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Sex and the Single Hemisphere: Specialization of the Right Hemisphere for Spatial Processing

Abstract. *Specialization of the right hemisphere for spatial processing was studied in 200 normal boys and girls between 6 and 13 years of age. Boys performed in a manner consistent with right hemisphere specialization as early as the age of 6. Girls showed evidence of bilateral representation until the age of 13. The results suggest a sexual dimorphism in the neural organization underlying cognition during a major period of childhood. The results, which have implications for reading instruction, are discussed in terms of a possible sex difference in neural plasticity during development and the clinical consequences of such a difference.*

The right hemisphere plays the major role in adults in nonlinguistic, spatial, and holistic cognitive processing, which includes two (possibly related) sets of skills: (i) visual- and tactile-spatial processing and (ii) nonlinguistic and nonsequential auditory processing (*1*). Study of hemisphere specialization during development has focused on the left hemisphere (*2–6*) and relatively ignored the right (*7–9*), particularly its role in spatial processing. Unlike language, spatial perception is prominent in the behavior of both human infants and nonhuman species. Consequently, hemisphere specialization for spatial processing may be critical in human ontogenetic and possibly in phylogenetic development of lateralization of function in general, and it is an important aspect of the neural substrate of cognition.

I now report some initial information concerning the early course of specialization of the right hemisphere for spatial processing, with regard to both age and sex. In the course of experiments with children, it was discovered that, in boys, the right hemisphere has the dominant role in processing nonlinguistic spatial information by at least age 6 years; in contrast, in girls the right hemisphere is not dominant even by age 13 years, but rather, there is bilateral representation. These results suggest (i) that boys have greater hemisphere specialization and (ii) that there is a sexual dimorphism in the neural organization related to cognition for an extended period of development.

Suitable methods for studying specialization of the right hemisphere in children have been lacking (*10*). I used a new behavioral test procedure involving tactual perception, which was devised specifically to assess the relative participation of the two hemispheres in spatial processing in neurologically intact children (*11*). In essence, the test requires that the subject palpate simultaneously, out of view, two different meaningless shapes for 10 seconds, each one with the index and middle fingers of one hand. He then tries to choose these two shapes from a visual display containing six such shapes. After many practice trials, ten test trials are given; the scores are the number of left- and right-hand objects correctly chosen. The test has two crucial features. (i) It requires tactile shape discrimination, which, in adults, depends mainly on the right hemisphere (*12*). Furthermore, to make the test as dependent on the right hemisphere as possible, the stimuli were designed to be meaningless shapes, not readily labeled; the simultaneous palpation of different stimuli tends to hinder linguistic encoding; and the incorrect items in the recognition display were designed to have details similar to those of the test stimuli, so that a correct response depends on a gestalt perception of the whole stimulus. (ii) Different stimuli are presented simultaneously, here termed "dichhaptic" stimulation: "dich," from dichotomy, to refer to the simultaneous and different stimulation; and "haptic," referring to active touch. It was hoped that this procedure would produce competition in the neural system (*13, 14*) such that any superiority of the right hemisphere for the required cognitive processing would be reflected in superior perception of the contralateral (left) hand stimuli (*15*). Such was the empirical result in an earlier study of a small group of boys (*11*), but the present study indicates it to be so only for boys.

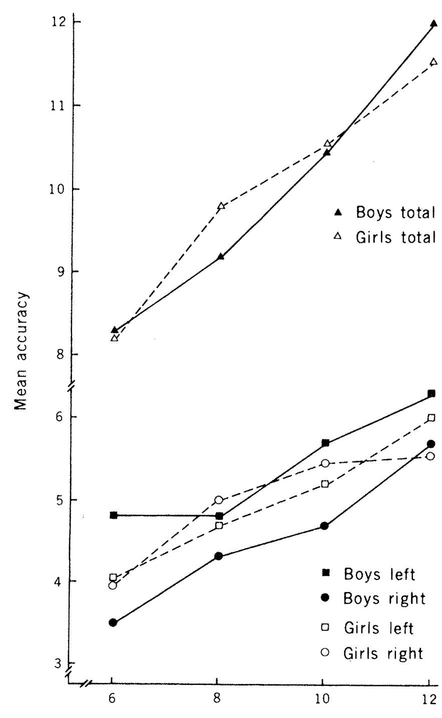

Fig. 1. Mean accuracy scores for recognition of nonsense shapes presented to the left and right hands on a dichhaptic stimulation test. Maximum possible score per hand is 10.

