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ABSTRACT

Sex differences in cerebral organization and functioning, and the apparent superiority of males in spatial ability are examined in this paper. Attention is given to several kinds of cognitive and perceptual tasks in which sex differences in spatial ability have been shown to exist; among these are tasks involving: (1) recall and detection of shapes, (2) geometry and mathematics, (3) directional sense, (4) Piagetian skills and (5) the game of chess. A neurological model for sex differences in spatial ability is discussed, which suggests that some brains are further specialized (lateralized) for spatial analysis than others, and that these "further specialized" brains are more frequently male than female. Medical research with war veterans who have suffered brain injuries, data from anatomical and clinical studies and results of testing of normal individuals are cited to suggest that the left hemisphere of the brain seems primarily organized for verbal function, the right hemisphere for visual-spatial functions. An alternative model for sex differences in spatial ability suggests that women prefer to code information phonologically (due to their earlier language development) and that men prefer to code information visually. Data are presented which support this view. The possibilities of evolutionary selection for male spatial superiority and the effects of sex steroid hormones on brain specialization and nervous system activity are considered. (BRT)

Interaction of experiential and neurological factors in the patterning of human abilities: The question of sex differences in 'right hemisphere' skills

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Perhaps the most persistent of individual differences in cognitive skills is a sex difference in spatial ability: males do better than females on a variety of spatial tests, including embedded figures; certain visual coding tasks; mental rotation and identification tasks; geometric problems, especially solid geometry; cube-painting and cube-cutting puzzles; visual and tactual maze-learning; map-reading; left-right discrimination; rod-and-frame test; and certain logical conservation tasks having visuo-spatial components. The size, reliability, and first appearance of this sex difference vary with the task, and the difference, generally, is stronger and more consistent in older children and adults, though differences have appeared at least as early as four years.

In light of evidence implicating a critical role for the right cerebral hemisphere in spatial perception, some of which I reviewed in my introductory remarks (Harris, Note 1; Harris, 1975; Harris, (a) in press), the most pertinent question to raise, in a symposium on functional specialization of the cerebral hemispheres, is whether sex differences in cerebral organization and functioning underlie the male's greater spatial ability. In this paper I shall briefly trace out lines of evidence bearing on this possibility. First, though, let us review some of the investigations in which the sex difference has appeared.

Recall and Detection of Shapes

The 'embedded figures test' is among the most familiar cognitive tasks on which sex differences are known to exist. In five- to 10-year-old children, sex differences in speed and accuracy on this task are typically absent (e.g., Bigelow, 1971; Corah, 1965; Keogh and Ryan, 1971), though where differences appear, they tend to favor boys (e.g., Chateau, 1959; Witkin et al., 1967). Between 12 to 18 years, the male's superior skill begins to emerge more reliably (e.g., Fiebert, 1967; Okonji, 1969; Witkin et al., 1967) until by adulthood (18 years to middle age) it appears routinely (e.g., Andrieux, 1955; Berry, 1966; Corah, 1965; Newbigging, 1954; Schwartz and Karp, 1967).

The embedded figures test makes use of modified Gottschaldt figures in which the subject first looks at and tries to remember a simple geometric form, and then, with the form no longer in view, tries to find it in a complex geometric figure. The critical factor underlying the sex difference typically is assumed to be the latter 'disembedding' skill, leading to the test's characterization (Witkin et al., 1954) as a measure of 'cognitive differentiation', 'analytic style', or 'field independence'. But males also appear to be better in the simple 'recollection' and visual coding of shapes. In a recent study (Coltheart et al., 1975), college students were instructed to proceed mentally through the alphabet from A to Z, counting the number of letters containing a curve in their upper-case form. Since no information about the sound constituting the name of a letter could assist in deciding whether its printed form contains a curve, the authors considered this task to be purely visual. Significantly more men than women gave the correct answer.

Mental Rotation and Identification

The aforementioned tests appear to require only static visual imagery. More commonly, 'spatial ability' presupposes an ability in 'kinetic' rather than 'static' mental manipulation. An example is the spatial subtest of the Differential Aptitude Test (Bennet, Seashore, and Wesman, 1959, 3rd ed.) wherein the subject visually constructs a three-dimensional figure from a two-dimensional pattern, remembers the three-dimensional image and matches it to perspective drawings of alternative objects, and, after locating a correct object, visualizes the rotation of the object in three-dimensional space and then matches it with other objects. Again, males excel, at least in the age range 11 years through college-age (Flanagan et al., Note 2; Harris and Wagner, Note 3; Hartlage, 1970; Vandenberg et al., 1968).

Another more 'kinetic' test is to count blocks from pictures of stacks of blocks when some blocks are partly obscured by others (thus, from a two-dimensional representation of a three-dimensional stack of blocks, to count, or otherwise estimate, the number of block surfaces visible from perspectives different from one's own). Boys routinely excel, maintaining their lead at least through young adulthood (e.g., Book, 1932; Stafford, 1961).

Geometric and Mathematical Skill

It has been suggested that these sex differences in spatial visualizing ability also underlie the male's superior academic achievement in geometry. Saad and Storer (1960) reported that fifth-grade boys had markedly better understanding than girls of geometric concepts and principles. And Gastrin (Note 4) reported superior performance by high school boys in solid geometry. Smith (1964, p. 123) has suggested that the difference may reflect boys' greater capacity "to perceive, recognize, and assimilate patterns within the conceptual structure of mathematics." This interpretation is supported by studies demonstrating a relation between geometrical ability and performance on standard spatial visualization tests (e.g., Siegvald, 1944; cited in Smith, 1964).

The male's greater skill also appears in arithmetic and algebra but not so strongly as in geometry (e.g., Saad and Storer, 1960). And in the more mechanical parts of mathematics, such as numerical addition, the sex differences may be negligible. Performance on standard spatial tests correlate higher on geometry tests than with marks in arithmetic and algebra (Smith, 1960), and, on factor-analytic studies, load higher on geometry than on algebra, and higher on algebra than mechanical arithmetic (Barakat, 1951). Thus the male's superior skill seems to be clearest in those disciplines for which spatial ability is most critical--that is, disciplines that are genuinely 'mathematical' as distinct from those involving more mechanical, computational processes.

