) The concepts embraced by these specialized classes can be communicated by those items of the lexicon shared by all language users, but this process would take "detour routes." Thus multiplicity of descriptive systems exists already within the immediate domain of natural language.

Descriptive systems which are outside the domain of natural language but explicitly exist in culture (such as formal mathematical languages, musical notation, and the process of games communicated via special notation) constitute an alternative type. Each of these descriptive systems is utilized by only a small subset of all language users (mathematicians, musicians, chess players) and the concepts described are not necessarily well definable through the system of natural language. These two types of descriptive systems are similar in the sense that they are culture dependent and are acquired via communication, therefore with great dependence on natural language.

A third type of descriptive system consists of those which develop in an individual during acquisition of new tasks (or the processing of previously unknown classes of stimuli) in an idiosyncratic way rather than

via internalization of a code preexisting in culture. This process involves assembly of a new code rather than learning it in the rote sense. The degree of involvement of natural language in this process is less obvious.

We propose that both the concept of a multiplicity of descriptive systems and the fact that any cognitive process may be conceptualized as belonging to one of two large classes, those which draw on preexisting codes and those which do not, have direct relevance to the aforementioned basic interhemispherical distinctions.

Consider the performance of two individuals on the same cognitive task. Imagine that one ("professional") has a task-relevant descriptive system at his disposal, and that the other ("novice") does not. The "professional" will be equipped with the means to break the problem down into its components, each of which will already be of a somewhat generalized nature. Informational considerations assure us that the availability of a relevant representational system reduces the complexity of any task which has a fixed practical outcome. This implies that a relatively less complex processor in a quantitative informational sense may be sufficient for cognitive processing which is judged to be relatively more elaborate on a cultural basis. In the context of a similar discussion, Whitaker and Ojemann wondered whether "the dominance for language is another case of 'less is more'" (1977, p. 460).

An additional feature which distinguishes the two types of processing (one which is based on a fixed code, and the other which is not) is the necessity to use either one or many modes of representation in the context of a single cognitive task. In cases where no descriptive system is immediately available, solution of a task may require a descent to the level of unsystematic application of various encoding strategies. Elements of various cognitive strategies which prove to be effective for the new task are subsequently re-stored in a compact fashion—leading to the formation of a new descriptive system. This process of combining elemental features will be best performed by that system which has the most equal access to the heterogeneous classes of feature detectors and the greatest combinatorial capacity.

Reliance upon a routinized descriptive system, on the other hand, imposes specific demands on memory. In order to be successfully applied once it is formed, a descriptive system must be easily accessed for retrieval; this implies compact storage. Semmes (1968) has proposed that in the left hemisphere cognitively similar units are represented compactly, in contrast to their intermixed representation in the right hemisphere. As far as sensory projections are concerned, this distinction has been discussed with respect to neuroanatomical differences and hemispherical performances on uni- versus multimodal tasks. It is possible that these hemispherical differences extend to the storage of sets of cognitive elements which may be defined other than on the basis of their sensory

modalities. It may alternatively be suggested that once formed, a cognitively specialized code translates multimodal inputs into a single modality (Conrad, 1973; Posner, 1972). In either case, the left hemisphere is organized in a way which will provide easier access to a compact cognitive set. Beaumont (1974) has compared the cerebral organization of a right-hander to a collection of compartmentalized libraries and that of a left-hander to a large eclectic library. This analogy may be extended to include a comparison of the hemispheres in a right-hander: the left hemisphere being a collection of compartmentalized libraries and the right hemisphere being an eclectic master library. A novice reader with no particular reference in mind will be better off in a single master library; once he has established relevant sets of references, he would be better off filing them in compact groupings for further needs.

Some experimental evidence exists in support of this hypothesis of hemispherical differences. Rauch (1977) studied problem-solving strategies in left and right anterior temporal lobectomized patients. It was found that patients with an intact left temporal lobe returned more extensively to previously accumulated hypotheses than the right temporal lobe intact group. In contrast, the latter group more frequently resorted to initial task orientation without utilizing previously formed hypotheses. This difference was diminished under a memory-assisting condition, i.e., when previously generated correct hypotheses were kept in view of the subject. The right temporal lobe intact group tended to shift away both from positively reinforced and negatively reinforced hypotheses, which resulted in more frequent changes of strategy. The left temporal lobe intact group, conversely, tended to stay with the hypotheses whether they had been positively or negatively reinforced. It thus appears that the left hemisphere has a greater facility for the utilization of previously learned information, while the right hemisphere tends to approach every task as a novel experience, as though previous learning was irrelevant. Similar findings were reported by Drewe (1974) for the Wisconsin Card Sorting Test in patients with frontal lesions: right-sided lesions were more frequently associated with perseveratory errors, while left sided lesions led to more nonperseveratory errors.

