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AUTHOR Harris, Lauren Jay
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ABSTRACT

This paper presents background information, an introductory statement of theoretical positions, and brief abstracts of research papers from a symposium on the functional specialization of cerebral hemispheres in infants and children. According to one view of the development of cerebral specialization, the two hemispheres are initially unspecialized, assuming their respective functions only with time and experience. The opposing view is that hemispheric specialization is a product of genetic endowment present, in some form, from the beginning of life. The five research papers summarized included some concrete evidence related to these views: (1) a study of hemispheric specialization for both speech and nonspeech sounds in infants; (2) a study of the relationship between the size of cerebral injury and the pattern of cognitive skills in adult patients who sustained brain injury during infancy; (3) an examination of hemispheric specialization for language in preschool and primary-grade children; (4) a study of hand specialization for shape discrimination in 3- to 13-year olds using the dichotic listening procedure for the haptic system; and (5) a discussion of the interaction of experiential and genetic factors in the patterning of cognitive abilities in normal individuals. (Author/JMB)

Functional Specialization of the Cerebral Hemispheres In Infants and Children: New Experimental and Clinical Evidence

Symposium Presented at The

Biennial Meetings of the Society for Research in Child Development

13 April 1975, Denver, Colorado

Introduction to Symposium

Lauren Jay Harris

Department of Psychology

Michigan State University

Running Head: Introduction

This symposium is entitled "Functional specialization of the cerebral hemispheres in infants and children: new experimental and clinical evidence." I am going to begin with a review--in rather broad strokes--of neuroanatomy and neuropsychology. For members of the audience with little or no background, this review should help in understanding the research reports to follow.

Neuroanatomy and Hemispheric Specialization

The human cerebrum. Figure 1 shows our subject in profile--the human brain--a mass of nerve tissue occupying the entire cavity enclosed by the skull, consisting of the cerebrum, cerebellum, pons, and medulla oblongata, and continuous with the spinal cord. This organ, when mature,

Insert Figure 1 about here

weighs about 1500 grams--a bit over three pounds--which makes it one of the heaviest organs in the body. Our interest is with the upper part of the brain--the part called the "cerebrum" (from the Latin word for brain). The cerebrum has several noteworthy features.

Size. First, unlike birds and 'lower' animals, whose cerebrums are not particularly well-developed, sometimes absent altogether, the human cerebrum is very large, constituting about half the weight of the entire nervous system. Indeed, it is so large and cramped into the skull that it shows a great number of ridges and surface folds, called "invaginations" (a word from the Latin 'in' plus 'vagina', meaning sheath, thus the telescoping of an organ in the manner of a sheath or pouch). These ridges and folds greatly increase the amount of cerebrum covering, or "cortex", which is composed of nerve cells or neurons ("gray matter") three to four mm. thick. It is the relative size of the cerebrum, but especially the amount of cortex, that most distinguishes us from other creatures.

Density of nerve cells. A second noteworthy feature is the great number and density of cerebral nerve cells and their processes (glia* and blood capillaries)--greater than any other tissue in the body. Estimates from electron microscope and biochemical research are that only 7 to 12 percent of the brain is extracellular space (the total volume of tissue outside the cells). This is probably the minimum possible volume of extracellular space for the packing together of nearly spherical objects such as nerve cells (Rose, 1974). By contrast, the extracellular space of other tissue, such as the liver, is in excess of 20 percent (Dobbing, 1969).

Major divisions. The curves, wrinkles, and grooves of the cortex appear in virtually the same place in all human brains and thereby demarcate particular cortical regions, lobes, or divisions. The 'frontal' lobe is, as its name suggests, at the front in the area just behind the forehead. The 'temporal' lobe is below and behind it, just above the ear when the brain is in the skull. The 'occipital' lobe is at the rear. Finally, the parietal region is located over the top, in the area under the hair on the head.