Chess

It is tempting, in a discussion of sex differences in spatial ability, to consider the game of chess. Throughout the world it is a game dominated by males (e.g., Byrne, 1975), so one wonders whether it involves a strong spatial element making it relatively more difficult for females. The grandmaster

Samuel Reshevsky, for one, comments that his chess skill was a manifestation of high spatial ability. Reschevsky had been a tremendous prodigy, who at eight years of age—before formal schooling—did excellently on psychological tests involving visualization of form and memory for digits, and outstandingly on tests requiring fitting and dissecting shapes (Reshevsky, 1948).

Such anecdotal evidence is strengthened by experimental analysis (e.g., Groot, 1965; Chase and Simon, 1973a). Chase and Simon (1973b) conclude that chess "...involves a great deal of visual-perceptual processing" (p. 215), and it is these immediate processes rather than the subsequent logical-deductive thinking processes that underlie chess ability. The basic underlying ability, they propose, is the quick perception of familiar patterns of pieces requiring information processing operations like mental rotation processes (e.g., Shepard and Metzler, 1971) or those processes involved in solving cube-painting and cube-cutting puzzles (Baylor, Note 5).

<u>Sense of Direction</u>

Perhaps the commonest expression of spatial ability is in orientation in space--"sense of direction." To orient oneself in space requires memory of and then movement or transformation of a spatial layout, but with the added complication that a critical part of the layout is the individual's own body. Much anecdotal evidence suggests that males have better direction sense than females. Research bears this out.

<u>Mazes</u>. The commonest test of direction sense is the spatial maze. On maze-tracing tests, males excel, beginning as early as four years and extending at least through middle adulthood (Book, 1932; Davies, 1965; Mellone, 1944; Porteus, 1965; Wilson, 1975). The usual maze test is visual, but the same sex differences appear on 'tactual' mazes, where vision is prevented (Harris and Best, Note 6; Langhorne, 1948).

<u>Map-reading</u>. Another instrument used to test 'directional sense' is Money et al.'s (1965) "Road-Map Test of Direction Sense", consisting of a schematic outline map of several city blocks with a standard route through the streets. The subject must imagine himself following the route and, without turning the map, must tell whether each turn on the route would be to his left or right. When this test was administered to over a thousand normal children between the ages of seven and 18, both boys and girls showed roughly parallel improvements across age, but the boys were slightly better than the girls at ages seven to 10 and 15 to 18, and substantially better at ages 11 to 14 (Money et al., 1965). The most difficult parts of the "road-map" test are the 'come back and turn' discriminations which require the subject to imagine himself turned around so that his left and right are reversed. Performance was poorest on these trials, especially for the girls.

<u>Left-right discrimination</u>. In the "Road-Map Test", a critical factor seems to be the skill with which the subject has mastered the basic left-right discrimination. In this regard, the sex differences found are surprising inasmuch as they have not appeared in other developmental studies (e.g., Harris,

1972; Long and Looft, 1972). These studies, however, did not place a premium on speed of discrimination as the Road-Map test seems to; nor did they require so many shifts in perspective. Sex differences in the basic discriminatory skill apparently do exist: in a recent study university students were instructed to look at slide projections of body parts and to identify each part as left or right. Each slide was shown for three seconds with three seconds for response. Men averaged fewer than five errors in 32 identifications; women averaged nearly eight (Bakan and Putnam, 1974).

Rod-and-frame test. The rod-and-frame test also might be called a test of 'direction sense' insofar as the subject must detect the true (gravitational) vertical axis in the face of distracting cues. The task is to adjust a luminescent rod to the vertical when the rod is inside a luminescent square frame which itself is tilted, and when the subject himself may be tilted as well. The test is conducted in a darkened room.

Compared with the embedded figures test, with which the rod-and-frame test is usually associated and with which it is often administered, sex differences on the rod-and-frame test appear earlier and more reliably. In children between five and 10 years, superior performance by boys has been reported in several investigations (e.g., Canavan, Note 7; Graves and Koziol, 1971, Keogh and Ryan, 1971; Witkin et al., 1967); beyond that age, male superiority is routine (e.g., Bogo et al., 1970; Morf et al., 1971; Okonji, 1969; Schwartz and Karp, 1967; Witkin et al., 1962; 1967).

Geographic knowledge. If females have poorer directional sense than males, one might expect them to do less well on more general tests of geographic knowledge. A survey of nearly 2,000 Michigan fifth-grade children bears out this prediction (Bettis, Note 8). Each child answered a 49-item multiple-choice test. The questions ranged broadly, including map-reading (e.g., interpretation of distances, traffic and population movement, direction of river flow); knowledge of place names on maps; knowledge of geographical facts (e.g., origin of swamps, the nature of the land surface in Michigan); and graph-reading. The boys scored higher than the girls on 42 questions, equal on three, lower on four. The largest differences appeared to be on questions requiring map-reading.

Piagetian Tests

Finally, consider certain Piagetian tests. Many are like conventional spatial visualization tasks, so sex differences might be expected. One such set was given to first- through fourth-graders (Tuddenham, 1971). The child had to choose from several photographs the one showing how a model of a farm would look from different vantage points ('Perspectives'), choose from several pictures of flat patterns those that could be folded to produce simple three-dimensional forms ('Geometric Forms'), and correctly place a small car painted a different color on each side at various places on a spiral track ('Tracks'). The fourth-graders also had to construct block buildings from plans and front elevations ('House-Plans'). Except for 'Tracks', the boys' mean score was higher than the girls' for every test.

Such tests are not universally deemed spatial visualization tests or at least are not used to assess spatial ability per se. The 'Perspectives' task, for example, more typically is used to determine when a child's perceptions come to be 'decentered', that is, when he can understand that his own spatial perspective is not necessarily shared by others. Clearly, the presence of sex differences on this task does not imply sex differences in 'decentration' in this sense, but only in the skill by which the decentration is measured.

"Logical conservation". Other Piagetian tests that have spatial elements are the various tests of 'conservation'. For instance, in the test of conservation of number, chips of one color are lined up parallel to an equal number of a different color. After the child confirms that there are an equal number of each, the chips of one set are bunched together, while the others are separated. The child then must compare the number of each color. In the test for conservation of distance, the child is shown two car tracks, one forming a straight line, the other segmented at right angles. The segmented track, while much longer (if straightened out), represents the same distance from one point to another when laid on a board. The child must move a toy car the same distance on the straight track as the experimenter moves a second car on the segmented track.

