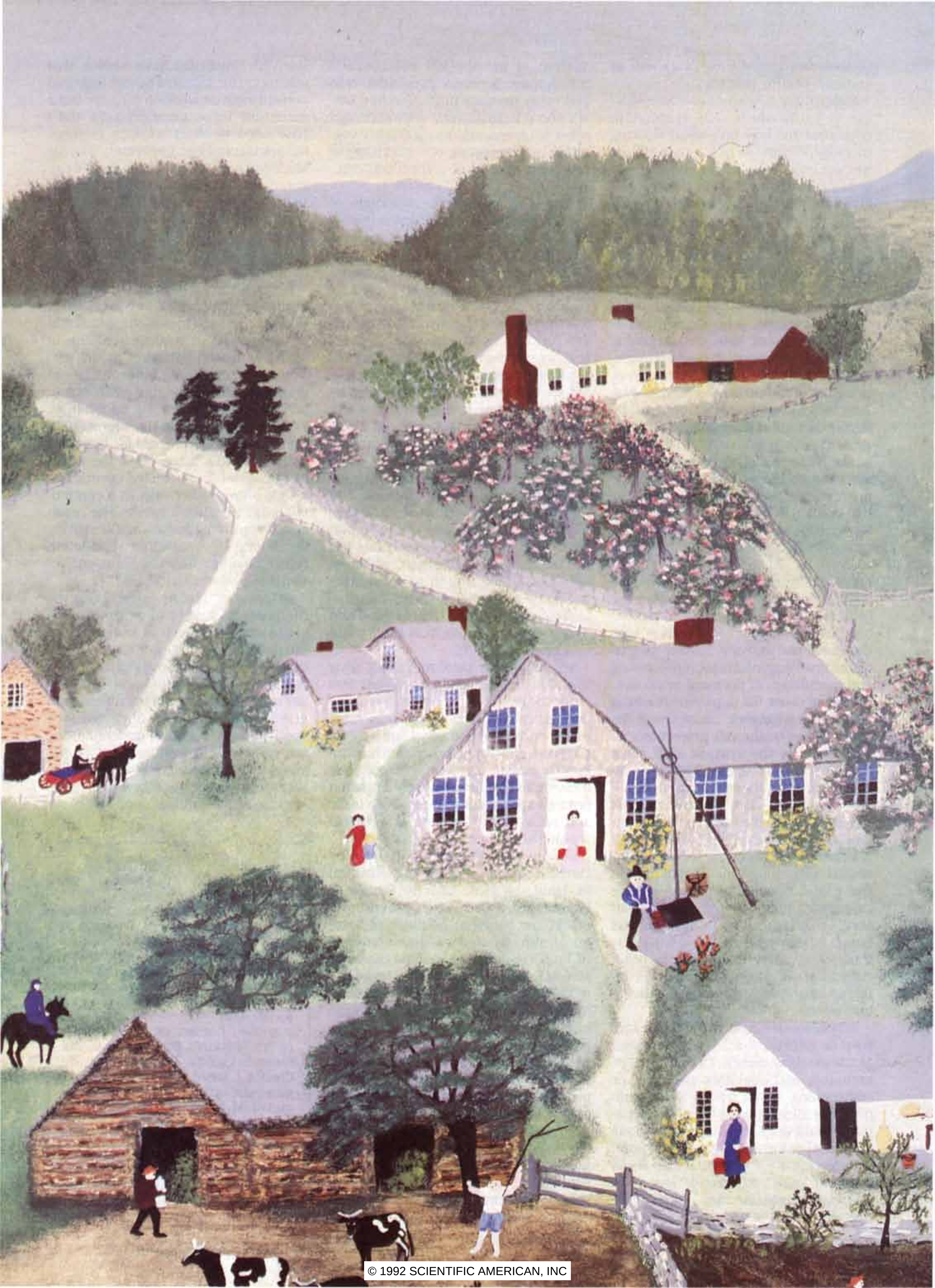
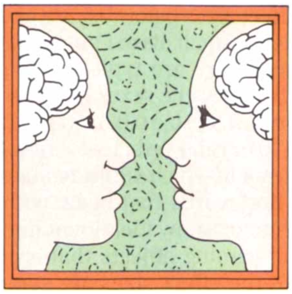


Sex Differences in the Brain

Cognitive variations between the sexes reflect differing hormonal influences on brain development. Understanding these differences and their causes can yield insights into brain organization

by Doreen Kimura

Women and men differ not only in physical attributes and reproductive function but also in the way in which they solve intellectual problems. It has been fashionable to insist that these differences are minimal, the consequence of variations in experience during development. The bulk of the evidence suggests, however, that the effects of sex hormones on brain organization occur so early in life that from the start the environment is acting on differently wired brains in girls and boys. Such differences make it almost impossible to evaluate the effects of experience independent of physiological predisposition.



Behavioral, neurological and endocrinologic studies have elucidated the processes giving rise to sex differences in the brain. As a result, aspects of the physiological basis for these variations have in recent years become clearer. In addition, studies of the effects of hormones on brain function throughout life suggest that the evolutionary pressures directing differences nevertheless allow for a degree of flexibility in cognitive ability between the sexes.

Major sex differences in intellectual function seem to lie in patterns of ability rather than in overall level of intelligence (IQ). We are all aware that people have different intellectual strengths. Some are especially good with words, others at using objects—for instance, at constructing or fixing things. In the same fashion, two individuals may have the same overall intelligence but have varying patterns of ability.