*cell type constituting supportive tissue of the vertebrate CNS

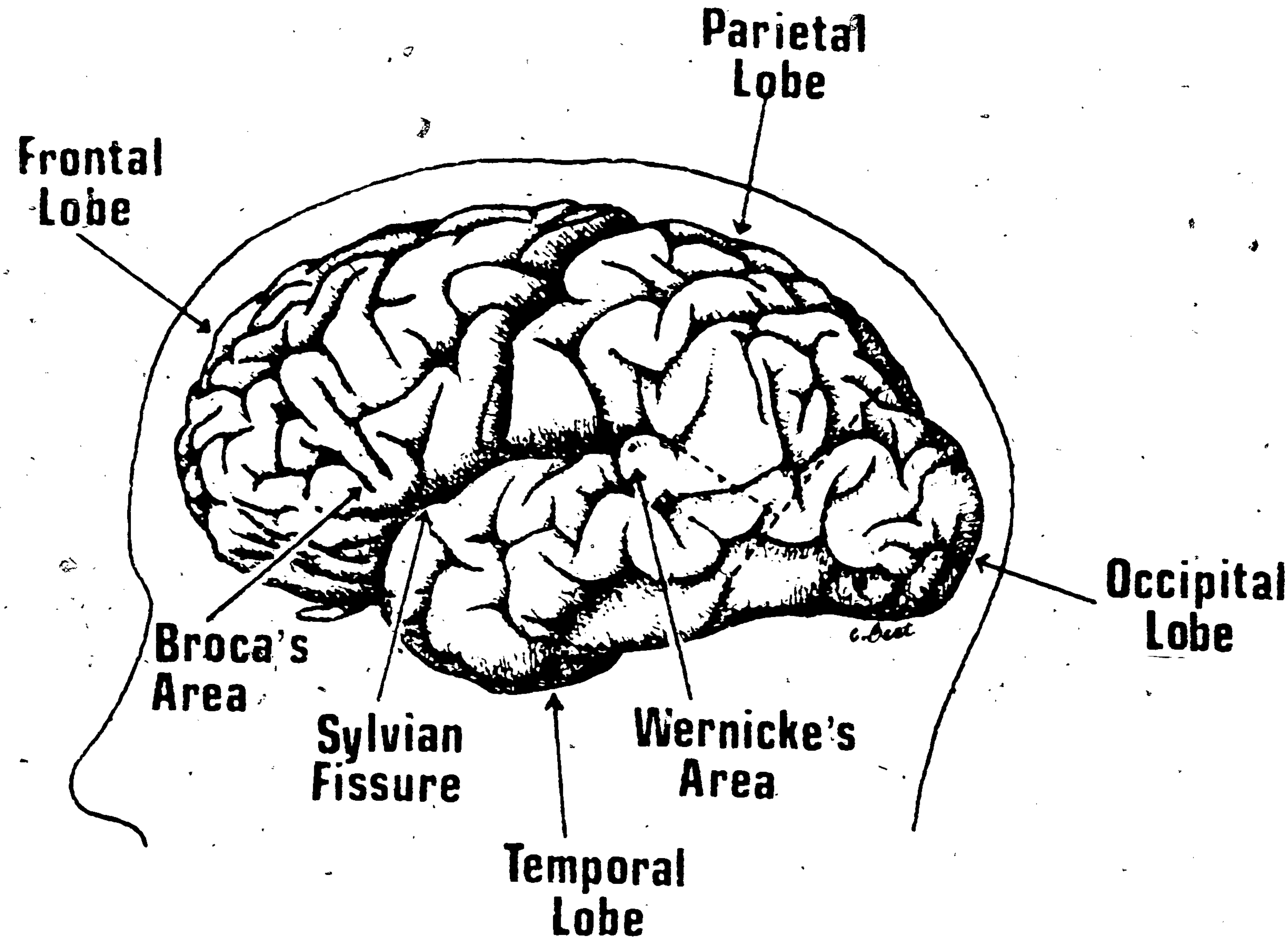
These divisions correspond roughly to a set of regions that have particular functions in the control of the activity of the body and in the processing of sensory information. The posterior part of the cortex--the occipital region--is concerned with vision, the parietal cortex with the coordination and control of sensory input and motor output. The functions of the frontal and temporal regions are more diffuse, less specifiable--but they generally are concerned with intellectual functions such as memory and learning.

Bilateral symmetrical structure. Still another remarkable feature is that there is not one cerebrum but two. A deep longitudinal groove, or fissure, that runs along the cerebrum's midline divides it into two virtually mirror-image or bilaterally symmetrical halves, or "hemispheres." Figure 1 therefore shows the left hemisphere. Each of the demarcations just described is found in each half.

Contralateral innervation. The hemispheres are linked to the body primarily 'contralaterally' (opposite side) rather than 'ipsilaterally' (same side), so that the left side of the body is controlled mainly by the right hemisphere, the right side of the body by the left hemisphere. (The functional and evolutionary significance of this contralateral innervation design is not clear, but this is a feature that all vertebrate brains show.) In the case, then, of the hands, this means that the left hand is better neurally 'projected' to the sensorimotor region of the right cerebral hemisphere, the right hand to the left hemisphere. Thus when an object is felt with the left hand, the tactual sensory information specifying its shape and texture travels primarily to the right brain.

Corpus callosum. Information, rather than being confined to one hemisphere, travels to the other side through a thick bundle of myelinated nerve fibers--"white matter"--called the corpus callosum. The corpus callosum links the hemispheres and, in a real sense, lets them communicate with one another. It is this structure that is severed in the so-called 'split-brain' studies (e.g., Sperry, 1964) so that the two brains and sides of the body function nearly separately or autonomously.