I studied 200 right-handed children, as defined by consistent preference for the right hand for writing and on at least eight of ten unimanual tasks. There were 25 subjects of each sex within each 2-year interval from 6 to 13 years, all with at least normal tested intelligence, age-appropriate academic achievement, and normal medical and behavioral status. Each child was given the dichhaptic stimulation test. The boys, but not the girls, obtained greater left- than right-hand scores (Fig. 1). A mixed design analysis of variance was done with sex and age as the between-subject variables and hand as the within-subject variable. There was no difference in overall accuracy between boys and girls ($F < 1.0$); overall performance improved with age in a linear fashion [F (3,192) = 24.2, $P < .0001$]; hand was a significant factor [F (1,192) = 7.1, $P < .01$]. In addition, there was a significant interaction between hand and sex [F (1,192) = 6.8, $P < .01$]. No other interactions were significant ($F < 1$ in all cases). The left-hand score of the boys (5.4) was significantly better than their right-hand score (4.6). There was no difference between hands (5.0 and 5.0) for the girls. The difference between the sexes for each hand was not significant ($.05 < P < .10$, in both cases). The Duncan Multiple Range Test (*16*) was used for all comparisons. Significantly more boys than girls had better left- than right-hand scores ($\chi^2 = 5.28$, d.f. = 1, $P < .05$). Since one of the a priori questions concerned the age at which evidence for asymmetry is first observed, I tested to determine whether the difference between hand scores was significant for the youngest subgroup of boys, and it was ($t = 3.20$, d.f. = 24, $P < .01$).

Each child was also given a typical verbal dichotic listening test as an index of left hemisphere specialization for language (*17*). Both boys and girls showed greater accuracy for right- than left-ear stimuli ($t = 5.09$, d.f. = 86, $P < .001$; $t = 2.76$, d.f. = 88, $P < .01$, respectively) (*18*). A chi-square analysis of the number of girls and boys with greater right- or left-ear scores indicated no difference between the sexes ($\chi^2 = 0.03$, d.f. = 1, $P > .85$).

The greater left- than right-hand score for the boys is consistent with earlier results (*11*). The difference in hand asymmetry between the sexes cannot be attributed to differential asymmetry in tactile sensitivity (*19*). Nor is it likely that the sex difference is due to greater use by girls than boys of a left hemisphere verbal-analytic strategy, as the test was devised to make the use of such strategies unlikely (if not impossible) and useless. Finally, the laterality difference between the sexes was specific to the spatial task. In both groups, the right ear was superior on the verbal dichotic test.

I have argued (*11*) that superiority of the left hand on this dichhaptic test reflects superiority of the right hemisphere for spatial processing. Within this context, I now suggest that for boys of at least 6 the right hemisphere is more specialized than the left for spatial processing; in girls, however, there is bilateral representation at least until adolescence. Thus, the same neural structures in males and females may have different functions with respect to at least one aspect of cognition during a major period of development. Conversely, the same cognitive process may be mediated by different parts of the brain in boys and girls.

The results are consistent with those of the few reports that studied the sexes separately for lateralization of spatial processing. Several studies with adults (*20*) and the one study with children (*21*) suggest greater participation of the left hemisphere in spatial tasks in females than in males. In contrast, no such sex difference has been observed in children for specialization of the right hemisphere for nonlinguistic auditory perception (*22*) or for specialization of the left hemisphere for language (*23*).

The most direct evidence for the existence of sexual dimorphism in neural organization underlying cognition during development comes from recent studies with rhesus monkeys (*24*). Bilateral lesions in infancy of orbital prefrontal cortex resulted in impaired performance on tests involving, interestingly, spatial discrimination in male monkeys when tested in infancy (2½ months) and again at maturity; but in females, early lesions did not induce deficits until the animals reached about 15 to 18 months of age.