Men, on average, perform better than women on certain spatial tasks. In particular, men have an advantage in tests that require the subject to imagine rotating an object or manipulating it in some other way. They outperform women in mathematical reasoning tests and in navigating their way through a route. Further, men are more accurate in tests of target-directed motor skills—that is, in guiding or intercepting projectiles.

Women tend to be better than men at rapidly identifying matching items, a skill called perceptual speed. They have greater verbal fluency, including the ability to find words that begin with a specific letter or fulfill some other constraint. Women also outperform men in arithmetic calculation and in recalling landmarks from a route. Moreover, women are faster at certain precision manual tasks, such as placing pegs in designated holes on a board.

Although some investigators have reported that sex differences in problem solving do not appear until after puberty, Diane Lunn, working in my laboratory at the University of Western Ontario, and I have found three-year-old boys to be better at targeting than girls of the same age. Moreover, Neil V. Watson, when in my laboratory, showed that the extent of experience playing sports does not account for the sex difference in targeting found in young adults. Kimberly A. Kerns, working with Sheri A. Berenbaum of the University of Chicago, has found that sex differences in spatial rotation performance are present before puberty.

Differences in route learning have been systematically studied in adults in laboratory situations. For instance, Liisa Galea in my department studied undergraduates who followed a route on a tabletop map. Men learned the route in fewer trials and made fewer errors than did women. But once learning was complete, women remembered more of the landmarks than did men. These results, and those of other researchers, raise the possibility that women tend to use landmarks as a strategy to orient themselves in everyday life. The prevailing strategies used by males have not yet been clearly established, although they must relate to spatial ability.

Marion Eals and Irwin Silverman of York University studied another function that may be related to landmark memory. The researchers tested the ability of individuals to recall objects and their locations within a confined space—such as in a room or on a tabletop. Women were better able to remember whether an item had been displaced or not. In addition, in my laboratory, we measured the accuracy of object location: subjects were shown an array of objects and were later asked to replace them in their exact positions. Women did so more accurately than did men.

ROUTES in a landscape such as the one in this painting, *The Old Oaken Bucket*, by Grandma Moses (1860–1961), may be learned differently by women and men. In laboratory experiments, researchers have found that women tend to remember landmarks—such as the well at the lower right or a tree at an intersection. Men appear to learn routes faster, but they cannot recall landmarks as readily: they may rely preferentially on spatial cues such as distance and direction.

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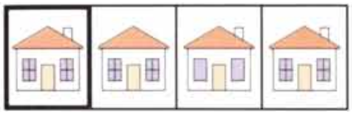
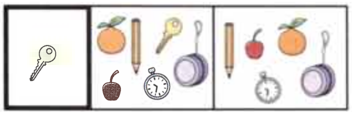
Problem-Solving Tasks Favoring Women

Women tend to perform better than men on tests of perceptual speed, in which subjects must rapidly identify matching items–for example, pairing the house on the far left with its twin:



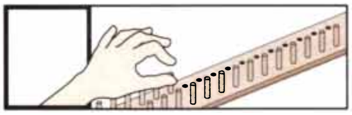
In addition, women remember whether an object, or a series of objects, has been displaced:



On some tests of ideational fluency, for example, those in which subjects must list objects that are the same color, and on tests of verbal fluency, in which participants must list words that begin with the same letter, women also outperform men:

L _ _ _	Limp, Livery, Love, Laser, Liquid, Low, Like, Lag, Live Lug, Light, Lift, Liver, Lime, Leg, Load, Lap, Lucid ...

Women do better on precision manual tasks–that is, those involving fine-motor coordination–such as placing the pegs in holes on a board:



And women do better than men on mathematical calculation tests:

77	$14 \times 3 - 17 + 52$
43	$2(15 + 3) + 12 - \frac{15}{3}$

It is important to place the differences described above in context: some are slight, some are quite large. Because men and women overlap enormously on many cognitive tests that show average sex differences, researchers use variations within each group as a tool to gauge the differences between groups. Imagine, for instance, that on one test the average score is 105 for women and 100 for men. If the scores for women ranged from 100 to 110 and for men from 95 to 105, the difference would be more impressive than if the women's scores ranged from 50 to 150 and the men's from 45 to 145. In the latter case, the overlap in scores would be much greater.

One measure of the variation of scores within a group is the standard deviation. To compare the magnitude of a sex difference across several distinct tasks, the difference between groups is divided by the standard deviation. The resulting number is called the effect size. Effect sizes below 0.5 are generally considered small. Based on my data, for instance, there are typically no differences between the sexes on tests of vocabulary (effect size 0.02), nonverbal reasoning (0.03) and verbal reasoning (0.17).

On tests in which subjects match pictures, find words that begin with similar letters or show ideational fluency—such as naming objects that are white or red—the effect sizes are somewhat larger: 0.25, 0.22 and 0.38, respectively. As discussed above, women tend to outperform men on these tasks. Researchers have reported the largest effect sizes for certain tests measuring spatial rotation (effect size 0.7) and targeting accuracy (0.75). The large effect size in these tests means there are many more men at the high end of the score distribution.