In most cases, where scores for boys and girls are separately reported on such tasks, the difference is nonsignificant (e.g., Brainerd, 1971; Gelman and Weinberg, 1972; Harris and Allen, 1971), but where sex differences are found, the male typically is ahead. There are two such reports for the six to nine year age range (Goldschmid, 1967; Hooper, 1969), and one for adults for the conservation of volume (Graves, 1972).

'Water level' test. A Piagetian task on which males more reliably excel is in the representation of horizontality. In the classical demonstration (Piaget and Inhelder, 1956), the child is shown a bottle partly filled with water, asked to notice the position of the water in the bottle, and then to predict where the water will be when the bottle is tipped. According to Piaget and Inhelder (1956), the principle that the water level will remain horizontal is mastered by about 12 years of age. This appears to be so, but for boys much more than for girls (Liben, Note 9; Thomas, Note 10; Thomas and Hummel, Note 11). Among adults, women also lag (e.g., Morris, 1971; Rebelsky, 1964); indeed, it now has been estimated that about 50 percent of college women do not know the principle (Thomas, Note 10; Thomas and Hummel, Note 11).

In all earlier studies, the subjects had to draw or otherwise construct the predicted waterline. But even when the subject need only pick that one of four drawings which correctly represents the water level of a tilted container (thus to pick the one drawing that shows the water as level with the table surface), males from first grade through college do better than females (Anderson, Note 12; Harris, et al., Note 13), though the difference is significant only by fourth grade.

If cognitive-developmental psychologists are puzzled by these findings, it is because they conceive of the principle that water seeks its own level, that horizontality is invariant, as strictly a milestone in logical, analytic thinking like the principles assessed in tests of abstract reasoning. On these other tasks, adults usually perform at their expected level of competence, and men are no better than women. Piaget and Inhelder (1956) themselves, however, are well aware of the spatial elements, as the following quotation shows:

> Now although it is doubtful whether failure to predict horizontality...is by itself proof of inability to conceive of a coordinate system--since it could be due to lack of interest, inattention, and so on--the repeated difficulty in appreciating the material facts themselves carries an entirely different implication. It undoubtedly indicates an inability to evaluate the perceptual data in terms of the orientation of lines and planes, and thereby suggests a failure on the part of coordination as such. What indeed is a system of coordinates but a series of comparisons between objects in different positions and orientations? (p. 390).

Consistent with this view is the finding that for high school seniors, performance on a test of horizontality is correlated significantly with performance on the Spatial Subtest of the Differential Aptitude Test (Liben, Note 14).

<u>Possible Neurological Basis for Sex Differences in Spatial Ability</u>

If there is a neurological basis for sex differences in spatial ability, of what might it consist? Several different models have been proposed and are reviewed elsewhere (Harris, 1975b). The neurological model I want to discuss here is the one that seems to me to hold the greatest promise. According to this model, some brains are further specialized than others for spatial analysis, and these 'further specialized' brains are more frequently male than female. More specifically, the difference in specialization is presumed to lie in a difference between males and females in the <u>extent</u> to which language and spatial-perceptual functions are lateralized to the left and right hemispheres, respectively, with the male brain being further lateralized than the female brain. The proposed result is that in females more than males, language functions are bilaterally represented, with negative outcome for spatial ability.

<u>Relation Between Cerebral Lateralization and Spatial Ability</u>

Before considering evidence for such a sex difference, two questions should be addressed: Why would bilateral language representation be expected to impede spatial ability? What does lateralization have to do with spatial ability in the first place? The phenemenon of lateralization now is so familiar that it is taken for granted, but, as I noted in my Introduction to this symposium (Harris, Note 1), consider that the other paired internal organs of the body--such as the lungs, kidneys, ovaries, testes--have identical functions, so far as is known, which means that we can survive quite well with but a single member of each of these pairs. The cerebral hemispheres are the exception. Why? And why, under normal circumstances, does lateralization proceed as it does in nearly all brains--to one hemisphere for language, to the other for visuo-spatial functions, rather than, say, to either side with equal probability? For that matter, why is there lateralization at all? Why do both hemispheres not subserve both linguistic and visuo-spatial functions equally, just as, say, both kidneys work equally to maintain proper water balance and excrete metabolic wastes? What we really are asking is, what is the nature of the difference between left- and right hemispheric processes, and how might the hemispheres be suited for their respective roles?

Nature of hemispheric specialization. One answer to these questions is suggested by the work of Semmes et al. (1960) with war veterans who had suffered penetrating injuries in either the left or right hemisphere. These patients showed deficits on tests of astereognosis (e.g., two-point threshold, pressure detection). The deficits expectedly were greater in the hand contralateral to the side of brain injury than in the ipsilateral hand. But unexpectedly, the relation between incidence and severity of loss of sensitivity and site of brain injury was asymmetrical. Loss of sensitivity of the right hand was clearly and reliably tied to regional damage within the sensorimotor region of the left hemisphere. But in the case of right-hemisphere lesions, sometimes there was loss of sensitivity in the left hand, sometimes not. The authors therefore suggested that the left and right hemispheres differ in degree of significant regional localization. The right hand's representation is finer, more 'focal', the left's, by contrast, more 'diffuse' or spread out.

Semmes (1968) suggests that this proposed difference in how the hemispheres represent elementary functions may be a clue to understanding hemispheric specialization of the more complex functions of language and spatial perception. Consider that the functional units of speech are highly similar to one another. That is, very similar kinds of muscular movements and coordinations of the speech apparatus--the lips, tongue, palate, and so forth--are required for speech production. The movements and coordinations required for vocal articulation are at the same time extremely fine and require a very precise degree of control. Speech production, therefore, may be helped by a focal representation of elementary functions that characterizes the left cerebral hemisphere. By contrast, diffuse organization for the right hemisphere would be advantageous for spatial abilities. Compared with speech functions that may depend on a high degree of convergence of like elements, spatial functions might depend instead on the convergence of unlike elements--visual, kinesthetic vestibular, and others--"combining in such a way as to create through experience a single supromodal space" (Semmes, 1968, p. 24).

This structural characterization is consistant with recent functional descriptions. For example, it has been suggested that there are two distinct modes of coding operations, each specific to a single hemisphere, the left hemisphere operating in a more logical, analytic, computer-like fashion, analyzing stimulus information input sequentially, abstracting out the relevant details to which it attaches verbal labels, the right hemisphere being primarily a synthesist, more concerned with the overall stimulus configuration, and organizing and processing information in terms of gestalts or wholes (Bogen, 1969; Levy-Agresti and Sperry, 1968; Zangwill, 1960).

