Sex, sexual orientation and sex hormones influence human cognitive function

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Superior performance by women on a task requiring object location memory has challenged the traditional view that men excel on all spatial tasks. Sexual orientation is also associated with variation in cognitive ability pattern, but such association appears to be more consistent for a real-world targetting task than for paper-and-pencil spatial tests. Finally, there is increasing evidence that early exposure to sex hormones has lasting effects on problem-solving behaviour; moreover, current fluctuations in sex hormones in both men and women are associated with changes in cognitive pattern.

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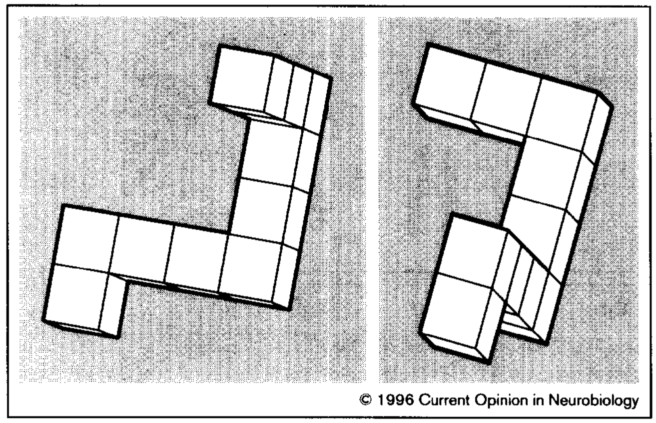
Figure 1



Example of a mental rotation task. The subject must decide if the two figures could be the same or not. Men typically perform better at this type of task.

Introduction

Inasmuch as variations in cognitive profile are related to biological characteristics such as hand preference and sex, the latter provide a useful method for studying the neurobiology of cognition. Scientific evidence for consistent differences in cognitive function between men and women has accumulated for well over 50 years [1,2]. A solid body of research, carried out primarily in North America and Western Europe, has established that men, on average, excel on spatial tasks (particularly those tapping ability to imaginally rotate a figure; see Figure 1), perception of the vertical and horizontal, mathematical reasoning, and spatio-motor targetting ability. Women, on average, excel on tasks of verbal fluency (where words must be generated with constraints on the letters they contain), perceptual speed (in which rapid pattern–identity matches are made), verbal and item memory, and some fine motor skills.

The question of what determines such ability differences between men and women has been the subject of much discussion. Most researchers currently working on sexual dimorphism in cognitive function have adopted as a useful organizing principle one that stresses the division of labour between the sexes during our hunter–gatherer history [2,3••,4,5]. Men were more likely to be involved in hunting game, and more likely to engage in long-distance travel, hence, they would be selected for spatial navigational and targetting ability. Women would be more engaged in foraging near the home base, in care of home and children, hence would have evolved greater sensitivity to small changes in the appearance of infants or the home environment, and would employ navigational strategies that emphasize familiar landmarks.

The evidence from structural brain differences between the sexes, sex hormone influences, and similarities in sex differences across cultures [6•,7], combine to suggest that men's and women's brains are to a significant extent wired differently from the start. Nevertheless, environmental influences must interact with diverse predispositions to produce large variation within each sex; and in the larger comparative context, the similarities between human males and females far outweigh the differences.

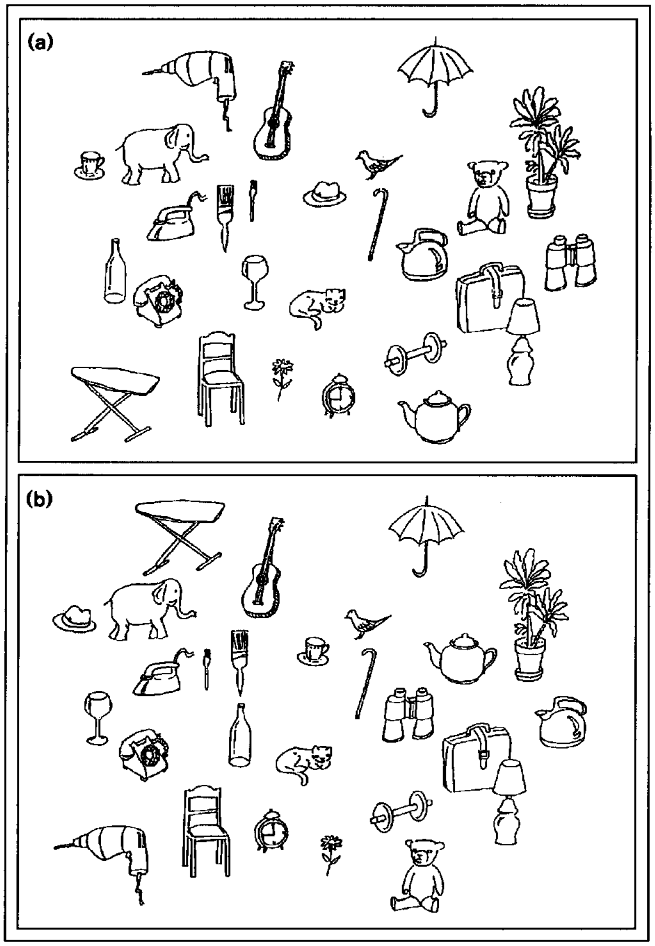
This review will focus on studies relating cognitive pattern to sex and sexual orientation, on sex hormone influences on cognitive pattern, and on some possibly relevant brain differences between men and women.