Bevilacqua, Capitani, Luzzati, and Spinnler (1979) tested recognition memory for tachistoscopically presented "scrawls" at various delays (0–60 sec). No delay-recognition interaction was found for right-hemispherical presentations but left-hemispherical presentations were better recognized than right-hemispherical at a 15-sec delay, with subsequent decrement in the quality of recognition which was directly related to the length of delay. These findings may indicate the involvement of the left hemisphere in the early stages of storage of patterns of distinct features, with subsequent effects of interference. If this explanation is valid, then it appears that the left hemisphere utilizes the selective storage of features

relevant to an on-line task while right hemisphere performance is no dependent on such stroage.

Relevance of hemispherical asymmetries to memory has been suggested by a variety of authors (White, 1969; Seamon, 1974; Davis & Wada 1977; Hardyck, Tzeng, & Wang, 1978). Peculiarities of the left hemisphere's neuronal organization compared to those of the right can probably account for the former's greater ability to retrieve previously accumulated information. It can be argued that this principle can be applied not only to fixed referential sets, (as was proposed by Hardyck et al. 1978) so that a left-hemispherical superiority will be expected for processes requiring direct matching, but also to the cognitive sets best described as descriptive systems which are capable of handling open classes of specific stimuli. In this respect, Davis and Wada's (1977) comment on the results of Molfese, Freeman, and Palermo (1975) is of particular interest. The differential hemispherical evoked potential responses to speech stimuli (the left hemisphere produces larger response) and mechanical and piano cord stimuli (the right hemisphere produces larger response) begin to appear at the mean age of 6 months. By then, argues Davis and Wada, a baby is clearly used to speech sounds but hardly mechanical noise or musical chords.

It was proposed by Goldberg et al. (1978) that without divesting the left hemisphere of what has traditionally been presumed its dominant function (linguistic encoding), a broader class of functions should be associated with this hemisphere, namely, any processing which utilizes a well-routinized descriptive system.

We further propose that it is the right hemisphere which is crucial for situations in which no task-relevant descriptive system is immediately available in the subject's cognitive repertoire. By definition, such situations are associated with task novelty, and can be of at least two types:

(1) Orientation in a novel task, when no descriptive system is immediately apparent, but the task is ultimately recognized as relevant to an existing one. The hypothesis predicts that the right hemisphere is essential for the initial orientation, and that the left hemisphere is superior in the utilization of an existing descriptive system once it is identified.

(2) Orientation in a novel task to which none of the available descriptive systems can be successfully applied. In this case a new descriptive system which is relevant to the cognitive task must be "assembled." The hypothesis predicts that right-hemispherical participation is essential for both the orientation and assembly stages. Once an appropriate system has been assembled, the left hemisphere should achieve a leading role in its utilization.

This concept presupposes a right-to-left shift of relative hemispherical control over cognitive processes as the latter undergo functional transformation in the course of their development. Superficially this appears

to be at odds with the hypothesis of the left-to-right maturational gradient proposed by Corballis and Morgan (1978). The domains addressed by these two viewpoints, however, are not identical. Whereas Corballis and Morgan are primarily concerned with morphogenesis, we are concerned with the formation of cognitive skills. Although not mutually supportive, the two hypotheses are not mutually contradictory either. Given that associative cortex is last to mature in ontogenesis (Conel, 1939), that hemisphere which contains relatively more of it (the right hemisphere) is predictably the one to mature later in a limited cytoarchitectonic sense.

Among the previously proposed dichotomies, those terming the left hemisphere "logical, analytic computer-like" and the right hemisphere a "synthesist in dealing with information input" (Levy-Agresti & Sperry, 1968) or, respectively, "propositional" and "appositional" (Bogen, 1969), are the most compatible with the one proposed here. Hopefully, our perspective adds more precision to the understanding of the respective contributions of the hemispheres and establishes the directionality of their relative involvements at different stages in the formation of a cognitive product.