Since, with the exception of the sex chromosomes, men and women share genetic material, how do such differences come about? Differing patterns of ability between men and women most probably reflect different hormonal influences on their developing brains. Early in life the action of estrogens and androgens (male hormones chief of which is testosterone) establishes sexual differentiation. In mammals, including humans, the organism has the potential to be male or female. If a Y chromosome is present, testes or male gonads form. This development is the critical first step toward becoming a male. If the gonads do not produce male hormones or if for some reason the hormones cannot act on the tissue, the default form of the organism is female.

Once testes are formed, they produce two substances that bring about the development of a male. Testosterone causes masculinization by promoting the male, or Wolffian, set of ducts and, indirectly through conversion to dihydrotestosterone, the external appearance of scrotum and penis. The Müllerian regression factor causes the female, or Müllerian, set of ducts to regress. If anything goes wrong at any stage of the process, the individual may be incompletely masculinized.

Not only do sex hormones achieve the transformation of the genitals into male organs, but they also organize corresponding male behaviors early in life. Since we cannot manipulate the hormonal environment in humans, we owe much of what we know about the details of behavioral determination to studies in other animals. Again, the intrinsic tendency, according to studies by Robert W. Goy of the University of Wisconsin, is to develop the female pattern that occurs in the absence of masculinizing hormonal influence.

If a rodent with functional male genitals is deprived of androgens immediately after birth (either by castration or by the administration of a compound that blocks androgens), male sexual behavior, such as mounting, will be reduced. Instead female sexual behavior, such as lordosis (arching of the back), will be enhanced in adulthood. Similarly, if androgens are administered to a female directly after birth, she displays more male sexual behavior and less female behavior in adulthood.

Bruce S. McEwen and his co-workers at the Rockefeller University have shown that, in the rat, the two processes of defeminization and masculinization require somewhat different biochemical changes. These events also occur at somewhat different times. Testosterone can be converted to either estrogen (usually considered a female hormone) or dihydrotestosterone. Defeminization takes place primarily after birth in rats and is mediated by estrogen, whereas masculinization involves both dihydrotestosterone and estrogen and occurs for the most part before birth rather than after, according to studies by McEwen. A substance called alpha-fetoprotein may protect female brains from the masculinizing effects of their estrogen.

The area in the brain that organizes female and male reproductive behavior is the hypothalamus. This tiny structure at the base of the brain connects to the pituitary, the master endocrine gland. Roger A. Gorski and his colleagues at the University of California at Los Angeles have shown that a region of the pre-optic area of the hypothalamus is visibly larger in male rats than in females. The size increment in males is promoted by the presence of androgens in the immediate postnatal, and to some extent prenatal, period. Laura S. Allen in Gorski's laboratory has found a similar sex difference in the human brain.

Other preliminary but intriguing studies suggest that sexual behavior may reflect further anatomic differences. In 1991 Simon LeVay of the Salk Institute for Biological Studies in San Diego reported that one of the brain regions that is usually larger in human males than in females—an interstitial nucleus of the anterior hypothalamus—is smaller in homosexual than in heterosexual men. LeVay points out that this finding supports suggestions that sexual preference has a biological substrate.

Homosexual and heterosexual men may also perform differently on cognitive tests. Brian A. Gladue of North Dakota State University and Geoff D. Sanders of City of London Polytechnic report that homosexual men perform less well on several spatial tasks than do heterosexual men. In a recent study in my laboratory, Jeff Hall found that homosexual men had lower scores on targeting tasks than did heterosexual men; however, they were superior in ideational fluency—listing things that were a particular color.

This exciting field of research is just starting, and it is crucial that investigators consider the degree to which differences in life-style contribute to group differences. One should also keep in mind that results concerning group differences constitute a general statistical statement; they establish a mean from which any individual may differ. Such studies are potentially a rich source of information on the physiological basis for cognitive patterns.

The lifelong effects of early exposure to sex hormones are characterized as organizational, because they appear to alter brain function permanently during a critical period. Administering the same hormones at later stages has no such effect. The hormonal effects are not limited to sexual or reproductive behaviors: they appear to extend to all known behaviors in which males and females differ. They seem to govern problem solving, aggression and the tendency to engage in rough-and-tumble play—the boisterous body contact that young males of some mammalian species display. For example, Michael J. Meaney of McGill University finds that dihydrotestosterone, working through a structure called the amygdala rather than through the hypothalamus, gives rise to the play-fighting behavior of juvenile male rodents.

Male and female rats have also been found to solve problems differently. Christina L. Williams of Barnard College has shown that female rats have a greater tendency to use landmarks in spatial learning tasks—as it appears women do. In Williams's experiment, female rats used landmark cues, such as pictures on the wall, in preference to geometric cues, such as angles and the shape of the room. If no landmarks were available, however, females used geometric cues. In contrast, males did not use landmarks at all, preferring geometric cues almost exclusively.

Interestingly, hormonal manipulation during the critical period can alter these behaviors. Depriving newborn males of testosterone by castrating them or administering estrogen to newborn females results in a complete reversal of sex-typed behaviors in the adult animals. (As mentioned above, estrogen can have a masculinizing effect during brain development.) Treated females behave like males, and treated males behave like females.

Natural selection for reproductive advantage could account for the evolution of such navigational differences. Steven J. C. Gaulin and Randall W. FitzGerald of the University of Pittsburgh have suggested that in species of voles in which a male mates with several females rather than with just one, the range he must traverse is greater. Therefore, navigational ability seems critical to reproductive success. Indeed, Gaulin and FitzGerald found sex differences in laboratory maze learning only in voles that were polygynous, such as the meadow vole, not in monogamous species, such as the prairie vole.