Sexual dimorphism in the neural organization underlying cognition may have educational implications. Reading is considered to involve both spatial and linguistic processing (*25*). The brains of girls and boys may be differentially organized for the cognitive processes involved in reading at a time in development when they are learning to read. Therefore, different approaches in teaching reading, such as the "look-say" and phonetic methods, that stress different cognitive strategies and, by inference, depend on different neural structures in the two sexes, may be differentially effective for each sex.

The superiority of males to females on many, although not all, spatial tests (*26*) may be related to the hypothesized neural dimorphism. Spatial ability seems to be related to sex chromosomes (*27*) and testosterone levels (*28*). Such genetic and hormonal factors may cause the neural dimorphism in the sexes (*29*), which in turn may underlie the sex difference in spatial ability. Interdependence of these physiological, neural, and cognitive factors suggests a relatively unexplored and possibly fruitful dimension for the study of (i) individual differences in cognition; (ii) the etiology of clinical disorders possibly associated with atypical patterns of neural lateralization, particularly of specialization of the right hemisphere (such as developmental dyslexia) (*30*); and (iii) the potential use of sex hormones in the clinical management of neural trauma and developmental disorders in which an extended period of neural plasticity and hemisphere equipotentiality may be beneficial (*31*).

If the right hemisphere in girls is not specialized for a particular cognitive function, then the brain of young females, particularly the right hemisphere, may have greater plasticity for a longer period than that of males. Thus, language functions may transfer more readily to the right hemisphere in females than in males following early damage to the left hemisphere; in fact, for patients with early lesions, women show less impairment than men on verbal tasks after neurosurgical removal of left hemisphere tissue at maturity (*32*).

Greater plasticity of the young female brain also suggests that females may have a lower incidence of developmental disorders associated with possible left hemisphere dysfunction and for which greater plasticity of the right hemisphere might be advantageous. Males do have a higher incidence than females of developmental dyslexia (*33*), developmental aphasia (*34*), and infantile autism (*35*), all of which have language deficits as a predominant symptom.

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References and Notes

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2. Evidence for early left hemisphere specialization for language comes from several diverse sources: (i) studies of language deficits in brain-damaged children [for example, L. S. Basser, *Brain* **85**, 427 (1962); M. Annett, *Cortex* **9**, 4 (1973)]; (ii) studies with normal children using verbal dichotic listening tests [for example (*3–5*)]; (iii) studies using cortical evoked potentials to speech sounds (*6*); and (iv) less directly, from reports of neuroanatomical asymmetry in language areas in neonates [for example, S. F. Witelson and W. Pallie, *Brain* **96**, 641 (1973); J. A. Wada, R. Clarke, A. Hamm, *Arch. Neurol. (Chicago)* **32**, 239 (1975)].
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7. In children, right hemisphere superiority for nonlinguistic auditory processing is indicated on the basis of nonlinguistic dichotic tests (*5, 8*) and electrophysiological recordings (*6*). Superiority of the right hemisphere for spatial processing is suggested by the superiority of the left hand in reading Braille symbols [B. Hermelin and N. O'Connor, *Neuropsychologia* **9**, 431 (1971); Rudel *et al.* (9)]; and by a few studies with brain-damaged children [for example, R. G. Rudel, H.-L. Teuber, T. E. Twitchell, *Neuropsychologia* **12**, 95 (1974)].
8. C. Knox and D. Kimura, *Neuropsychologia* **8**, 227 (1970).
9. R. G. Rudel, M. B. Denckla, E. Spalten, *Neurology* **24**, 733 (1974).
10. The various possible strategies [such as (i) naturalistic observation of clinical cases; (ii) objective study of cognitive deficits in individuals with unilateral brain damage, hemispherectomy, or commissurotomy; and the study, in normal individuals, of (iii) visual field asymmetry with tachistoscopic stimulation and (iv) electrophysiological asymmetry] have all been, for technical or practical reasons, of limited use in the study of the role of the right hemisphere in spatial processing in early childhood.
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13. Simultaneous but different stimulation to the two ears (dichotic listening) is a useful tool in tapping hemisphere functional differences (*14*). Analogously, dichhaptic stimulation was devised for the tactual modality. When one tactile object is presented to either hand, there is no difference between the hands in accuracy for shape recognition [for example, A. Carmon and