Hemispheric specialization. We have yet to mention the cerebrum's most remarkable feature--the feature that is the special concern of this symposium. All other paired internal organs of the body, such as the lungs, kidneys, or ovaries, have identical functions, as far as we know, so that one can get along quite well with only one of each. In the case of the cerebral hemispheres, this mold is broken: the left hemisphere is specialized for language functions; the right hemisphere is relatively mute but instead subserves visuo-spatial-perceptual functions. Thus a person feeling an object with his left hand (but not looking at it) can say what the object is because the sensory information projected to the right 'spatial' hemisphere travels through the corpus callosum to the left hemisphere where it can be described in language.


Frontal Lobe
Parietal Lobe
Occipital Lobe
Broca's Area
Sylvian Fissure
Wernicke's Area
Temporal Lobe
c. Best

This is the most familiar contemporary description of hemispheric specialization. It may be more useful to draw the characterizations more abstractly in terms of the quality of coding operations by each hemisphere. Thus, the left hemisphere has been characterized as working in a logical, analytic, sequential, or serial way, and as controlling the sequencing of those motor functions that happen to lend themselves to communication, whether vocal or manual (Liepmann, 1908; Kimura, 1973). The right hemisphere, by contrast, is primarily a synthesist, especially good at organizing and processing information coming from several different sources in parallel, even heteromodally, in terms of wholes or gestalts--a kind of processing that, it has been suggested, is especially suitable for the detection and analyzing of spatial information (e.g., Levy-Agresti & Sperry, 1968; Semmes, 1968).

Studies of Brain-Injured Persons

The earliest evidence for cerebral specialization is from analysis of the psychological deficits associated with lesions, or injuries, of the brain, such as might come about through the obstruction or rupturing of blood vessels in the brain ('stroke'), as a result of a spontaneous growth (tumor), through an injury like that produced by a bullet wound, or after epileptic attacks. Injury to the left side is associated with a variety of language disorders known as 'aphasias' (the term is from the Greek word "phasis", for utterance, so, with the prefix "a", it means "without speech.") (e.g., Costa and Vaughn, 1962, Gazzaniga, 1970, Kimura, 1973; Milner, 1958; Weisenburg and McBride, 1935; Zangwill, 1964).

The kind of language disturbance is related to the part of the hemisphere affected, the most important of which for language are the frontal and temporal areas. Within the frontal lobe is an area called "Broca's area" after its discoverer Paul Broca (1861), a French pathologist, anthropologist, and pioneer in neurosurgery. This area is just in front of that part of the cortex that controls the muscles critical for the production of speech--the jaw, tongue, palate, lips, and larynx. Speaking requires very precise, coordinated movements of these parts, and in the Broca's aphasic, this coordination seems to be disrupted, though the organs of speech themselves are not paralyzed. The victim's speech is typically slow, his articulation poor, with many words and parts of words omitted. Ability to understand language, however, is often unimpaired.

A different kind of disturbance is associated with damage to an area within the temporal lobe called "Wernicke's area", after its discoverer Carl Wernicke (1874). The victim's articulation seems fairly normal, but the content is often confused, and, unlike the person with Broca's aphasia, language comprehension is often disturbed.

Injury to the right hemisphere generally has negligible effects on language skills but has been associated with impairment of various non-language spatial skills, such as visual pattern discrimination, including facial recognition; sense of direction in the macroenvironment; visual spatial localization; depth perception (here, apparently the ability to

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use binocular information), tactual discrimination of shape; even the ability to put one's clothes on--a skill that, if one has watched young children trying to dress themselves, requires discrimination of the spatial planes of the body and the garment, and also perception of musical structure--such as recognition of melody and decomposing of chords (e.g., Carmon and Benton, 1969, DeRenzi, Faglioni and Scotti, 1971; Reitan, 1964; Tueber and Weinstein, 1954; Weinstein, 1962).

It is worth noting that while the left hemisphere's special functions have long been known and accepted, it is only in the last few decades that the right hemisphere's special functions have been appreciated, even though Hughlings Jackson had postulated such functions as early as 1864 (Jackson, 1874, 1876; Head, 1926). Instead, the right hemisphere was called the 'minor' hemisphere and deemed merely a copy of the left, 'major' hemisphere, but a copy without language. One hears these terms 'major' and 'minor' used even today, along with the term 'cerebral dominance', without the specification, dominant for what?

Dichotic listening. There are ways to study hemispheric specialization in healthy as well as in brain-injured persons. One procedure is called "dichotic listening." The subject wears earphones that permit a different signal to be played to each ear simultaneously. To one ear the signal might be a sequence of spoken digits, while different digits are presented to the other ear. The subject is asked to report what he has heard, and typically, makes a more accurate report of the signal presented to the right ear. This right-ear superiority has been interpreted as reflecting the fact that the auditory system, like the hand-motor system, has more contralateral than ipsilateral connections. (Presumably, at the auditory cortex of each hemisphere, each ear is represented by a population of cortical units, and the population representing the contralateral ear is larger than that representing the ipsilateral ear; Tunturi, 1946; Rosenzweig, 1951). Thus the left hemisphere might be said to 'understand', or process, speech better through the right ear.