Again, behavioral differences may parallel structural ones. Lucia F. Jacobs in Gaulin's laboratory has discovered that the hippocampus—a region thought to be involved in spatial learning in both birds and mammals—is larger in male polygynous voles than in females. At present, there are no data on possible sex differences in hippocampal size in human subjects.

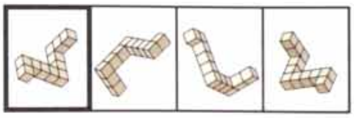
Evidence of the influence of sex hormones on adult behavior is less direct in humans than in other animals. Researchers are instead guided by what may be parallels in other species and by spontaneously occurring exceptions to the norm in humans.

One of the most compelling areas of evidence comes from studies of girls exposed to excess androgens in the prenatal or neonatal stage. The production of abnormally large quantities of adrenal androgens can occur because of a genetic defect called congenital adrenal hyperplasia (CAH). Before the 1970s, a similar condition also unexpectedly appeared when pregnant women took various synthetic steroids. Although the consequent masculinization of the genitals can be corrected early in life and drug therapy can stop the overproduction of androgens, effects of prenatal exposure on the brain cannot be reversed.

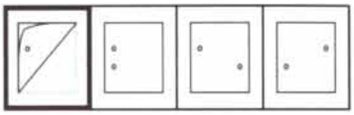
Studies by researchers such as Anke A. Ehrhardt of Columbia University and June M. Reinisch of the Kinsey Institute have found that girls with excess expo-

Problem-Solving Tasks Favoring Men

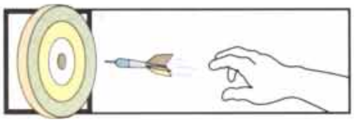
Men tend to perform better than women on certain spatial tasks. They do well on tests that involve mentally rotating an object or manipulating it in some fashion, such as imagining turning this three-dimensional object



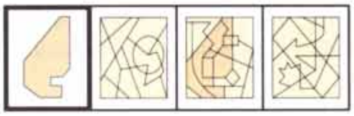
or determining where the holes punched in a folded piece of paper will fall when the paper is unfolded:



Men also are more accurate than women in target-directed motor skills, such as guiding or intercepting projectiles:

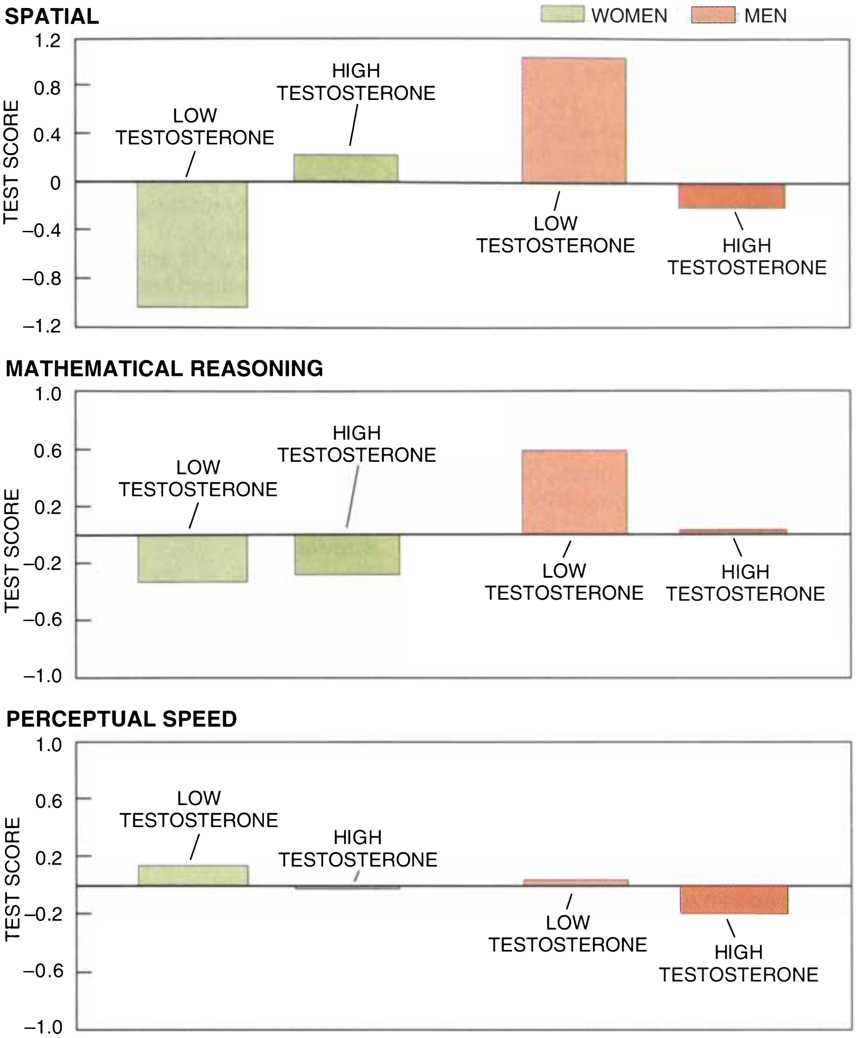


They do better on disembedding tests, in which they have to find a simple shape, such as the one on the left, once it is hidden within a more complex figure:



And men tend to do better than women on tests of mathematical reasoning:

1,100	If only 60 percent of seedings will survive, how many must be planted to obtain 660 trees?