Analytic-synthetic incompatibility: Basis for cerebral lateralization. There is a further implication in Semmes' (1968) characterization which Levy-Agresti and Sperry (1968) make explicit. They propose that the left hemisphere therefore would be "...inadequate for the more rapid complex syntheses achieved by the [right] hemisphere" (p. 1151) and on this supposition propose, as a possible basis for cerebral lateralization in man, a "...basic incompatibility of language functions on the one hand and synthetic perceptual functions on the other" (p. 1151). The consequence of an incompatibility between analytic and synthetic-gestalt perception, they go on to say, is that during the evolution of the hominids, gestalt perception may have lateralized into the mute hemisphere.

Lateralization thus may be said to serve the function of providing separate cerebral loci for the two major, different types of information-coding operations. Unlike the kidneys or lungs, each cerebral hemisphere must be 'programmed' predominantly for one kind of operation or the other. This design, Levy believes, does not provide for either maximum linguistic or maximum spatial function, but rather that "given that both abilities are present, it provides for a joint maximization" in the majority of people (Levy, Note 15). Neither kind of coding operation, of course, is likely to be sufficient for most complex intellectual problems, but 'cooperation' between the hemispheres is made possible through the medium of the corpus callosum which connects them.

Implication of incomplete lateralization. The most important implication of the model for our purposes is that some poeple may be more lateralized than others. The idea is that during pre- and post-natal development, genetic factors will predispose each neural blueprint--language for the left hemisphere, spatial for the right--to seek control of organization not only for its designated hemisphere but for the other as well. "If the verbal blueprint wins, then the language dominant hemisphere is fully and appropriately organized for verbal function, but the nondominant hemisphere also is partially organized for verbal functions, so that this hemisphere's organization is, to some extent, misappropriately designed for spatial functions. Such people will manifest perceptual-spatial defects...because the neural organization within this hemisphere is incompletely developed to serve spatial functions" (Levy, Note 15).

We should emphasize here that the implication of the model is not necessarily that some people are less lateralized than others in left-hemispheric functioning but that in some people more than others, language functions are represented in the right hemisphere in addition to their primary representation in the left hemisphere.

Evidence for Model

Analytic-synthetic incompatibility. Are left- and right-hemisphere coding operations 'incompatible'? Clinical studies that relate lesion location to the performance of spatial problems suggest that they are. After removal of the left-temporal lobe, memory for verbal materials is significantly impaired, while effects are negligible on nonverbal spatial tasks for which the right hemisphere is specialized, such as maze-learning (Milner, 1965; Corkin, 1965) or memory for faces (Milner, 1968) and nonsense figures (Kimura, 1963). But on the same spatial tasks, patients with right-temporal lobectomies are significantly deficient though their verbal ability is unimpaired. Their intact verbal skills thus seem to be inadequate for spatial analysis.

Bilateral language representation and spatial ability. The next question is, are nonverbal skills impaired in persons for whom verbal and nonverbal functions are known to be subserved by the same hemisphere? There are two subjects of choice: one is someone who sustained early left brain damage (before acquisition of speech) and in whom language functions subsequently are known to be lateralized to the right (intact) cerebral hemisphere, so that both verbal and spatial functions would be subserved by the same hemisphere. Milner (1969) has reported impaired nonverbal skill in such patients (lower Performance than Verbal IQ scores on the Wechsler Adult Intelligence Scale).

Another subject of choice, and the one to whom Levy specifically applies her model, is the left-hander. Since left-handers are less well-lateralized than right-handers (e.g., Goodglass and Quadfasel, 1954), language in left-handers would tend to be represented bilaterally, presumably reducing overall right-hemisphere efficiency for spatial analysis. The model therefore predicts worse spatial skill in left-handers than in right-handers or, alternatively, a greater discrepancy between language and nonlanguage skills in left-handers than in right-handers.

As a first test, Levy (1969) compared 10 left-handed and 15 right-handed young men on the Verbal and Performance scales of the WAIS. The predictions were supported: the handedness groups differed significantly on Performance IQ (left, 117; right, 130) but not on Verbal IQ (left, 142; right, 138). The results are more striking when expressed as discrepancy scores: for right-handers, the average difference between the Verbal and Performance scores was 8 IQ points; for left-handers, 25 points.

Poorer performance by left-handers than right-handers has been reported for other nonverbal tasks in four other studies (James et al., 1967; Miller, 1971; Nebes, 1971; Silverman et al., 1966), though in still other investigations no differences were found (Newcombe and Ratcliff, 1975; Gibson, in press; Annett, Note 16). On balance, though, Levy's hypothesis as applied to left-handers can be said to have found a reasonable degree of support.

Sex Differences in Lateralization

Now the question is whether the model explains sex differences in spatial ability. Are females less lateralized, on average, than males? Do women number more than men among the group for whom the 'verbal blueprint' wins?

Anatomical differences. Let us begin with anatomical data. Our interest here is with the right hemisphere. It is known that the occipital horns of the lateral ventricles are asymmetrical (Penfield, 1925), with the right occipital horn usually smaller or shorter than the left (McRae, 1948).

If the occipital horn is smaller, the corresponding part of the cortex will be larger. This asymmetry has been associated with handedness. McRae et al. (1968) scored pneumoencephalograms and ventriculograms for occipital horn length for 100 hospitalized neurological and neurosurgical patients. Of the 100 patients, 87 were right-handed of whom 52 showed a shorter right occipital horn, 9 a shorter left horn, and 26 showed horns of equal length. A shorter right occipital horn (i.e., larger right occipital cortex) thus correlated moderately well with right-handedness. Thus the right hemisphere, in right-handed persons, appears to be slightly larger than the left hemisphere in the posterior regions, the regions most critically involved in visual-spatial functions.

If males are better lateralized than females such that their right hemispheres are more nearly completely specialized for spatial processing, this asymmetry in the occipital region ought to be more marked in males than females. Though McRae et al. did not report separate analyses for men and women, there is an indirect indication of such a sex difference. It has long been known that a portion of the temporal lobe known as the "planum temporale" (temporal plain) is larger on the left than the right side (Kakeshita, 1915; Pfeiffer, 1936; VonEconomo and Horn, 1930). A recent demonstration by Geschwind and Levitsky (1970) disclosed mean differences in length on the order of 9 mm., or 33%. This order of magnitude of difference has been confirmed (Witelson and Pallie, 1973; Wada et al., 1975), and a comparable asymmetry now is known to exist as well in the speech area of the frontal lobe (Wada et al., 1975).