The notion of interhemispherical differences presented here puts greater emphasis on experiential factors and predicts greater individual differences than does a strictly natural language-based dichotomy. It also follows from this hypothesis that instructional biases may have a profound effect on the pattern of lateralization seen in a given experimental situation. Even a "novice" subject in a novel task may show a left hemispherical superiority if the nature of a discrimination is made explicit prior to the execution of the task. Instructions may provide the initial "orientation" to the stimuli, and performance will immediately be linked to existing descriptive systems of the left hemisphere.

It would follow from the idea of multiplicity of descriptive systems that throughout the life span their repertoire and the domain of cognition mediated by them progressively increases far beyond the time course of language acquisition. Brown and Jaffe (1975) reviewed evidence of progressive left-hemispherical lateralization of functions throughout the life span. This can hardly be accounted for by the process of language acquisition as it is commonly understood but can be predicted on the basis of our hypotheses.

DYNAMICS OF HEMISPHERAL INVOLVEMENT IN THE ROUTINIZATION OF CODES

We will now present the experimental evidence which is relevant to the hypothesis discussed. At least three kinds of evidence can be offered:

(1) Demonstrations that different patterns of hemispherical superiority exist in individuals who have differential command of certain cognitive skills with "novices" showing right hemispherical superiority on a given

task and "professionals" showing left hemispherical superiority. This type of evidence can be viewed as necessary but not sufficient. Indeed, evidence of this nature does not involve within-individual comparison over time and therefore leaves open the possibility, unlikely as it is, that different hemispherical patterns are implicit in the two compared groups. Apart from this, the possibility remains that the two hemispheres learn a skill independently at different rates during the course of acquisition.

(2) Within-individual change from right to left hemispherical superiority during the acquisition of a skill. This eliminates the first alternative interpretation but not the second.

(3) Exclusion of the right hemisphere from the learning process in early stages, leading to relative inability of the left hemisphere to acquire the skill.

We shall now analyze existing evidence of these three types in reference to the acquisition of language, the acquisition of nonlinguistic descriptive systems, and intraexperimental learning.

Language Acquisition

McFie (1961) reported considerable deficits in verbal performance following early left hemiplegia. In fact, the observed deficits were as severe as those in nonverbal tasks. When infantile and juvenile hemiplegia were compared, negative interaction of verbal deficit with age of onset was significant. Right hemiplegias, on the other hand, had very small effect on nonverbal tasks and there was no interaction with age.

Basser (1962) reported comparable findings, demonstrating that the delaying effect of early left hemiplegia on speech onset is at least as profound as that of right hemiplegia. Duration of the initial speech loss following a lateralized lesion was reported not to be a function of the side of the lesion but rather of the age of onset (the earlier the age, the longer the initial speech loss).

Woods (1980) reported equally impaired verbal and performance I.Q. following both left- and right-sided cerebral lesions incurred before age 1. Although no statistical analysis is offered, the right-sided lesions appear to have greater effect on both measures than do the left-sided lesions. When incurred after age 1, the left-sided lesions lead to equal decrements of verbal and performance I.Q., while right-sided lesions affect performance but not verbal I.Q. Interpretation of the latter (postage 1) data is complicated by the wide age range at which pathology ensued (up to 15 years old). If the breakdown established for this composite group accurately reflects the breakdown within certain subgroup (i.e., 1-6 year olds) then this finding must be considered contradictory to the hypotheses offered here.

It is apparent that early exclusion of the right hemisphere does affect language acquisition, and that the magnitude of this effect is inversely

related to age of onset of the pathological condition. The asymmetry of the deficit-age interaction for the two hemispheres supports the idea that the right hemisphere is involved in the initial stages of language acquisition and weakens the alternative explanation that there is an initial hemispherical equipotentiality. In view of these findings, the well-established notion that the degree of language recovery following a left hemispherical lesion is inversely related to age of onset (Zangwill, 1960; Lenneberg, 1967) has to be seen as indicating that both hemispheres are relevant to language acquisition, but each in its own way.

Studies of lateralization as a function of age in normal subjects offer another source of inference about hemispherical involvement in language acquisition. Dichotic findings are inconsistent: some demonstrate an early (ages 4 to 5) onset of a right ear advantage (REA) with subsequent lack of REA-age interaction (Berlin, Hughes, Lowe-Bell, & Berlin, 1973; Nagafuchi, 1970) or even a decrease of REA with age (Kimura, 1963; Knox & Kimura, 1970), while other studies have demonstrated a positive REA-age interaction until ages 9-11 (Satz, Bakker, Teunissen, Goebel, & Van der Vlugt, 1975) and even 12-14 (Bryden, 1973).