For non-verbal sounds, such as a clock ticking, coughing, water pouring, or musical passages, a left-ear advantage is found, a result interpreted as evidence of more efficient right-hemisphere processing for these stimuli (e.g. Knox and Kimura, 1970; Kimura, 1964).

Lateralization and Handedness

It should be pointed out that all of the foregoing evidence for hemispheric specialization applies predominantly to right-handed persons or dextrals, who, according to various estimates, constitute from 90 to 98 percent of the population. Nearly 99 percent of right-handers have left hemisphere laterality for language, compared to only 53 to 65 percent of sinistrals, that is, left-handers (Goodglass and Quadfasel, 1954; Roberts, 1969). Moreover, left-handers as a group tend to be less well-lateralized than right-handers, as suggested by the substantially higher percentage of left-handers than right-handers who show aphasic symptoms after either left- or right-hemisphere injury (Goodglass and Quadfasel, 1954). On other measures of lateralization, such as dichotic listening, or conjugate lateral eye movements during mental problem solving, left-handers also show weaker lateralization than right-handers (e.g., Bryden, 1965; Kinsbourne, 1972, Gur, Gur, and Harris, 1975). Precisely why left-handers are peculiar in this regard is still unclear (sinistrals may take satisfaction in knowing that they resist easy analysis), but for obvious reasons, it is important to know the handedness of the subject in studies of the development of hemispheric specialization.

Development of Hemispheric Specialization

These basic generalizations about human cerebral specialization are reasonably well-established. Much less is known or understood of the developmental history of this specialization, and this is the subject of this symposium. At least two points of view about this development can be contrasted: One holds that the two hemispheres are initially unspecialized and only with time and experience, such as would come from continued exposure to and practice of language and spatial analysis, do they gradually assume their respective roles.

The evidence most frequently cited in support of this view is surveys of cases of hemispherectomy--the total or partial removal of a diseased hemisphere (e.g., Basser, 1962). These surveys indicate that when a left-sided lesion occurs very early in life, e.g., in infancy, and the hemisphere is removed later in life (after the age of about 10 years), usually no permanent aphasia results. But if the victim acquires a left-sided lesion in later life, after he has begun to speak, serious and persistent aphasia results when later the diseased hemisphere is removed. No aphasia results if it is the right hemisphere that was diseased and was removed. The conclusion frequently drawn from such evidence is that the earlier a left-sided lesion is incurred, the better the victim's chances that the healthy right hemisphere will have been able to "take over" language functions.

In their most general form, these findings are unexceptional: it is well known from ablation studies with animals that the victim's age and the 'momentum' of a lesion's development are important factors in determining the impact of lesions. For example, ablation of the frontal isocortex in infant cats or monkeys, or ablation of somatosensory areas, does not lead to behavioral motorsensory deficits that the very same lesions would lead to in older animals. Indeed, Broca himself, in 1861, had surmised that injury to the left hemisphere at birth or shortly after would not preclude normal speech development. But an inference frequently drawn from the studies of hemispherectomized individuals is that the cerebral hemispheres are equipotential at birth such that either hemisphere may, with equal ease, subserve either language or spatial functions. In some quarters the still more radical inference is drawn that the brain is a 'tabula rasa', and that any organization or reorganization is possible.

A rather different view is that hemispheric specialization is a product of our genetic endowment and is present, in some form, from the very beginning. How else explain why, under normal circumstances,

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lateralization proceeds as it does in nearly all brains--to the left hemisphere for language, to the right for visuo-spatial functions, rather than, say, to either side with equal probability? For that matter, why is there lateralization at all? Why do not both hemispheres subserve both linguistic and visuo-spatial functions equally, just as both kidneys work equally to maintain proper water balance, to regulate acid-base concentrations, and to excrete metabolic wastes? Or, to put the question a different way, why do we have two hemispheres instead of only one? Why isn't the brain more like the liver?

Our intention in this symposium is to address these different theoretical positions so as to better understand the meaning and merits of each view. In so doing we also hope to shed light on a variety of other, related questions of current, as well as historical, interest to developmental psychologists, e.g., the origin and nature of language acquisition, the growth of handedness and sidedness and the meaning of that familiar and frequently misused term "cerebral dominance," a proper explication of the concepts of behavioral and cerebral 'specificity' and 'plasticity', the fundamental question, why is there lateralization?, and the question, being raised more and more often in recent years, of the development of individual differences in cognitive skills such as sex differences in spatial ability.

Various techniques have been used to address these questions in both healthy and brain-injured persons. The first four papers in this symposium report original research employing different techniques, some of which were mentioned earlier.

The first speaker, Anne K. Entus, has combined a dichotic listening procedure with an habituation of sucking paradigm to study hemispheric specialization for both speech and non-speech sounds in infants.