TESTOSTERONE LEVELS can affect performance on some tests (see boxes on pages 120 and 121 for examples of tests). Women with high levels of testosterone perform better on a spatial task (*top*) than do women with low levels; men with low levels outperform men with high levels. On a mathematical reasoning test (*middle*), low testosterone corresponds to better performance in men; in women there is no such relation. On a test in which women usually excel (*bottom*), no relation is found between testosterone and performance.

sure to androgens grow up to be more tomboyish and aggressive than their unaffected sisters. This conclusion was based sometimes on interviews with subjects and mothers, on teachers' ratings and on questionnaires administered to the girls themselves. When ratings are used in such studies, it can be difficult to rule out the influence of expectation either on the part of an adult who knows the girls' history or on the part of the girls themselves.

Therefore, the objective observations of Berenbaum are important and convincing. She and Melissa Hines of the University of California at Los Angeles observed the play behavior of CAH-affected girls and compared it with that of their male and female siblings. Given a choice of transportation and construction toys, dolls and kitchen supplies or books and board games, the CAH girls preferred the more typically masculine toys—for example, they played with cars for the same amount of time that normal boys did. Both the CAH girls and the boys differed from unaffected girls in their patterns of choice. Because there is every reason to think that parents would be at least as likely to encourage feminine preferences in their CAH daughters as in their unaffected daughters, these findings suggest that the toy preferences were actually altered in some way by the early hormonal environment.

Spatial abilities that are typically better in males are also enhanced in CAH girls. Susan M. Resnick, now at the National Institute on Aging, and Berenbaum and their colleagues reported that affected girls were superior to their unaffected sisters in a spatial manipulation test, two spatial rotation tests and a disembedding test—that is, the discovery of a simple figure hidden within a more complex one. All these tasks are usually done better by males. No differences existed between the two groups on other perceptual or verbal tasks or on a reasoning task.

Studies such as these suggest that the higher the androgen levels, the better the spatial performance. But this does not seem to be the case. In 1983 Valerie J. Shute, when at the University of California at Santa Barbara, suggested that the relation between levels of androgens and some spatial capabilities might be nonlinear. In other words, spatial ability might not increase as the amount of androgen increases. Shute measured androgens in blood taken from male and female students and divided each into high- and low-androgen groups. All fell within the normal range for each sex (androgens are present in females but in very low levels). She found that in women, the high-androgen subjects were better at the spatial tests. In men the reverse was true: low-androgen men performed better.

Catherine Gouchie and I recently conducted a study along similar lines by measuring testosterone in saliva. We added tests for two other kinds of abilities: mathematical reasoning and perceptual speed. Our results on the spatial tests were very similar to Shute's: low-testosterone men were superior to high-testosterone men, but high-testosterone women surpassed low-testosterone women. Such findings suggest some optimum level of androgen for maximal spatial ability. This level may fall in the low male range.

No correlation was found between testosterone levels and performance on perceptual speed tests. On mathematical reasoning, however, the results were similar to those of spatial ability tests for men: low-androgen men tested higher, but there was no obvious relation in women.

Such findings are consistent with the suggestion by Camilla P. Benbow of Iowa State University that high mathematical ability has a significant biological determinant. Benbow and her colleagues have reported consistent sex differences in mathematical reasoning ability favoring males. These differences are especially sharp at the upper end of the distribution, where males outnumber females 13 to one. Benbow argues that these differences are not readily explained by socialization.

It is important to keep in mind that the relation between natural hormonal levels and problem solving is based on correlational data. Some form of connection between the two measures exists, but how this association is determined or what its causal basis may be is unknown. Little is currently understood about the relation between adult levels of hormones and those in early life, when abilities appear to be organized in the nervous system. We have a lot to learn about the precise mechanisms underlying cognitive patterns in people.