A. L. Benton, *Neurology* **19**, 525 (1969); E. De Renzi and G. Scotti, *Cortex* **5**, 53 (1969)]. However, for some tactile-spatial tasks, such as the perception of direction of brief tactile stimulation to the hands, even unimanual stimulation may yield perceptual asymmetry [A. L. Benton, H. S. Levin, N. R. Varney, *Neurology* **23**, 1248 (1973)].
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15. Ipsilateral somesthetic pathways contribute only to gross perception, such as the presence or absence of tactile stimulation [R. W. Sperry, M. S. Gazzaniga, J. E. Bogen, in *Handbook of Clinical Neurology*, P. J. Vinken and G. W. Bruyn, Eds. (North-Holland, Amsterdam, 1969), vol. 4, pp. 273–290.
16. D. B. Duncan, *Biometrics* **11**, 1 (1955).
17. The particular test used involved free recall of series of three dichotic pairs of digits, presented at the rate of two pairs per second. On such tests, accuracy is greater for material presented to the right than to the left ear in adults [for example (*14*)] and in children [for example (*3*, *4*)], which is considered to reflect left hemisphere specialization for linguistic processing.
18. The total number of subjects in each sex group for this test is less than 100 due to the exclusion of those subjects whose audiometric testing indicated depressed or differential ear acuity.
19. Although some studies with adult men and women [for example, S. Weinstein, in *The Skin Senses*, D. R. Kenshalo, Ed. (Thomas, Springfield, Ill., 1968), pp. 195–222] indicate greater pressure sensitivity for the left fingers and palm, whereas other studies report no laterality difference [for example, A. Carmon, D. E. Bilstrom, A. L. Benton, *Cortex* **5**, 27 (1969)], the one study with children reports greater left sensitivity in girls by the age of 6, but in boys only by the age of 11 [L. Ghent, *J. Comp. Physiol. Psychol.* **54**, 670 (1961)]. In contrast, in my study boys as young as age 6 showed a left-hand superiority for shape discrimination; girls did not, in spite of possibly greater left-finger sensitivity.
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21. The study of Braille reading by Rudel *et al.* (*9*) suggests greater participation of the right hemisphere on this task in boys by the age of 11 years but not in girls even by the age of 13. The late appearance of left-hand superiority in boys in this study may be related to the verbal component in the particular task used, and, by inference, to left hemisphere processing. One study using a "conflict drawing test" [A. W. H. Buffery and J. A. Gray, in *Gender Differences: Their Ontogeny and Significance*, C. Ounsted and D. C. Taylor, Eds. (Churchill Livingstone, London, 1972), pp. 128–157] suggests the opposite hypothesis, that boys develop right hemisphere specialization for spatial functioning later than girls. However this interpretation does not follow unequivocally from their data.
22. Although Knox and Kimura (*8*) found that overall (left plus right) accuracy for recall of environmental sounds was greater for boys than girls, superiority of the left ear occurred as early and was of the same magnitude in girls as in boys. Entus (*5*) also found no sex differences.
23. No data indicative of sex differences in speech representation are reported in studies of acquired aphasia in children. Many studies using verbal dichotic tests in normal children analyzed performance of the sexes separately, and most found no sex difference in age of onset, incidence, or magnitude of superiority of the right ear [for example, Kimura (*3*); Knox and Kimura (*8*); C. I. Berlin, L. F. Hughes, S. S. Lowe-Bell, H. L. Berlin, *Cortex* **9**, 393 (1973); Entus (*5*)]. A few studies did find no superiority of the right ear in some age-sex groups: in some cases for girls, in others for boys, and sometimes at age levels beyond those for which significant ear asymmetry was obtained [for example, Kimura (*14*); M. Nagafuchi, *Acta Oto-Laryngol.* **69**, 409 (1970); Ingram (*4*)]. These data do not provide evidence of a sex difference in lateralization of language functions in children.
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25. E. J. Gibson, *Cognitive Psychol.* **2**, 351 (1971).
26. For reviews, see L. M. Terman and L. E. Tyler [in *Manual of Child Psychology*, L. Carmichael, Ed. (Wiley, New York, ed. 2, 1954), pp. 1064–1114] and L. J. Harris [in *Hemispheric Asymmetries of Function*, M. Kinsbourne, Ed. (Cambridge Univ. Press, Cambridge, England, in press)].
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31. F. Nottebohm [*Science* **167**, 950 (1970); *J. Exp. Zool.* **179**, 35 (1972)] reports that lateralization of neural control for bird song is fixed and plasticity is no longer possible by the end of song learning, and that termination of the critical period for normal full song development is postponed by reduced early testosterone concentrations. Therefore, reduced testosterone may prolong the period of latent neural plasticity.
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33. For example, M. Critchley, *The Dyslexic Child* (Heinemann, London, 1970), p. 91; Witelson (*30*).
34. A. L. Benton, *Cortex* **1**, 40 (1964); T. T. S. Ingram, *Brain* **82**, 450 (1959).
35. M. Rutter, L. Bartak, S. Newman, in *Infantile Autism: Concepts, Characteristics and Treatment*, M. Rutter, Ed. (Churchill Livingstone, London, 1971), pp. 148–171.
36. Supported by the Ontario Mental Health Foundation research grant 322. I thank the staff members of the Wentworth County Roman Catholic Separate School Board for their cooperation in providing subjects; H. Evenden, M. Irvine, J. Swallow, and D. Clews for technical assistance; and A. B. Kristofferson and J. Diamond for their constructive comments on earlier drafts of this report. Some of these data were presented in a paper given at the Biennial Meeting of the Society for Research in Child Development, Denver, Colo., 10 to 13 April 1975.