Satz et al. (1975) argued that negative or no-interaction findings can be accounted for by methodological artifacts (e.g., employment of overly simple tasks so that ceiling effects are reached, or use of arbitrary or inappropriate statistical procedures) which were avoided in those studies which revealed positive interaction.

Porter and Berlin (1975), on the other hand, suggested that these differences are not inconsistent but rather reflect different developmental courses for acquisition of different aspects of linguistic processing, such that the no-interaction findings were obtained for tasks which rely upon characteristics of auditory and phonetic processing whose acquisition is fully accomplished by the ages of 4-5. Conversely, positive interaction findings were obtained for tasks which rely upon aspects of processing known to mature only by the ages of 11-12 (e.g., short-term memory). Geffner and Hochberg (1971) found that REA becomes significant in children of a lower socioeconomic group later than in children of a middle socioeconomic group, (at ages 7 and 5, respectively). This supports the idea that the development of REA is a function of language acquisition.

Barroso (1976) reported the emergence of a right hemifield advantage (RHA) only at the ages of 10-12 on an essentially semantic task: matching words with schematic pictures of objects. Forays (1953) reported that RHA for three-to-four letter word recognition becomes significant only by seventh to eighth grades. Miller and Turner (1973, 1975) reported that the hemifield-related differences emerge between fourth and ninth grades and suggested that the longer the words, the more positive is the hemifield-age interaction. Educational age (as revealed by reading scores) was a more significantly interacting factor than chronological age.

Carmon, Nachshon, and Starinsky (1976) reported change from a slight left-hemifield advantage (LHA) to a RHA by the fifth grade for two- and four-letter words and for two- and four-digit numbers. This study is important in that the language employed was Hebrew, where right-to-left scanning is required, and subjects were native Hebrew speakers. Since the direction of change in hemifield superiority was no different from that obtained with the English language and American subjects, evidence is offered that observed asymmetries are related to hemispherical specialization rather than reading habits. Further support of this assumption has been offered by Kershner and Jeng (1972) in their demonstration of RHA with vertically oriented Chinese words.

Single-letter discrimination appears to be the only task for which data on hemifield-age interaction are inconsistent. Broman (1978) has reported a LHA for 2 year olds and a subsequent shift to RHA with increasing age. Carmon et al. (1976), on the other hand, have reported no interaction, while Miller (1973) demonstrated that the hemifield-age interaction was cancelled with age. This pattern of findings is consistent with that reported for the dichotic listening paradigm, indicating that more elementary and purely phonetic (or graphemic) tasks show relatively earlier REA (RHA) with subsequent ceiling effects, while more complex phonetic (graphemic) tasks and those involving semantic judgment show a later emergence of REA (RHA) as opposed to initial ear (hemifield) equality of LEA (LHA).

Studies of reading disabilities cast further light on this issue. Zurif and Carson (1970) reported greater REA for dichotically presented linguistic stimuli in fourth grade average readers than in poor readers. A similar finding was reported by Bryden (1970). Sparrow and Satz (1970) reported a higher incidence of LEA in poor readers.

Marcel, Katz, and Smith (1974), and Marcel and Rajan (1975) reported a greater RHA in good compared to poor readers (subjects were 7-9 years old and five-letter words were employed). Similar findings were reported by Olson (1973), Kershner (1977), and (for haptic presentation of letters) by Witelson (1977). These results are consistent with the contention that normal readers establish adequate left-hemisphere-mediated descriptive systems for reading earlier than poor readers.

McKeever and Huling (1970), on the other hand, noted no difference in the degree of RHA between good and poor seventh graders for four-letter words. Yeni-Komshian, Isenberg, and Goldberg (1975) found no difference in the degree of REA for digits between good and poor fifth to seventh grade readers and depression of left-hemifield scores on tachistoscopic tasks in poor readers.