The asymmetries are innate. In addition to adult brains, Witelson and Pallie (1973) found the same asymmetries in the brains of eleven 1- to 21-day-old infants and three 1- to 3-month-old infants. Comparable differences have been reported in fetal brains as well, in both frontal and temporal areas, as early as the fifth post-conceptional month (Wada et al., 1975).

In adult brains, these structural asymmetries appear to be unequal in degree and consistency for males and females. Wada et al. (1975) found that while a majority of the 100 adult brains in their sample showed a larger left planum, in a certain number of cases the asymmetry was reversed so that the right planum was the larger. Of these brains, there were significantly more female than male. If the parietal and occipital regions are larger in the right hemisphere, this would imply correspondingly reduced size of frontal and temporal areas. That is, there should be a correlation between right occipital horn size and right planum size. (A relation between horn size and planum size has been found for the left hemisphere: preliminary studies by Sheremata and Geschwind (Note 17) suggesting a high correlation between a longer left occipital horn and a larger left planum.) Thus the enlarged parietal-occipital areas simultaneously bestow a right-hemisphere advantage for visual-spatial functions and a disadvantage for language functions. If, however, a portion of the right temporal cortex is enlarged more frequently among females than males, as Wada et al.'s (1975) data suggest, this would imply reduced size of those posterior regions relative to males, thereby lessening the right hemisphere's effectiveness as a spatial processor.

Clinical data. The anatomical data should be regarded very conservatively--the absolute number of female brains with reverse planum asymmetry in Wada et al.'s study, though larger than the number of male brains, still was but a small fraction of the total, and the suggested link with right posterior hemispheric asymmetry has no independent confirmation, though Scheremata and Geschwind's findings for the left hemisphere make such a link a reasonable possibility. Nevertheless, the implied sex difference in lateralization is supported by certain clinical findings. Wada (1972) proposes that the language area in the right hemisphere suggested in his anatomical study is a 'reserve' area which figures in determining whether the speech center will shift if the left hemisphere is injured during early childhood (while the person is learning to speak). If this 'reserve' language area is small, speech functions may shift partially or not at all. But if this area is large, language functions will shift to the right, undamaged side, and speech will be relatively unaffected. This proposition is a familiar one in neuropsychology but with respect to left-handers rather than to females (e.g., Hécaen and Ajuriaguerra, 1964).

One immediate clinical implication of Wada's proposal, therefore, is that speech disturbance after left-hemisphere injury will be less severe and more short-lived in females than in males, as has been found for left-handers. Though detailed, extensive surveys are lacking, it does appear that the number of reported cases of profound aphasia in females is small, with most cases unusual in some way (e.g., Chesher, 1936; Goodglass and Quadfasel, 1954; Ettlinger, Jackson, and Zangwill, 1956; Botez and Crighel, 1971). These reports, furthermore, are buttressed by several recent accounts of different patterns of deficit in males and females after brain injury.

Lansdell (1961) reported sex differences in the effects of temporal-lobe operations on an explanation-of-proverbs test. After an operation on the language-dominant side, women's proverb scores were unaffected, while men's scores dropped.

Lansdell (1962) later tested patients on the Graves design judgment test before and after undergoing unilateral temporal-lobe surgery for the relief of temporal-lobe epilepsy. The Graves test is designed to measure "certain components of aptitude for the appreciation or production of art structure" (Graves, 1948). The subject chooses the design he prefers from two or three designs. Choices presumed to reflect 'inartistic' preference are generally symmetrical, 'artistic' choices less symmetrical. Of patients operated in the 'language' hemisphere, the men's scores for artistic preference rose post-operatively, women's scores dropped. Contrarily, of patients operated in the 'spatial' hemisphere, the men's scores dropped, while the women's rose.

In a still later study of patients with either left- or right-temporal lobectomies, Lansdell (1968) reported that males with operations on the right side had the lowest Wechsler 'nonverbal' scores of all patient groups. There also was a significant correlation between extent of tissue removal on the right side and the 'nonverbal' score for males but not for females.

Similar findings have been reported in commissurotomized patients (severing of the corpus callosum). Post-operatively, male patients showed impairment on a perceptual test (Street-Gestalt) relative to a verbal test ("Similarities") to a greater degree than female patients did (Bogen, 1969).

Finally, McGlone and Kertesz (1973) found that for patients with left-hemisphere lesions, scores on a perceptual test (block design) and language test were significantly correlated for women (r = .63) but not for men.

The authors of all these reports came to similar conclusions. Lansdell (1962) writes that "some physiological mechanism underlying artistic judgment and verbal ability may overlap in the female brain but are in opposite hemispheres in the male" (p. 854). Bogen infers that right-hemisphere-type thinking ("appositional" thinking) is less lateralized in females than in males. McGlone and Kertesz conclude that spatial ability may be more unilaterally represented in the right hemispheres in males than in females.

Research with Normal Subjects

One problem with clinical evidence is that months or even years can go by before examination, in which time not only specific functional systems but their interaction may be affected. Fortunately, data on normal individuals are available and appear to support the clinical evidence.

Dichotic listening. One source of support is from dichotic listening studies. Bryden (1966) found right-ear superiority for spoken digits for 67 percent of left-handed males and 74 percent of right-handed males compared to only 50 percent and 57 percent for left-handed and right-handed females, respectively, among a large sample from the general population. Bryden also tabulated scores for males and females separately from a number of his earlier published and unpublished studies. Among 98 subjects tested on a free recall dichotic task with digit pairs, 73.6 percent of males (11 left- and 42 right-handers) showed right-ear superiority, compared to only 62.2 percent of females (3 left- and 42 right-handers). Lake and Bryden (Note 18) corroborated this sex difference in a sample of 144 undergraduate subjects tested with pairs of consonant-vowel (CV) syllables. Finally, Remington et al. (Note 19) report, in two dichotic studies with pairs of CV syllables, that only males showed a significant right-ear superiority.