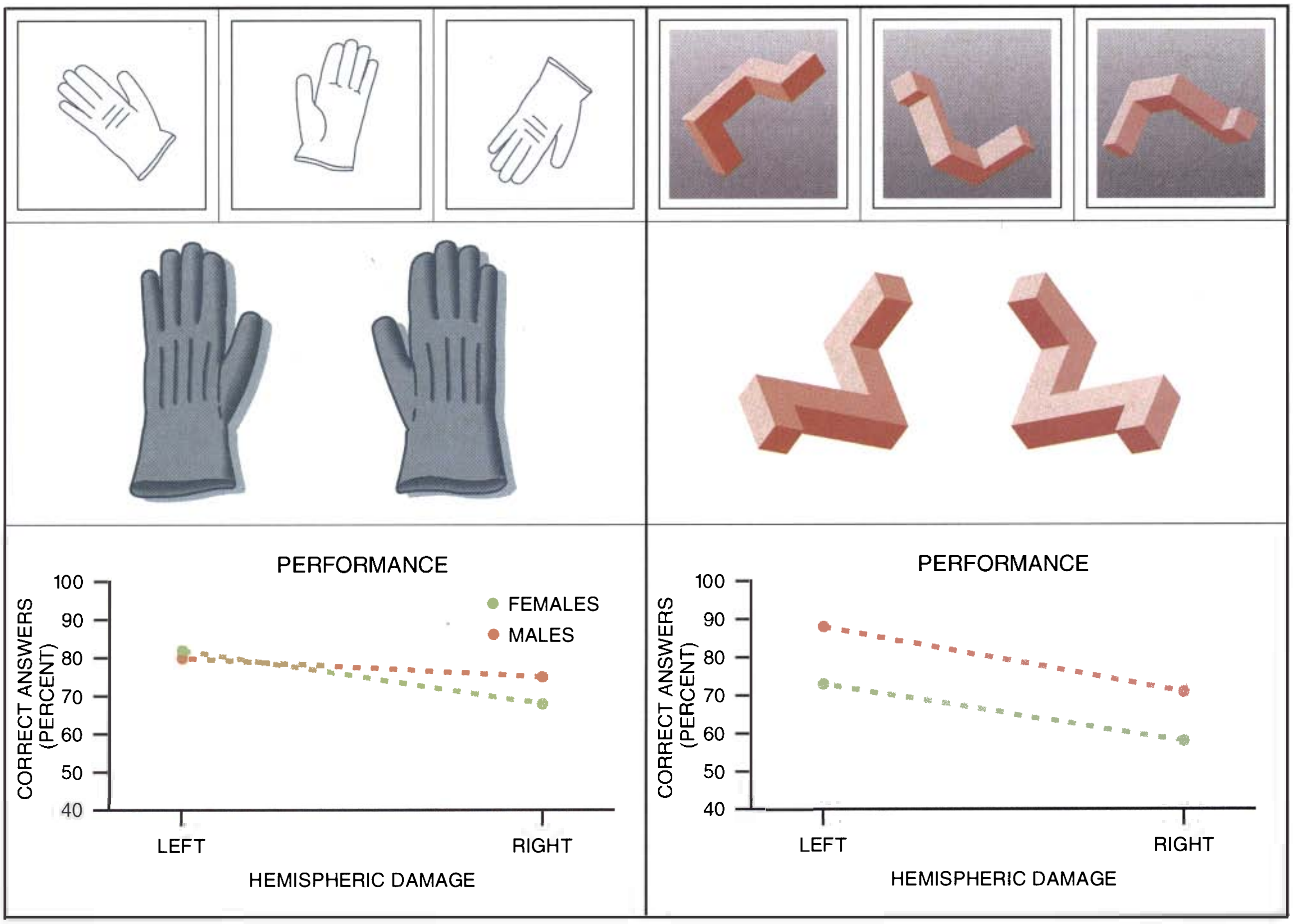
Another approach to probing differences between male and female brains is to examine and compare the functions of particular brain systems. One noninvasive way to accomplish this goal is to study people who have experienced damage to a specific brain region. Such studies indicate that the left half of the brain in most people is critical for speech, the right for certain perceptual and spatial functions.

It is widely assumed by many researchers studying sex differences that the two hemispheres are more asymmetrically organized for speech and spatial functions in men than in women. This idea comes from several sources. Parts of the corpus callosum, a major neural system connecting the two hemispheres, may be more extensive in women; perceptual techniques that probe brain asymmetry in normal-functioning people sometimes show smaller asymmetries in women than in men, and damage to one brain hemisphere sometimes has a lesser effect in women than the comparable injury has in men.

In 1982 Marie-Christine de Lacoste, now at the Yale University School of Medicine, and Ralph L. Holloway of Columbia University reported that the back part of the corpus callosum, an area called the splenium, was larger in women than in men. This finding has subsequently been both refuted and confirmed. Variations in the shape of the corpus callosum that may occur as an individual ages as well as different methods of measurement may produce some of the disagreements. Most recently, Allen and Gorski found the same sex-related size difference in the splenium.

The interest in the corpus callosum arises from the assumption that its size may indicate the number of fibers connecting the two hemispheres. If more connecting fibers existed in one sex, the implication would be that in that sex the hemispheres communicate more fully. Although sex hormones can alter callosal size in rats, as Victor H. Denenberg and his associates at the University of Connecticut have demonstrated, it is unclear whether the actual number of fibers differs between the sexes. Moreover, sex differences in cognitive function have yet to be related to a difference in callosal size. New ways of imaging the brain in living humans will undoubtedly increase knowledge in this respect.

The view that a male brain is functionally more asymmetric than a female brain is long-standing. Albert M. Galaburda of Beth Israel Hospital in Boston and the late Norman Geschwind of Har-



RIGHT HEMISPHERIC DAMAGE affects spatial ability to the same degree in both sexes (*graphs at bottom*), suggesting that women and men rely equally on that hemisphere for certain spatial tasks. In one test of spatial rotation performance (*left*), a series of drawings of a gloved right or left hand must be matched to a right- or left-handed glove. In a second test (*right*), photographs of a three-dimensional object must be matched to one of two mirror images of the same object.

vard Medical School proposed that androgens increased the functional potency of the right hemisphere. In 1981 Marian C. Diamond of the University of California at Berkeley found that the right cortex is thicker than the left in male rats but not in females. Jane Stewart of Concordia University in Montreal, working with Bryan E. Kolb of the University of Lethbridge in Alberta, recently pinpointed early hormonal influences on this asymmetry: androgens appear to suppress left cortex growth.

Last year de Lacoste and her colleagues reported a similar pattern in human fetuses. They found the right cortex was thicker than the left in males. Thus, there appear to be some anatomic reasons for believing that the two hemispheres might not be equally asymmetric in men and women.