The second speaker, Maureen Dennis, has adduced evidence pertinent to the question of behavioral and cerebral plasticity as well as specificity in early life. She examines the relation between the side of early cerebral injury and the pattern of cognitive skills in adult patients who sustained brain injury during infancy.

The third speaker, Marcel Kinsbourne, uses the dichotic listening task to study hemispheric specialization for language in preschool and primary-grade children. He also employs two other techniques: measurement of conjugate lateral eye movements (gaze direction) as an index of differential hemispheric activation during mental problem-solving, and analysis of the effects of left-hemisphere activity (vocalization) on a concurrent motor task (finger tapping). The close-packing of cerebral nerve cells mentioned earlier is an important feature in an 'attentional' theory of laterality effects that Kinsbourne has proposed (e.g., Kinsbourne, 1972).

The fourth speaker is Sandra Witelson, who has adopted the dichotic listening procedure for the haptic system to study hand (i.e., hemispheric) specialization for shape discrimination in three- to thirteen-year-old children.

Finally, the last paper, by Lauren Jay Harris, deals with the interaction of experiential and genetic (neurological) factors in the patterning of cognitive abilities in normal individuals, with special attention to the question of sex differences in spatial skill.

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Functional specialization of the cerebral hemispheres in infants and children: new experimental and clinical evidence.

Abstracts of Papers for a

Symposium presented at the Biennial Meetings of the

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13 April 1975, Denver, Colorado

Chairman of session: Lauren Jay Harris, Department of Psychology, Michigan State University, East Lansing, Michigan 48824.

Participants

Anne Kasman Entus, Department of Psychology, McGill University, Montreal, P.Q., Canada.
"Hemispheric assymmetry in processing of dichotically presented speech and nonspeech sounds by infants."

Maureen Dennis, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario, Canada.
"Hemispheric specialization in adulthood after hemidecortication for infantile cerebral disease."

Marcel Kinsbourne, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario, Canada.
"Cerebral activation and lateral bias in orientation: an 'attentional' model for understanding the behavioral expression of hemispheric specialization."

Sandra F. Witelson, Department of Psychiatry (Child and Family Centre, Chedoke Hospital), McMaster University, P.O. Box 590, Hamilton, Ontario, Canada.
"Age and sex differences in the development of right hemisphere specialization for spatial processing as reflected in a dichotomous tactual stimulation task."

Lauren Jay Harris, Department of Psychology, Michigan State University, East Lansing, Michigan 48824.
"Interaction of experiential and neurological factors in the patterning of human abilities: the question of sex differences in 'right hemisphere' skills.

Functional specialization of the cerebral hemispheres in infants and children: new experimental and clinical research

Abstracts of Papers

Introduction (L. J. Harris)

It is well known that the two cerebral hemispheres of the human adult brain, though physically nearly identical, are important for different mental processes. In nearly all persons, the left hemisphere is specialized for language-analytic-sequential processing, the right hemisphere for spatial-perceptual-gestalt, or parallel, processing. The clearest support for these characterizations comes from clinical studies of neurological patients with identifiable unilateral cortical lesions or ablations, or with commissurotomy, and from the experimental study of normal individuals by means of various perceptual tasks such as dichotic listening and tachistoscopic stimulation.

Much less well understood is the developmental history of this specialization. According to one popular view, the two hemispheres are initially 'unspecialized' and 'equipotential', and only with time and experience, such as would come from continued exposure to and practice of language, do they gradually take on their respective functions. An opposing view is that hemispheric specialization is a product of our genetic endowment and is present, in some form, from the very beginning of life.

A consideration of the evidence for and against these different positions can shed light on a variety of questions of current, as well as historical, interest to developmental psychologists, e.g., the origin and nature of language acquisition, the growth of handedness and the meaning of 'cerebral dominance', and explication of the concept of behavioral (and cerebral) plasticity, and the general question of the development of individual differences in cognitive skills such as the well-known sex differences in spatial ability.

A variety of techniques have been used to address these questions in normal and brain-injured persons. The first four papers in this symposium will be reports of original research employing several different means of studying hemispheric specialization in infants and children. The last paper will be an overview of research, with special attention to the question of individual differences.

1. Entus combines a dichotic listening procedure with a non-nutritive sucking paradigm to study hemispheric specialization for both speech and non-speech sounds in infants.

2. Dennis adduces evidence pertinent to the question of behavioral and cerebral plasticity as well as specificity. She examines the relation between the side of cerebral injury and the pattern of cognitive skills in adult patients who sustained brain injury during infancy.

3. Kinsbourne uses the dichotic listening task to study hemispheric specialization for language in preschool and primary-grade children. He also employs two other methods appropriate for children: measurement of conjugate lateral eye movements (direction of gaze) as an index of differential hemispheric activation during mental problem-solving (verbal or spatial), and analysis of the relation between vocalization (i.e., left-hemisphere activity) and hand differences on a concurrent motor task (finger tapping).