Electrophysiological activity. Some electrophysiological data also suggest sex differences in lateralization. A comparison of left and right hemisphere EEG activity scores during verbal vs. musical tasks for males (Herron, Note 20) with scores for females during a speech task (Johnson, Note 21) disclosed a higher incidence of lateralization among the males (Johnson and Herron, Note 22). Another study (Brown, Marsh, and Smith, Note 23) indicates greater male lateralization of differences in the processing of nouns vs. verbs. The comparison was of average evoked potential within each hemisphere across two stimulus conditions: the word "fire" in "ready, aim, fire", and the same word "fire" in the sentence "sit by the fire." The difference in shape of the AER was greater in the left hemisphere than the right, but this asymmetry was far more pronounced in the male than female subjects.

<u>Visual field effects</u>. Evidence of stronger language lateralization in males appears also in tachistoscopic measures. Males reportedly show stronger right-field superiority for verbal stimuli (Ehrlichman, Note 24). The same conclusion is implied, indirectly, when <u>spatial</u> stimuli are tachistoscopically projected: males show greater, more consistent left-field effects (Kimura, 1969; 1973; McGlone and Davidson, 1973).

On balance, the model of greater lateralization in males seems to have a broad degree of support. According to Levy's model, individuals, in her example, left-handers, whose right hemispheres subserve both linguistic and perceptual modes would be expected to have less efficient (right hemisphere) perceptual processing abilities than would individuals whose right hemispheres are more nearly exclusively taken up with perceptual processing. As we have seen, the evidence indicates that less lateralization also may be more characteristic of females than males, and females are poorer in a variety of cognitive tasks known to be subserved by the right hemisphere.

<u>An Alternative View: Sex Differences in 'Preferred Mode' of Cognitive Analysis</u>

An alternative or supplement to a 'lateralization difference' model is possible. Recall Coltheart et al.'s (1975) finding that males were more accurate than females in counting from memory the number of upper-case letters of the alphabet containing a curve in their printed form. The same subjects also were asked to proceed mentally through the alphabet from A to Z, counting the number of letters containing the sound "ee", including E, and without the aid of speaking aloud or writing. On this task the <u>women</u> did better than the men. Just as no information about the sounds constituting the name of a letter could help in deciding whether its printed form contains a curve, so in this task no information about a letter's shape could help decide whether its name contains the "ee" sound. The authors concluded that as much as the 'shape' task was purely visual, the 'sound' task was purely verbal. Thus just as the men excelled on a visual coding task, the women excelled on a verbal, or phonological, coding task.

The sex differences, furthermore, were not confined to tasks requiring imagery. The authors next had their subjects scan through a passage of prose with instructions to cross out all occurrences of the letter "e". It previously had been found that unpronounced "e's" (as in the word "late") were more frequently missed than pronounced "e's" (as in the word "let") (Corcoran, 1966). Coltheart et al. (1975) therefore expected women to have more difficulty than men in detecting the 'silent' letters, since a verbal analysis is incapable of detecting such letters. This was just what was found.

Women thus seem to be better than men not only in a phonological coding task involving auditory imagery, but to be more disposed than men to code visual information phonologically, or left hemispherically, during reading. This difference suggests an alternative to the 'lateralization difference' model.

Consider McGlone and Kertesz's interpretation of their correlational data. Recall that they found a fairly high correlation between block design scores and language scores for female patients with left hemisphere lesions, but no such relation for females with right-sided lesions, or for males with lesions on either side, results they viewed as indicating "distinct sex differences in the cerebral lateralization of spatial functions..." But the same results could reflect sex differences in 'preferred mode' of analysis of spatial problems, with females relying more on left hemisphere modes, males on right hemisphere modes, without there necessarily being any sex difference in amount of lateralization per se.

Lansdell's (1962) findings similarly are subject to a different interpretation. Recall that from evidence of greater dependence of performance on a 'aesthetic preference' task on the nonlanguage hemisphere in males, and on the language hemisphere in females, he concluded that females are less completely lateralized than males for language skill. But the findings could mean instead that females rely, in making aesthetic judgments, more on their left hemisphere, and males more on the right. In other words, in aesthetic judgments (as in spatial-problem solving) females rely more on language. Consequently, one would expect to find the relations Lansdell obtained: in females, greater dependence of aesthetic judgment on the integrity of the left hemisphere; in males, greater dependence on the integrity of the right hemisphere. From such relations, we need not infer different degrees of lateralization of functions in males and females.

Developmental Differences in Language Development

Why should females rely more on the less-efficient language modes in attempting to solve spatial problems? Such a disposition might well be set in action early in their development in consequence of their faster rate of language growth lending females greater early expressive linguistic skill compared to males. There is space to consider only a few examples (see Harris, in press, b, for review).

Phonemes and words. For instance, girls vocalize the full variety of English phonemes slightly sooner than boys (Irwin and Chen, 1946; Harms and Spiker, 1959); speak their first words sooner (Abt et al., 1929; Mead, 1913; Morley, 1957; Terman, 1925); and develop vocabularies earlier, at least through the early years (Nelson, 1973).

Articulation. There also may be differences in articulation--in the fine, precise, coordinated movements of the speech apparatus. In spontaneous speech, boys' and girls' articulation skills seem to develop at the same rate--until about three to five years when girls start to improve faster than boys (Matheny, Note 25; Poole, 1934; Templin, 1953, 1957). Beyond eight years, reports disagree as to whether the girl's lead is maintained (e.g., Saylor, 1949; Templin, 1957).

Comprehensibility. Perhaps because of superior articulation, girls' speech also may be easier to understand: among 18- and 24-month-olds, McCarthy (1930) reported substantially higher percentages of comprehensible vocalizations for girls than boys; by 36 months, 99% of girls' speech was comprehensible, a level reached by boys only a year later. Slight differences favoring girls also have been reported for two-and-a-half to five-and-a-half-year-olds (Young, 1941) and eight- to 10-year-olds (Eisenberg et al., 1968).

Fluency. Girls also excel on tests of word fluency, for instance, writing, as rapidly as possible, words containing a specified letter, or the names of things belonging to a given class. On such tasks, significant sex differences have been reported for children between eight and 18 years of age (Havighurst and Breese, 1947; Herzberg and Lepkin, 1954).

Reading. Among grade school children, girls also generally are better readers than boys (Gates, 1961; Prescott, 1955; Stanford Research Associates, Note 26).

Most of the childhood sex differences probably are reflections of the faster rate of maturation in girls than boys, so that many are no longer evident by early adulthood. This is not the case for all differences by any means, such as the differences in 'phonological coding' (Coltheart et al., 1975), so that one expects that more is involved than maturational differences. The point, though, is that females, because of their earlier linguistic development, thereby could set off onto a course of intellectual development in which language plays a larger role than is true for boys. This possibility is supported in recent studies of the relation between intellectual development in infancy and later life.