Once the role of the right hemisphere in language acquisition is established, it would be interesting to determine the specific nature of its involvement. It has been demonstrated conclusively that left hemispherical

dominance for language reflects a strong biological predisposition (Levy, 1974) which operates from the very beginning of life (Molfese, 1972). It is clearly related to phonetic decoding (Krashen, 1976; Molfese, 1978; Oscar-Berman, Zurif, & Blumstein, 1975). This predisposition, however, is not necessarily specifically related to linguistically significant acoustic features, but to certain more general aspects of acoustic discrimination (Molfese, 1977; Wada, 1977) and fine oral motor control, regardless of its relationship to linguistic production (DeRenzi & Spinnler, 1966; Semmes, 1968). Zurif and Sait's (1970) demonstration that REA in phonetic decoding is contingent upon the presence of "acoustic correlates of linguistic structure" (intonation, rhythm, stress) may indicate that specific phonetic decoding ability is developmental rather than innate. Van Lancker and Fromkin (1973) have shown that Thai speakers have a REA for tonal differentiations in linguistic context. This apparent cultural dependence of phonetic differentiation may indicate that the developmental nature of left-hemispherical superiority in phonetic encoding is secondary to a certain prelinguistic advantage—auditory and/or motor.

Studies of hemidecorticate subjects offer further insights into the relative inputs of the two hemispheres in language acquisition and the establishment of linguistic competence. The numbers of subjects used in these studies are usually small, thus limiting the conclusions which can be drawn on their basis. Nevertheless, the findings are intriguing and deserve detailed analysis.

Phonetic discrimination related to real words is equally accurate following early left and right hemidecortication (Dennis & Whitaker, 1976). However, the appreciation of the statistical rules characterizing permissible phonemic and graphemic sequences as assessed by phonologists and paralogues appears to be intact in cases of infantile right hemidecortication but is severely impaired following left hemidecortication (Dennis, Lovett, & Wiegel-Crump, 1981). Phonemic-orthographic-correspondences also appear to be only marginally available to the isolated right hemisphere (Zaidel, 1977; Dennis et al., 1981).

Syntactic processing is another domain of clear left-hemispherical advantage. Dennis and Kohn (1975) and Dennis and Whitaker (1976) demonstrated an inability to process passive-negative transformations in infantile left hemidecorticates. The right hemisphere does have a limited ability to decode the meaning of syntactic constructions (Zaidel, 1977; Dennis, 1980), but this ability is limited to inference on the basis of lexical information and general logical constraints rather than decoding semantically salient features of surface structure (Dennis, 1980; Dennis, 1979). Short-term memory capacity appears to be another limiting factor for syntactic processing by the right hemisphere (Zaidel, 1977; Dennis et al., 1981).

It has been demonstrated, on the other hand, that hemispherical asymmetry for linguistic processing cannot be fully accounted for by the hypothesis of left hemispherical superiority in the appreciation of semantic structure. Some lexical competence was reported for the right hemisphere of commissurotomy patients (Gazzaniga & Sperry, 1967; Gazzaniga, 1970). Hemidecortication studies demonstrated that either hemisphere has an adequate repertoire of semantic skills (Dennis & Whitaker, 1976). Zaidel (1977) demonstrated that the auditory lexicon of the right hemisphere approaches that of an 11- to 16-year-old; Dennis et al. (1980) reported a considerable ability of the right hemisphere to retrieve names following semantic and visual cues. In tasks which require establishment of *ad hoc* referential relationships between sets of nonsense words and nonsense shapes, the right hemisphere outperforms the left (Dennis, 1979). On the other hand, when semantic processing must go beyond utilization of referential knowledge of separate lexical items, and presupposes semantic inference on the basis of interrelations among lexical entries, the right hemisphere fails (Dennis, 1979; Dennis, 1980; Dennis & Whitaker, 1976).

It thus appears that the implicit left hemispherical advantage is overwhelming for phonetic and orthographic processing, less decisive for syntax, and least decisive for semantic processing. The left-hemispherical advantage appears to be twofold: (1) processing of elemental units of the linguistic signal (probably secondary to a more basic acoustic and/or oral-motor advantage); and (2) processing of those aspects of the linguistic signal and/or code which are based upon fixed systems of rules and manipulation of the code or internal derivations within the code according to these rules. In this respect we follow Liberman (1974) in attributing to the left hemisphere the role of storage for "grammars." The right hemisphere, on the other hand, appears to be proficient in establishing the referential basis of the code.

The distinction between the referential basis of the code and the internal derivations within the code is compatible with the experiential versus paradigmatic distinction proposed by Zaidel (1977). This dichotomy eludes direct mapping onto the traditional breakdown of linguistic processing into phonetic, syntactic, and semantic levels; instead, it cuts across these categories.