4. Witelson adapts the dichotic listening procedure for the haptic system to study hand (hemispheric) specialization for shape discrimination in 3- to 13-year-old children.

5. Harris discusses the interaction of experiential and genetic (neurological) factors in the patterning of cognitive abilities in normal individuals, with special attention to the question of sex differences in spatial skill.

Hemispheric Asymmetry in Processing of Dichotically Presented Speech and Nonspeech Sounds by Infants (A. K. Entus)

The dichotic listening procedure presents different auditory stimuli simultaneously to each ear: the listener must recall or recognize what he has heard. Because the contralateral auditory pathways from ear to cortex are functionally dominant over the ipsilateral ones, this procedure typically yields a right-ear advantage for speech stimuli, such as words, digits, or consonants, and a left-ear advantage for nonspeech sounds, such as music, thus reflecting the known specializations of the left and right cerebral hemispheres, respectively. Where the dichotic listening procedure has been used in developmental studies, a right-ear (left hemisphere) superiority with verbal stimuli has been found in children ranging in age from two and a half to twelve years (Bever, 1971; Bryden, 1970, Sinclair, 1968; Kimura, 1963), and a left-ear (right hemisphere) superiority with nonverbal stimuli in children between five and twelve years old (Bakker, 1967; Knox & Kimura, 1970). These studies support the view that language lateralization emerges only as the child experiences language both as listener and speaker. More recent studies, however, suggest much earlier functional asymmetry. It is now known that young infants discriminate speech in a manner paralleling adult speech perception (e.g., Trehub & Rabinovitch, 1972)--a capacity thought to depend on functional properties which in adults are usually confined to the left hemisphere.

In the current study, the dichotic listening procedure was combined with a non-nutritive sucking paradigm to assess hemispheric specialization in infants for both speech and non-speech stimuli. After obtaining a baseline rate of an infant's non-nutritive sucking for one minute, dichotic auditory stimulation (via stereophonic headphones) was made contingent on sucking. Typically, the sucking rate then rose above the baseline, but with continued presentation of the initial stimulus pair, decreased or habituated. The criterion of habituation was a decrement of at least one third of the infant's previous maximum rate, maintained for two consecutive minutes. Then the stimulus in one ear was changed, while the other ear continued to receive the stimulus heard during habituation. The new combination was presented for five minutes. After a break, the procedure was repeated; sucking was allowed to habituate to this combination, and then a novel stimulus was presented to the other ear.

In experiment 1 the stimuli were the consonant-vowel syllables /ma/, /ba/, /da/, and /ga/, spoken by an adult male voice. In Experiment 2, the stimuli were renditions of the note A (440Hz) on four instruments--piano, viola, bassoon, and cello. In each experiment, there were 48 babies (24 males and 24 females) ranging in age from 22-140 days (mean age 72 days). The data for each infant consisted of recorded number of sucks per minute, expressed as a percentage of the maximum pre-shift sucking rate.

Analyses of variance disclosed a significant difference in recovery scores between ears, favoring the right ear in Experiment 1 (right ear mean = 71.5%, left ear mean = 59.9%, $p < .01$) and the left ear in Experiment 2 (right ear mean = 58.4%, left ear mean = 71.0%, $p < .001$). With respect to individual performance, 71% of the infants in Experiment 1 showed a right-ear superiority, and 79% in Experiment 2 showed a left-ear superiority--proportions consonant with those reported for dichotic listening studies with older children (e.g., Bryden & Allard, 1973).

Twenty-two- to 140-day-old infants thus display the typical adult pattern of lateral asymmetry for dichotically presented speech and non-speech stimuli. Hemispheric asymmetry therefore seems to be part of man's biological endowment, and is functional by at least three weeks of age.

Hemispheric Specialization in Adulthood After Hemidecortication for Infantile Cerebral Disease (M. Dennis)

Do the effects of early cerebral disease depend on which side of the brain is injured? In patients with one hemisphere surgically removed for perinatal brain damage, does the pattern of cognitive functions in maturity depend on whether the left or right hemisphere has been removed?

To answer these questions, studies (in collaboration with Bruno Kohn) were made of the verbal and non-verbal abilities of infantile hemiplegics (mean age: 20), one group with the left, another with the right, hemisphere removed. The ability to discriminate the meaning of spoken sentences varying in syntactic form was tested. The subjects heard a sentence in one of four voices: active affirmative (e.g., "The boy pushes the girl."), passive affirmative (e.g., "The girl is pushed by the boy."); active negative (e.g., "The boy does not push the girl."), and passive negative (e.g., "The girl is not pushed by the boy."). Immediately after hearing the sentence, the subjects were shown a picture illustrating the subject-object relationship of the statement (in one segment) and a subject-object relationship inconsistent with the statement (in the other segment). The subjects' task was to point to the segment which showed what they had just heard. Right hemidecorticates, relative to the left-operated group, showed superior comprehension of passive negative but equivalent comprehension of active affirmative and active negative, sentences. Specialized language skills, it appears, are mediated more efficiently when the remaining cerebral hemisphere is the left.