Role of Language in Intellectual Development

Two reports stand as illustrations. One is a reanalysis, by Cameron, Livson, and Bayley (1967), of data from intelligence tests that had been administered to 35 male and 39 female subjects when they were between five and 13 months of age and again during the ages six to 26 years. By calculating the correlations among all the various items on the infant scales, Cameron et al. identified six different clusters of items which correlated significantly with one another but not with other items. One cluster was concerned with vocalization and included the following measures typical of the age range from about five to 13 months: vocalizes eagerness, vocalizes displeasure, makes vocal interjections, says "da-da" or equivalent, says two words, and uses expressive jargon. Here emerged a sex difference in the relation between intelligence in infancy and later life. While school-age intelligence cannot be predicted from total test scores until much later than 13 months, scores from this cluster during infancy were related to intelligence at ages six through 26 years, but for girls, not for boys. Specifically, females who had high Stanford-Binet IQs during the period from six to 26 years but especially between adolescent and adulthood were found to have had high vocalization scores in infancy. Females with low IQs during the period had low vocalization scores in infancy. For boys, IQ in later childhood and early adulthood was unrelated to vocalization scores in infancy.

This finding has been confirmed in a study of 76 English children by Moore (1967). Each child was assigned a 'speech quotient' as a measure of spontaneous babbling at six months, and use of words at 18 months. The children were tested for general intelligence at three, five, and eight years of age. As Cameron et al. had found, the language scores during infancy were highly predictive of later measures of general intelligence in girls but not in boys. Moore concludes that intellectual development in girls takes place primarily through linguistic channels, whereas in boys, nonverbal skills play a relatively more prominent role.

If Moore is right, we can begin to understand why, for instance, girls, but not boys, show positive correlations between their level of artistic interest and their competence on verbal reasoning tests (Bennett, Seashore, and Wesman, 1959), and why the Verbal and Performance scores on the WISC are more highly correlated for kindergarten girls than boys (Fagin-Dubin, 1974). And perhaps we can understand what surprised Porteus when, in his first normative maze study (1918), he compared the children's maze-test performance with their scores on the new and, in Porteus' view, too heavily verbal Binet test: the girls' scores showed closer agreement between the two estimates of intelligence: on the maze test, 79 percent of the girls tested within one year of their Binet mental age, compared with 67 percent of the boys.

While the girl's early lead in language skills may dispose her along one intellectual course, the boy's lag, though eventually overcome, may dispose him along a different path inasmuch as it would create an enforced longer period of time during which his primary way of encoding information from his environment would be nonlinguistic. Hutt (1972, p. 102) puts it this way:

> ...when boys are still concerned with active exploration of their environment and with perceptual and motor skills, the girls are becoming increasingly adroit in their verbal and social functions.

If we further suppose that boys are more interested in and skillful in mechanical and spatial relationships, the circumstances are created for sex differences, even among adults, in the degree of linguistic involvement in life activities. It is conceivable, then, that in addition to sex differences in hemispheric lateralization, the different developmental histories of males and females may predispose them to the use of different modes of analysis of spatial problems, with females relying more on the less efficient left-hemisphere modes, males on right-hemisphere modes.

There is no reason, of course, why, depending on the type of problem and level of individual skill, both a 'preferred mode of cognitive analysis' and a 'lateralization' explanation cannot be correct. If females are neurologically disposed to be better in linguistic than visuo-spatial skills, it is reasonable that they should come to play to their strength and so depend on linguistic modes more than males do and in more situations. Definitive separation and independent assessment of the 'lateralization' and 'preferential processing' accounts may be impossible, for the tendency to exploit those skills to which one is genetically predisposed must begin at the very outset. The problem, for females is that such dependency could work to their disadvantage for certain kinds of problems for which left-hemisphere modes are less efficient.

Evolutionary Selection for Male Spatial Superiority

Having come this far in our analysis, we still have not addressed two questions. First, inasmuch as spatial ability is expressed more frequently in males, and assuming that this expression is at least partly under genetic control, what evolutionary processes might have been responsible? What is the species advantage of this behavioral sexual dimorphism? The answer is sheerest speculation, with most speculators offering variations on the theme of Man as hunter and territory-marker, and Woman as bearer and nurse of children. Thus Masica et al. (1969) suggest that sex differences in spatial ability are remnants of "specialized evolutionary adaptations, reflecting the sharper visual-perceptual skills employed by the male in territoriality and mating." Lee and DeVore (1968) emphasize the importance of the adoption of a hunting-gathering way of life which, because of the female's different biological role, would have necessitated some division of labor. The female's food gathering therefore would be closer to the vicinity of the camp, the male's farther-ranging. That these differences continue to appear even among contemporary hunter-gatherers such as the Ainu (Watanabe, 1968) is seen as supporting this line of reasoning. Since males appear to range farther than females even in societies which gather their food at the local supermarket (cf. Harper and Sanders, 1975), the ancestral lights presumably are still flickering.

Another essential of evolution is thought to have been walking erect, thus freeing the hands for increased manipulation and use of tools and weapons. Leakey (1961) has speculated how prehistoric man (i.e., males) probably used bone to split flakes from pieces of flint to make stone tools and weapons. It may be that spatial visualization and an ability to anticipate the results of a given blow would have high survival value in such practices, and therefore would be selected for in the practitioners.

Possible Effects of Sex Steroid Hormones on Brain Specialization and Nervous System Activity

The second question is, how, in any individual male or female, does it happen? What actually sets off one brain and nervous system more than another to be a better subserver of spatial ability? A critical role apparently is played by the sex steroid hormones. For instance, Turner's syndrome individuals suffer from a specific cognitive deficit that Money (1968) has described as a combination of space-form or visual-constructional dysgnosia, directional sense dysgnosia, and mild dyscalculia. About 80 percent of Turner's syndrome individuals are sex-chromomatic-negative females (the sex-chromatin is missing from the cells when test-stained), so that the karyotype is XO (44 + XO) instead of the usual XX. The specific pathognomic symptoms are an absence of ovaries (gonadal agenesis or dysgenesis). The affected person is sterile and remains sexually infantile in appearance until treated with female sex hormones, which also produce menstruation. Since it is known that normal females produce and respond to detectable levels of testosterone (Rosenfield, 1971), it may be that proficiency in spatial tasks is linked to the production of testosterone, and that the capacity of the normal female to express the spatial trait depends on the production of ovarian testosterone above some threshold level.