Despite this expectation, the evidence in favor of it is meager and conflicting, which suggests that the most striking sex differences in brain organization may not be related to asymmetry. For example, if overall differences between men and women in spatial ability were related to differing right hemispheric dependence for such functions, then damage to the right hemisphere would perhaps have a more devastating effect on spatial performance in men.

My laboratory has recently studied the ability of patients with damage to one hemisphere of the brain to rotate certain objects mentally. In one test, a series of line drawings of either a left or a right gloved hand is presented in various orientations. The patient indicates the hand being depicted by simply pointing to one of two stuffed gloves that are constantly present.

The second test uses two three-dimensional blocklike figures that are mirror images of one another. Both figures are present throughout the test. The patient is given a series of photographs of these objects in various orientations, and he or she must place each picture in front of the object it depicts. (These nonverbal procedures are employed so that patients with speech disorders can be tested.)

As expected, damage to the right hemisphere resulted in lower scores for both sexes on these tests than did damage to the left hemisphere. Also as anticipated, women did less well than men on the block spatial rotation test. Surprisingly, however, damage to the right hemisphere had no greater effect in men than in women. Women were at least as affected as men by damage to the right hemisphere. This result suggests that the normal differences between men and women on such rotational tests are not the result of differential dependence on the right hemisphere. Some other brain systems must be mediating the higher performance by men.

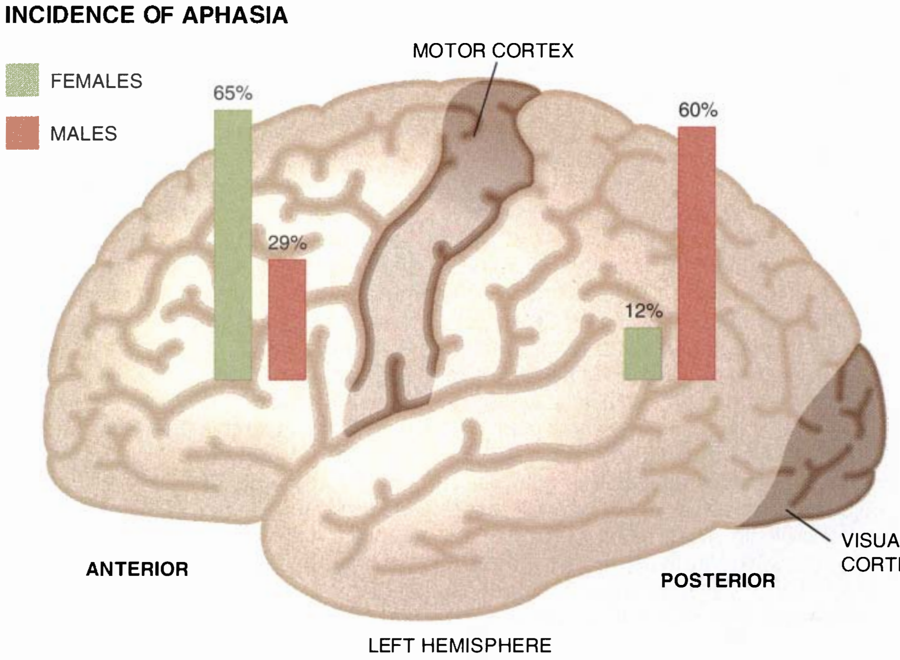
Parallel suggestions of greater asymmetry in men regarding speech have rested on the fact that the incidence of aphasias, or speech disorders, are higher in men than in women after damage to the left hemisphere. Therefore, some researchers have found it reasonable to conclude that speech must be more bilaterally organized in women. There is, however, a problem with this conclusion. During my 20 years of experience with patients, aphasia has not been disproportionately present in women with right hemispheric damage.

In searching for an explanation, I discovered another striking difference between men and women in brain organization for speech and related motor function. Women are more likely than men to suffer aphasia when the front part of the brain is damaged. Because restricted damage within a hemisphere more frequently affects the posterior than the anterior area in both men and women, this differential dependence may explain why women incur aphasia less often than do men. Speech functions are thus less likely to be affected in women not because speech is more bilaterally organized in women but because the critical area is less often affected.

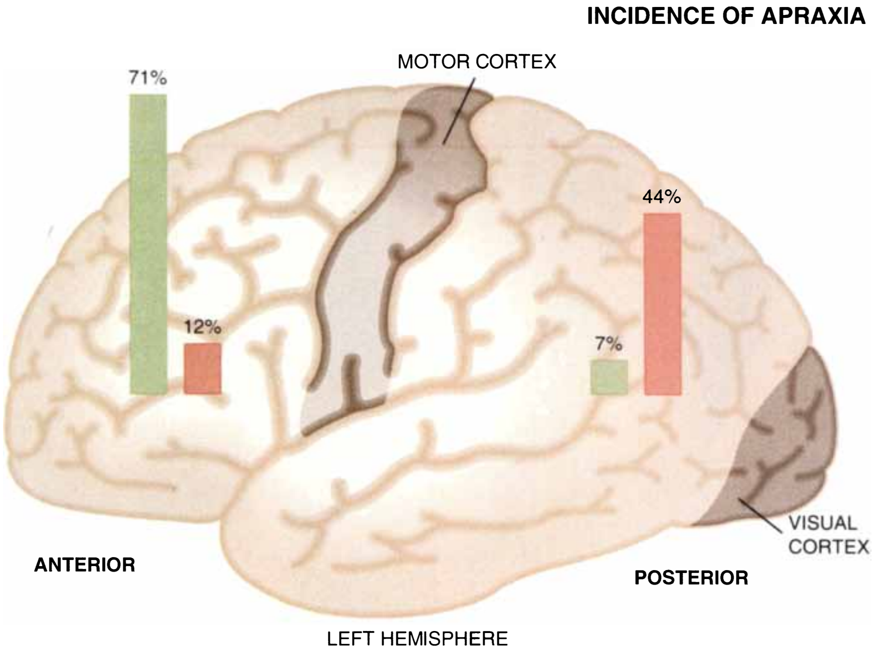
A similar pattern emerges in studies of the control of hand movements, which are programmed by the left hemisphere. Apraxia, or difficulty in selecting appropriate hand movements, is very common after left hemispheric damage. It is also strongly associated with difficulty in organizing speech. In fact, the critical functions that depend on the left hemisphere may relate not to language per se but to organization of the complex oral and manual movements on which human communication systems depend. Studies of patients with left hemispheric damage have revealed that such motor selection relies on anterior systems in women but on posterior systems in men.