Although the auditory lexicon of the isolated right hemisphere approximates the competence of an 11- to 16-year-old (Zaidel, 1977) and it shows a superior ability to form sign-symbol associations (Dennis, 1979), its capacity to establish categorical (functional rather than perceptual) links between objects is only on the level of a 6-year-old (Zaidel, 1977). Vygotsky (1962) suggested that the shift from a perceptually based to a categorical, definition based lexical organization

occurs between the ages of 6 and 12. This implies that the isolated right hemisphere is incapable of making the shift and the left hemisphere's involvement is needed for the formation of hierarchical categorical networks interrelating referential entries. It appears, by the same token, that the right hemisphere may play a critical role in the early, preconceptual stages of semantic acquisition which decreases with age. Consistent with this view is the observation that concrete words are better recognized in the left visual field than abstract words (Ellis & Shepherd, 1976) and high-frequency words are more accurately matched (Gibson, Dimond & Gazzaniga, 1972). This conclusion is strengthened by the rough coincidence of the age when brain plasticity with respect to language becomes minimal (Lenneberg, 1967), and the age when acquisition of the categorical structure of language is completed (Vygotsky, 1962; Piaget & Inhelder, 1969). Both critical points appear to fall in the range of 11-12 years.

Although the isolated right hemisphere shows very limited syntactic competence (Zaidel, 1977; Dennis, 1980), so does an acallosal brain (Dennis, 1981). These findings may imply that the right hemisphere plays a role in the early stages of acquisition of syntactic rules. Certain aspects of syntax are functional (and therefore involve referential properties) whereas the role of others is limited to the formal coordination of lexical entries within the surface structure. The two hemispheres may be differentially involved in the acquisition of these two aspects of syntax.

This difference between referential processing and rule-manipulation may also be applied to phonetics. Here, a distinction should be drawn between the correct identification of an allophone and competence regarding the statistical rules of phonemic sequences.

The differential roles played by the two hemispheres in various aspects of language acquisition are in agreement with the basic features of neuro-anatomical organization and the cognitive consequences of this organization as discussed above. Relatively greater representations of the temporal planum, parietal operculum, and pars opercularis of inferior frontal gyrus in the left hemisphere account for its relatively strong predisposition for elemental phonetic processing; greater representation of associative zones of intermodal integration in the right hemisphere accounts for its relative importance in the formation of the referential basis of semantics. Syntax may be said to occupy an intermediate position, in that it is involved in both coordination of the elements of surface structure (for which unimodal learning may be proposed), and also serves a functional role, mastery of which may involve intermodal integration.

It is possible that the time course for acquisition of descriptive systems underlying various linguistic processes differs, in which case the time course of right- and left-hemispherical involvement will reflect these differences.

Nonlinguistic Descriptive Systems

Bever and Chiarello (1974) and Johnson (1977) reported a LEA for musical discrimination in musical laymen but a REA in trained musicians. Consistent with these data is the report of musical deficits in a professional violinist following a left-hemispherical stroke (Wertheim & Botez, 1961). Gordon (1978) compared ear preferences to overall performance on a listening task, and those subjects with a low total score (left and right ears) were found to have a LEA, while those who had high total scores showed a REA. In terms of the perceptual processing necessary for musical tasks of different complexities, Gordon (1970) has shown that as the number of dimensions in a musical task is increased, a more pronounced LEA is found.

Gates and Bradshaw (1977) reported the somewhat contradictory finding that "familiar" melodies are better recognized by the right hemisphere than "unfamiliar" melodies, but in this analysis the results of males and females of both "musician" and "nonmusician" classes are pooled. When analyzed separately, male musicians show a REA, while male nonmusicians demonstrate a LEA for both types of melodies, as might be predicted from the hypothesis given their relative training levels. Results of the female group show more variable performance (and weak significance for musicians) which might be explained by the fact that females tend to show less robust patterns of lateralization (Kimura & Durnford, 1974). Pizzamiglio and Zocolatti (1979) suggest, however, that the issue of lateralization patterns in females is confounded by field dependency.