This hypothesis is made plausible in light of known intellectual deficits in other individuals who, like Turner's syndrome victims, are insensitive to androgen. One such individual is the male with testicular feminizing syndrome.

The defect in testicular feminization is known to be a specific end-organ insensitivity to testosterone, and the victim shows a deficit in spatial skill similar to that shown by the Turner's syndrome individual (Money et al., 1968; Masica et al., 1969; Masica et al., 1971). Presumably, then, the male and female sex hormones, respectively, set into operation the 'spatial' and 'verbal' blueprints for organization of the cerebral hemispheres. Presumably, too, these different patterns of cerebral organization originate in embryonic or fetal neuro-hormonal events. If so, it is understandable that hormonal substitutes given Turner's syndrome individuals later in life fail to alleviate their deficits in direction sense (Money, 1968). The Turner's syndrome victim's space-form dysgnosia thus might be traceable to the effects of early hormonal insufficiencies on right cerebral hemispheric functioning and organization.

Little is known as to how the sex hormones actually influence nervous system activity. An account by Broverman et al. (1968) has gained some attention. These investigators conceptualize cognitive functioning to be the result of an interplay between two competing systems: the adronergic nervous system, which has a mobilizing function that prepares it for activation and thereby facilitates performance of simple perceptual-motor tasks, and the cholinergic system which, in contrast, functions to promote protection, conservation, and relaxation or inhibition of activity, and thereby contributes to the cognitive ability to delay initial responses to obvious stimulus attributes in favor of responses to less obvious stimulus relationships. These latter are the requirements, Broverman et al. argue, commonly found in such spatial tasks as mazes, embedded figures, and rod-and-frame.

Males therefore excel on spatial tasks presumably because males' androgen steroids produce a balance of biochemical factors favoring the cholinergic type of neural functioning. Females tend to be adronergic, and excel on tasks that Broverman et al. characterize as requiring "rapid, skillful, repetition, articulation, or coordination of 'lightweight', over-learned responses..." (p. 25), for example, speed of color naming (Staples, 1932; Stroop, 1935); the Digit Symbol Subtest of the WISC and WAIS and other tests requiring rapid perception of details and frequent shifts of attention (Gainer, 1962; Miele, 1958; Norman, 1953; Paterson and Andrew, 1946); fine manual dexterity (Gesell et al., 1940; Tiffin and Asher, 1948). Inasmuch as speech involves the motoric coordination of the vocal apparatus--tongue, larynx, diaphragm, and other organs--it is consistent with this view that females suffer less than males in disorders of speech and articulation (Schnell, 1946; 1947; Bentzen, 1966; Yedinack, 1949).

The theory has been attacked (Singer and Montgomery, 1969) and vigorously defended (Broverman et al., 1969). Unfortunately, most of the direct supporting evidence is from animals. The evidence for human beings suggests a relationship between sex steroid level and spatial skill, but one that is highly complex and different for males and females. Broverman et al. (1964; Broverman and Klaiber, 1969) determined the relation between androgenicity and performance on spatial tasks (actually, a measure of the contrast between tests loading on a spatial factor and tests loading on a 'fluent' production factor, i.e., rapid repetition of over-learned skills) in adolescent boys and young men, where androgenicity was indexed by appearance of body and genital hair and other somatic features. The relation was inverse: the more androgenized (in the adolescent group, earlier maturing) males were relatively worse on spatial tests, the less androgenized males, relatively better. Peterson confirmed this relation for males (Note 27) but found the opposite relation in females, namely, the contrast was related directly to androgenicity. On this basis, Peterson proposes that the relation between the cognitive contrast and the androgen/estrogen ratio is curvilinear such that at intermediate levels the androgen/estrogen ratio is most favorable to high spatial ability and least favorable to 'fluent' production. That is, the less androgenized male is a better visualizer and is less fluent than the more androgenized male, while the more androgenized female is a better visualizer and is less fluent than the well estrogenized female. The good visualizer of either sex therefore is less sexually differentiated than the fluent producer (Bock, 1973, p. 451). That spatial ability requires some minimum level of androgen, as can be adduced from the spatial deficits characteristic of Turner's syndrome in females and testicular feminization syndrome in males, is consistent with the proposed curvilinear relation between androgenicity and spatial ability.

Spatial Ability and 'Cognitive Style'

I want to end this discussion with a caution: certain tasks--the rod-and-frame and embedded figures tests in particular--are usually called tests of 'field-independence' and 'field-dependence', and sex differences on these tasks are cited as evidence that females are more 'field-dependent', 'global-thinking', or 'cognitively undifferentiated', while males are more 'field-independent', 'analytical', or 'cognitively differentiated' in general cognitive or mentative style. Such interpretations are groundless. Since the most popularly-used tests of 'field-dependence'--the rod-and-frame and embedded figures tests--are visual-spatial tasks, the male's superior performance is understandable and should be narrowly interpreted, not generalized into an all-encompassing statement about cognitive 'style'. Other measures of field dependence lacking a spatial component (e.g., rotator-match brightness constancy, paper-square-match brightness constancy) have not yielded sex differences (Witkin et al., 1954). As Sherman (1967) has said, sex differences on such tests might be explainable "without any reference to field, without any need to infer a passive approach to the field, globality, or lack of analytical skill. The fallacy involved is similar to concluding that women are more analytical than men based on findings of superior female ability to decontexualize the red and green figures on the Isihara Color Blindness Test" (p. 292).

Sherman's point is underscored when the assumption that males are analytic, females global (or synthetic) in general cognitive style, is carried to its logical conclusion: as we have seen, the kinds of abilities or skills subserved by the right cerebral hemisphere have been characterized as 'diffuse', 'synthetic', or 'appositional'; if females are global in general cognitive style, they should be better, not worse, than males in spatial tasks. In other words, to explain females' poorer performance on embedded figures, rod-and-frame, and a host of other spatial tasks as a reflection of females' less analytic cognitive style is contrary to accepted characterizations of the nature of spatial tasks and spatial ability and the nature of hemispheric specialization. The relation between sex differences in spatial ability and 'thinking style' or 'cognitive style' therefore remains to be determined.

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