Non-verbal abilities develop more fully when the remaining hemisphere is the right. The hemidecorticate subjects were compared on tests of visuo-spatial abilities, sense of direction or orientation, and route-finding skills (Street Completion Test, Ghent Hidden Figures Test; Weinstein Test of Personal Orientation, Semmes Test of Extrapersonal Orientation; Money Road-Map Test; WISC Mazes; Porteus Mazes). The left and right hemidecorticate groups performed with similar competence if the task was one which normal children would master by the age of 10. But on tests of later-developing spatial abilities, the right hemidecorticates, but not the left-operated subjects, were severely impaired.

The behavioral consequences of brain damage sustained during infancy do appear to reflect hemispheric asymmetries of both verbal and non-verbal functions. Upon removal of one side of the brain for perinatal cerebral disease, a more extended language development is possible in a remaining left hemisphere, and more competent perception of spatial relations requires right hemisphere processes.

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Cerebral Activation and Lateral Bias in Orientation: An 'Attentional' Model for Understanding the Behavioral Expression of Hemispheric Specialization (M. Kinsbourne)

Four experiments will be described, contributing to the existing evidence for asymmetrical hemispheric function in very young children. The results enable us to make an informed guess as to the nature of cerebral dominance in very early life.

Experiment 1. (Kinsbourne and Sessions)
In a dichotic listening paradigm, children were asked to respond only to the presence or absence of a target digit name. There was a right ear advantage for pre-schoolers down to age 3, at least as great as that usually found in adults. The results reflect the existence of dichotic asymmetry, and therefore underlying cerebral asymmetry of function, in young children, even when the subject is not required to name the digits he heard.

Experiment 2. (Kinsbourne and Hotch).
Pre-schoolers were asked to divide their attention in dichotic listening so as to report the input at one ear only. There was an overwhelming tendency for the right ear input to be reported whether the right ear or the left ear was asked for. The degree of right advantage in this task was greater than that of any as yet reported in literature. In young children, asymmetry thus can be shown to be even greater than it is later in life. The results further indicate that attentional bias accounts for much if not all of this asymmetry.

Experiment 3. (Kinsbourne and Jardino)
We have shown in previous work that lateral bias of attention itself indicates asymmetry of cerebral functioning. When the left hemisphere is differentially active, people look right, whereas when the right hemisphere is active they look left. In Experiment 3, we were able to show that this relationship also holds true for pre-schoolers. When set a verbal task to solve 'in their head', they usually looked right, when set a spatial task, they usually looked left.

Experiment 4. (Kinsbourne and McMurray)
Not only verbal input and verbal thought processes, but verbal output mechanisms as well are lateralized in pre-schoolers. When children were asked to finger tap while speaking, the speaking significantly decreased the tapping rate of the right index finger but not of the left.

The findings from the four experiments will be discussed in terms of a model which suggests that behavioral asymmetry arises from asymmetrical lateralization of brain function from the very beginning. At or before the onset of the developmental sequences that culminate in mature verbal, spatial and other cognitive skills, the asymmetry manifests itself primarily in terms of a lateral bias in orientation. Lateralized processes and directional orientation are inextricably integrated by the organization of each cerebral hemisphere.

Age and Sex Differences in the Development of Right Hemisphere Specialization for Spatial Processing as Reflected in a Dichotomous Tactual Stimulation Task (S. F. Witelson)

Study of the right hemisphere's special role in perception and memory was relatively ignored for a long time compared to the attention given the left hemisphere's role in speech and language functions. The same situation now holds for the study of the development of hemispheric functional asymmetry. Although there are numerous studies, using different methodologies, relevant to the development of left hemisphere specialization, there are only a few concerned with the development of right hemisphere specialization. In adults, it is well documented that the right hemisphere is dominant for two, possibly related, sets of skills: nonlinguistic auditory processing, and visual and tactual spatial processing. The few studies of right hemisphere functional development have focused on the nonlinguistic auditory processing skills.

The work to be reported here is concerned with the developmental course of right hemisphere specialization for spatial processing using a behavioral task developed specifically for this purpose. The task, labelled dichotomous tactual stimulation, involves simultaneous presentation of two different two-dimensional nonsense shapes, one to each hand, and not visible to the subject. The subject palpates them and then indicates his response by pointing to the two stimuli he felt from a visual display of a group of shapes. The rationale of this procedure is as follows: the shape discrimination requires processing via the contralateral somesthetic pathways, that is right hand-left hemisphere and left hand-right hemisphere. With the condition of dichotomous stimulation, it is possible that some competition between the processing of left and right stimuli may occur at some level in the central nervous system. In such a case, if the right hemisphere is more effective in spatial processing, then some advantage might be observed for those objects presented to the contralateral (left) hand. This test paradigm of dichotomous tactual stimulation could then provide a behavioral tool for the study of the development of right hemisphere specialization in neurologically-intact individuals.