In another comparison of musicians and nonmusicians, Gaede, Parsons and Bertera (1978) attempted to disentangle the effects of aptitude and experience, and concluded that experience has no effect on ear preference. Unfortunately, the nature of the tasks employed for this study was such that subjects were effectively "primed" before a discrimination task as to the type of discrimination they would have to make. This type of instructional bias could easily lead to the results reported for their "memory sequence analysis." The impact of such instructional bias was directly controlled in the study of Gates and Bradshaw (1977) in which REA was found for conditions in which "naive" subjects were informed of the type of discrimination they would be making; in the one task in which subjects were required to make two different kinds of discriminations within a single block, and thus were not equipped with a single "cognitive set," no ear differences were found.

For Morse Code, a stronger REA was found in Morse operators than in naive subjects, independent of the length of the signal. In naive subjects, a REA was observed in sequences not exceeding seven elements (dots and/or dashes), but for longer sequences a LEA was found (Papcun, Krashen, Terbeek, Remington, & Harshman, 1974). The authors inter-

preted these split results in naive subjects in terms of Miller's (1956) notion of the limit of the immediate memory span and the limit of the human channel capacity for the transmission of information. If this interpretation is valid, and it appears to be, then what makes longer sequences demonstrate a REA in trained Morse operators is the availability of a descriptive system which enables them to code Morse signals into larger chunks.

Formal mathematical languages constitute another domain of nonverbal descriptive systems. Franco and Sperry (1975) studied hemispherical asymmetries in performance on visuotactile tests involving apprehension of geometrical relations in Euclidian, affine, projective, and topological spaces. The right-hemisphere superiority was established for all four sets of tasks, but the degree of this superiority increased in the following order: Euclidian, affine, projective, topological. The authors argue that the less structured the input (the fewer the spatial constraints) the greater is the right-hemispherical superiority. This is consistent with the notion that left-hemispherical performance is contingent upon stimulus encodability in terms of some kind of descriptive system. Franco and Sperry's data show no interaction between the degree of input structuredness and right-hemispherical performance. A clear positive interaction exists, however, between the degree of stimulus structuredness and left-hemisphere performance. These findings are consistent with (but do not necessitate) the explanation that the observed order of decrement in left-hemispherical performance is a function of the relevance of different classes of geometric objects to the preexisting descriptive systems, which in the case of an average subject can be assumed to be limited to Euclidian geometry. This being so, the gradient of the left-right hemispherical performance reflects the gradient of "trainedness" of the subjects for the tasks involved.

A comparable finding was reported by Goldberg et al. (1978): shape-texture discrimination ratio is higher for the left than for the right hemisphere in most subjects. Interior decorators, however, appear to demonstrate the opposite relationship. Of the visual artists, interior decorators are most involved in texture discrimination.

Face recognition is usually assumed to show a LHA (Rizzolatti, Umiltà & Berlucchi, 1971; Hilliard, 1973; Geffen, Bradshaw, & Wallace, 1971), but evidence exists that this effect decreases with age (Broman, 1978). Marzi and Berlucchi (1977) demonstrated a RHA for the recognition of famous faces. This is difficult to explain by the assumption that famous faces are recognized as "templates"; in fact this assumption would predict a still greater LHA. It was also demonstrated by these authors that the RHA for this task was independent of the use of a naming procedure. The authors argue that for famous faces recognition relies on "the analysis of single, salient physiognomical features or details," which is, in

effect, utilization of a descriptive system. The difference between processing famous as opposed to unfamiliar faces is comparable to the difference between trained and naive subjects.

Intraexperimental Learning of Novel Tasks

Analysis of the change of hemispherical performances within a single experimental sequence has been attempted by a number of investigators. It can be predicted from the hypothesis outlined in this paper that in early stages of acquisition, the right hemisphere should show superiority in performance, but as the skills necessary for the execution of the task are acquired and routinized, the left hemisphere should attain superiority.

There are at least two limitations to this method. An experimental sequence may not be long enough to reveal all stages of the learning process before fatigue factors come into play; also essential to this procedure is a unihemispherical input, with subsequent limitations on hemispherical transfer, while the "real life" learning situations obviously involve both hemispheres.

Gordon and Carmon (1976) demonstrated the transfer of LHA to RHA for verbal naming of unfamiliar visual symbols (taken from the digit-symbol subtest of the WAIS and modified binary representations of digits) over blocks of trials. A similar LHA to RHA shift for letter-pairs same-judgment in terms of both accuracy and reaction times was reported by Hellige (1976).