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Susceptibility of Mice to Audiogenic Seizures Is Increased by Handling Their Dams During Gestation

Abstract. *Fetal mice treated on days 10, 11, and 12 of gestation by injecting the mothers with (i) 50 milligrams of β-2-thienylalanine, (ii) solvent, or (iii) sham injection had identical frequencies of audiogenic seizures when tested 23 days after birth; these frequencies were significantly higher than those of an unhandled control group. Results of the sham treatment suggest that maternal stress induced by handling, rather than the nature of the substance injected, increased the susceptibility of the offspring to seizures.*

Riley has reported that C3H/He mice that had been routinely handled developed mammary tumors earlier than mice reared under conditions designed to minimize what he called "environmental stress factors" (*1*). He interpreted his observations and those of others as showing that stress is associated with "subtle modulating factors" in the environment and described the effects of such stress.

We now report that inducing even transient mild stress in the pregnant mouse increased the frequency of audiogenic seizures among the progeny. The experiments were originally designed to clarify an ambiguous result on seizure frequency after prenatal treatment with the phenylalanine analog β-2-DL-thienylalanine (*2*). In those experiments, the frequency of audiogenic seizures induced 23 days after birth following a priming sound stimulus at 21 days (*3*), while highest among animals treated with thienylalanine, was not significantly higher in that group than in the control mice treated with solvent. Both groups of mice showed seizure frequencies significantly higher than those of unhandled controls.

Our investigation was a repetition of the earlier study with minor variations in methodology and with the addition of a group of sham-treated subjects. The mice were the 23rd and 24th generation of a cross of C57BL/Gr, CBA/Gr, C3H/C-Hw, and A/Gr strains maintained by maximum outbreeding, and were designated as CBHA-C (*4*). A subgroup was subjected to brother-by-sister mating in generation 23. The sexes were housed separately, four or five females in a cage adjacent to a cage containing a single male. Females were placed with the male in late afternoon or early evening; they were checked for a vaginal plug as evidence of mating and removed to their own pens the following morning. The date the plug was found was considered day 0 of pregnancy. Mated females were assigned to one of four treatment groups. Treatments were randomized over males and cages. Mice were isolated during the 17th or 18th day of gestation. Litters were reduced where necessary to seven pups to minimize the influences of variation in litter size and of crowding (*5*). All mice had free access to food and water and were housed in the same room with 18 hours of light in 24 hours (LD 18 : 6). Treatments and sound stimuli were presented between 11 a.m. and 1 p.m.

Treatments consisted of intraperitoneal injection, on days 10, 11, and 12 of gestation, of either (i) 50 mg of β-2-DL-thienylalanine in 1 ml of 0.5*N* NaOH, 0.5*N* HCl, and 0.9 percent NaCl (1 : 1 : 5), (ii) solvent alone, or (iii) a sham treatment, in which a needle was inserted into