In the first study, 100 normal right-handed boys, age 6 to 13 years, were given this touch task. It was found that the recognition of left hand objects was significantly greater than right-hand accuracy, even for the youngest children. These results support the view that right hemisphere specialization for at least some aspects of spatial processing may be present by at least six years of age in normal boys.

The next study questioned whether right hemisphere specialization exists prior to age 6. A modified version of the task was developed for use with younger children in which passive rather than active touch was used. Sixty-five normal boys, age 3 to 5 years who preferred to write with their right hand, were tested. No hand difference was observed at age 3 or 4 years, but a significant difference in favor of left hand superiority was observed at age 5. These results suggest that the right hemisphere may be specialized for spatial processing as early as age 5 in boys. It does not necessarily follow that right hemisphere specialization for spatial

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processing is not present earlier, since other tasks or methods may be more sensitive measures of the special skills of the right hemisphere.

Recently, sex has been indicated as a possible relevant variable in neural organization. Sex differences in cognitive skills have been well documented for some time. In respect to spatial skills, considerable evidence attests to the superiority of males. It thus seemed fruitful to compare the course of right hemisphere specialization for spatial processing in girls and boys. In the last study to be reported here 165 normal, right-handed girls, age 3 to 13 years, were tested with a dichotomous tactual task, as in the studies with the boys. The girls did not show any left hand superiority until approximately age 13 years, at which age they showed for the first time a trend similar to the performance of the boys. It is suggested that in girls right hemisphere superiority for spatial processing may not be present until many years after lateralization of spatial function has occurred in males. This is the first suggestion of a sex difference of such magnitude in the development of the neural substrate of cognition in humans.

The results will be discussed in terms of their contribution to and implications for the general development of hemispheric specialization and brain-behavior relationships.

Interaction of experiential and Neurological Factors in the Patterning of Human Abilities: The Question of Sex Differences in 'Right Hemisphere' Skills (L. J. Harris)

After verbal ability, 'space' may be the second most frequently identified of all factors in factorial studies of intelligence. Spatial ability has been of particular interest to differential psychologists because one of the more persistent of individual differences is a sex difference in this skill--males do better than females on a variety of spatial tasks, including embedded figures, certain visual coding tasks; mental rotation and identification (e.g., spatial subtest of Differential Aptitude Test), geometry, especailly solid geometry; chess; cube-cutting puzzles; visual and tactual maze-learning; map-reading; left-right discrimination; rod-and-frame test; certain logical conservation tasks having visuo spatial components (representation of horizontality). The size, reliability, and first appearance of this sex difference varies with the task and group studied, and the difference generally is stronger and more consistent in older children and adults, though it has appeared at least as early as four years.

All these tasks appear to require, to different degrees and in different combinations, some subset of the following abilities: perceiving and comparing spatial patterns, forming and retaining a clear impression of a shape or pattern and detecting that shape in the face of distracting or obscuring cues; turning or rotating an object in 3-space and recognizing a new appearance after the prescribed manipulation; fitting together and dissecting shapes; making discrimination as to the directions up, down, left, and right; thinking about those spatial relations in which one's body orientation is an essential part of the problem; organizing and processing information coming from several different sources in parallel, heteromodally, or in terms of wholes or gestalts.

These cognitive skills are known to be subserved in large measure by the right cerebral hemisphere, especially the temporal, parietal, and occipital regions. The possiblity thus arises that sex differences in spatial skills are traceable, at least in part, to differences between males and females in these cerebral areas, in particular, that the right hemisphere is more efficient, or further specialized, for spatial processing in males than in females.

Several possible, different expressions of such a sex difference will be discussed; and evidence, where available, presented. Major attention will be paid to the possiblity that females, on average, are less completely lateralized than males such that females' right hemispheres subserve language functions in addition to their usual visuo-spatial role. The evidence comes from various sources, including new studies of dichotic listening, electrophysiological activity of the hemispheres during mental problem-solving, visual field differences with tachistoscopic stimulus projection, clinical surveys, and finally recent anatomical investigations.

On the premise that left hemisphere modes are insufficient for the complex syntheses required for spatial perception a sex difference in cerebral lateralization wherein language and spatial modes co-exist in the female's right hemisphere would begin to account for the female's poorer spatial ability.

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An alternative hypothesis will also be considered--that at least some of the behavioral findings in the studies named above, instead of, or in addition to, reflecting different degrees of lateralization in males and females, reflect females' greater reliance on their left hemisphere (language modes) in attempting to solve spatial problems, while men rely more nearly purely on the right hemisphere.

Discussion then will turn to the question whether there are early developmental events that encourage male and female children to follow different cognitive 'paths' such that in females, more than males, intellectual development is dominated by left-hemisphere modes of thinking.