Miller and Butler (1980) reported differential patterns of hemifield superiority in letter recognition as a function of subjects' ability to discern the fact that only a subset of the alphabet was used in the procedure: those subjects who were able to do so, demonstrated a shift from LHA to RHA across blocks of trials. The subjects who failed to discern the effective subset showed a LHA throughout blocks of trials.

In a face recognition task, Reynolds and Jeeves (1978) demonstrated transfer from LHA to RHA over a period of 4 days. This effect was seen in 7- and 8-year-olds, but not in 13- to 20-year olds, who showed an overall LHA. Holtzman (1978) investigated the process of acquisition of four visual tasks presented tachistoscopically. Two of the tasks used linguistic stimuli (noun-verb and E-rhyming letter discrimination) the third involved face recognition and the fourth, symbol array recognition. He found significant LHA on early blocks of trials in all four experiments and attributed this to an initial orientation phase of task acquisition which is right hemisphere mediated. Later crossover to RHA varied as a function of both the nature of the stimuli and the task demand characteristics of each experiment.

Kallman and Corballis (1975) demonstrated elimination of the initial LEA for dichotically presented musical sounds; Spellacy (1970) demonstrated a similar effect for musical patterns. These findings are con-

sistent with the hypothesis only in part, since no actual crossover in ear superiority was demonstrated. In Kallman and Corballis' study, however, no significant improvement of performance was observed after the elimination of the LEA. This might well mean that fatigue interfered with further learning.

Thus, transfer of initial right-hemispherical to left-hemispherical superiority has been demonstrated by more than one author for both nonverbal (visual forms, patterns of dots) and verbal (same-letter judgments) visual input tasks. Therefore the effect appears to be material nonspecific. This effect was at least partially demonstrated for auditory tasks (musical sounds and patterns) demonstrating that the effect is modality nonspecific as well.

Several alternative explanations have been offered to account for these effects. Dimond and Beaumont (1972) proposed selective hemispherical fatigue as a contributing factor. In most of the reported studies, however, improvement of performance occurred in both hemispheres even after the crossover. Kinsbourne's (1970) attentional model is equally implausible for the cases where no changing concurrent tasks were introduced or where no considerable effects of fatigue were observed.

CONCLUDING COMMENTS

It has been proposed that fundamental neuroanatomical differences between the hemispheres can lead to a wide range of cognitive consequences; one which appears to be of considerable importance is explored here. It is hypothesized that the left hemisphere achieves superiority in the utilization of a multiplicity of descriptive systems which are fully formed in an individual's cognitive repertoire and which are relevant to specific classes of materials or tasks. The right hemisphere, conversely, was described as being most crucial in the processing of materials to which none of the descriptive systems preexisting in a subject's cognitive repertoire is readily applicable, and in assembling new descriptive systems. The concept of multiplicity of descriptive systems appears to be of heuristic value in that the notion of verbal encoding need not be inflated to imply that virtually every process which appears to have elaborate structure involves verbal encoding.

The right-to-left shift of the relative hemispherical control over cognitive skills in the course of their development follows from this premise and a variety of such shifts, both long and short-term, was demonstrated. Consequently, this approach emphasizes individual (experiential and developmental) differences and in most cases argues against the assignment of fixed hemispherical specificities for particular materials or tasks. Instead, this approach presupposes a gradient of relative hemispherical involvement in a wide range of cognitive processes, reflecting the degrees of their routinization.

No value judgment regarding the relative importance of either hemisphere is implied in this model. The two types of hemispherical organization are different in that they superimpose alternative orchestrations or similar processing components: the emphasis is on modality specific cortical areas and integration within them in the left hemisphere; and on associative areas and intermodal integration in the right hemisphere. These distinctions make the two hemispheres differentially suited for different dimensions and stages of processing. Terming the left hemisphere as "dominant" or "more advanced" is meaningful only insofar as it is understood that we refer to the dimensions of processing which are more elaborate in a cultural sense, or to later stages of processing. Neither of these two characteristics ought to be confused with the corresponding complexities of the networks in a quantitative informational sense.

The theory as presented above is not free of the oversimplification of treating the brain as consisting of two separate processors. The authors have a full appreciation of the fact that interaction of the hemispheres occurs in every on-line process and this is what makes the system "more advanced." It is, however, necessary to clearly specify the relative roles of the two hemispheres before building composite models. Any concept of interaction has very little value until it is clearly established what each element is doing in the ensemble.

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