The synaptic proximity of women's anterior motor selection system (or "praxis system") to the motor cortex directly behind it may enhance fine-motor skills. In contrast, men's motor skills appear to emphasize targeting or directing movements toward external space—some distance away from the self. There may be advantages to such motor skills when they are closely meshed with visual input to the brain, which lies in the posterior region.

Women's dependence on the anterior region is detectable even when tests involve using visual guidance—for instance, when subjects must build patterns with blocks by following a visual model. In studying such a complex task, it is possible to compare the effects of damage to the anterior and posterior regions of both hemispheres because per-



APHASIAS, or speech disorders, occur most often in women when damage is to the front of the brain. In men, they occur more frequently when damage is in the posterior region. The data presented above derive from one set of patients.



APRAXIA, or difficulty in selecting hand movements, is associated with frontal damage to the left hemisphere in women and with posterior damage in men. It is also associated with difficulties in organizing speech.

formance is affected by damage to either hemisphere. Again, women prove more affected by damage to the anterior region of the right hemisphere than by posterior damage. Men tend to display the reverse pattern.

Although I have not found evidence of sex differences in functional brain asymmetry with regard to basic speech, motor selection or spatial rotation ability, I have found slight differences in more abstract verbal tasks. Scores on a vocabulary test, for instance, were affected by damage to either hemisphere in women, but such scores were affected only by left-sided injury in men. This finding suggests that in reviewing the meanings of words, women use the hemispheres more equally than do men.

In contrast, the incidence of non-right-handedness, which is presumably related to lesser left hemispheric dependence, is higher in men than in women. Even among right-handers, Marion Annett, now at the University of Leicester in the U.K., has reported that women are more right-handed than men—that is, they favor their right hand even more than do right-handed men. It may well be, then, that sex differences in asymmetry vary with the particular function being studied and that it is not always the same sex that is more asymmetric.

Taken altogether, the evidence suggests that men's and women's brains are organized along different lines from very early in life. During development, sex hormones direct such differentiation. Similar mechanisms probably operate to produce variation within sexes, since there is a relation between levels of certain hormones and cognitive makeup in adulthood.

One of the most intriguing findings is that cognitive patterns may remain sensitive to hormonal fluctuations throughout life. Elizabeth Hampson of the University of Western Ontario showed that the performance of women on certain tasks changed throughout the menstrual cycle as levels of estrogen went up or down. High levels of the hormone were associated not only with relatively depressed spatial ability but also with enhanced articulatory and motor capability.

In addition, I have observed seasonal fluctuations in spatial ability in men. Their performance is improved in the spring when testosterone levels are lower. Whether these intellectual fluctuations are of any adaptive significance or merely represent ripples on a stable baseline remains to be determined.

To understand human intellectual functions, including how groups may differ in such functions, we need to look beyond the demands of modern life. We did not undergo natural selection for reading or for operating computers. It seems clear that the sex differences in cognitive patterns arose because they proved evolutionarily advantageous. And their adaptive significance probably rests in the distant past. The organization of the human brain was determined over many generations by natural selection. As studies of fossil skulls have shown, our brains are essentially like those of our ancestors of 50,000 or more years ago.

For the thousands of years during which our brain characteristics evolved, humans lived in relatively small groups of hunter-gatherers. The division of labor between the sexes in such a society probably was quite marked, as it is in existing hunter-gatherer societies. Men were responsible for hunting large game, which often required long-distance travel. They were also responsible for defending the group against predators and enemies and for the shaping and use of weapons. Women most probably gathered food near the camp, tended the home, prepared food and clothing and cared for children.

Such specializations would put different selection pressures on men and women. Men would require long-distance route-finding ability so they could recognize a geographic array from varying orientations. They would also need targeting skills. Women would require short-range navigation, perhaps using landmarks, fine-motor capabilities carried on within a circumscribed space, and perceptual discrimination sensitive to small changes in the environment or in children's appearance or behavior.

The finding of consistent and, in some cases, quite substantial sex differences suggests that men and women may have different occupational interests and capabilities, independent of societal influences. I would not expect, for example, that men and women would necessarily be equally represented in activities or professions that emphasize spatial or math skills, such as engineering or physics. But I might expect more women in medical diagnostic fields where perceptual skills are important. So that even though any one individual might have the capacity to be in a "nontypical" field, the sex proportions as a whole may vary.

FURTHER READING

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