Sex differences in cognitive strengths

Several studies in the past year have confirmed the typical differences between men and women — better performance by men on mathematical reasoning [8,9], mental rotation [10••,11,12••], perception of the horizontal [10••,13], and targetting accuracy [14••]. Women were confirmed to have larger colour vocabularies [15], better verbal memory [16], and better performance on a test of finger dexterity [14••].

A significant departure from the expected findings on sex differences has been the discovery that women excel also on a test of location memory for objects [17]. The procedure entails the presentation of an array of

Figure 2



Object location memory task. **(a)** The first array is viewed for one minute, **(b)** then the second array is shown and the task is to indicate which objects have changed locations, as well as which have not. Women perform better on this task. Reproduced with permission from Silverman and Eals [17].

objects (Figure 2) for one minute. Then a second array is presented, in which half of the object locations are exchanged, and the subject is required to indicate both the changed and unchanged locations. Women correctly identify more of these than do men, and this is not accounted for by their better item memory. A recent paper by the same authors finds a female advantage even when the objects are unfamiliar and difficult to name [3••]. Since this task would by most definitions be considered spatial, the question for future research is how it differs from other spatial tasks on which men are superior.

Sex hormones and cognitive pattern

Hormones secreted by the gonads are known to exert potent effects on behaviour. During critical periods early in the life of mammals, androgens and their metabolites organize the brain to produce lifelong, irreversible effects on a variety of reproductive and non-reproductive sexually dimorphic behaviours ('organizational' influences) [18]. Moreover, fluctuations in the levels of these hormones in adulthood, called 'activational' influences, may alter the likelihood that the same behaviours will occur. A perinatal influence of androgens on adult spatial ability has been demonstrated in rodents [19].

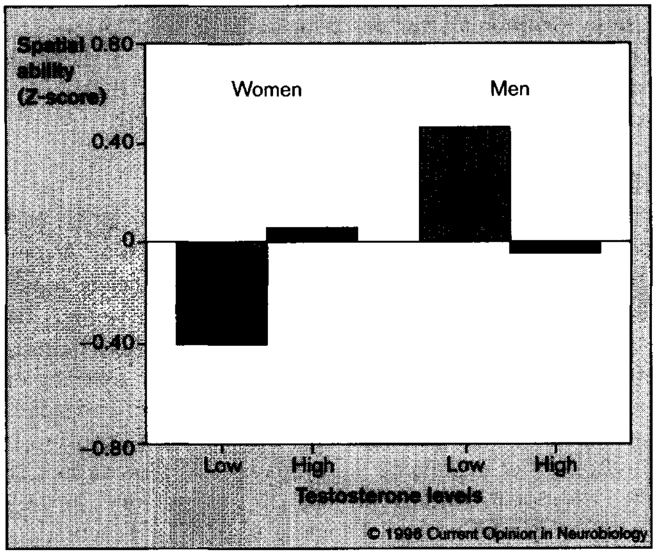
In humans also it appears that the early presence of androgens may organize the male brain to enhance certain spatial functions. The best evidence for this comes from a condition called congenital adrenal hyperplasia (CAH), in which there is an excess of androgens in fetal life due to an adrenal enzyme deficiency. Girls with this condition tend to have virilized genitalia at birth, later corrected by surgery. The hormonal balance can be restored to normal by administration of cortisone. What is of interest here is that the effects of early androgen exposure can be seen later in life in a number of behavioural differences, including enhanced spatial ability in CAH girls when compared with their unaffected sisters ([20–22]; E Hampson, JF Rovet, D Altmann, abstract 68, 25th meeting International Congress of Psychoneuroendocrinology, Seattle, August 1994). The necessity for comparison with family members to control for general intelligence, when dealing with small special populations like CAH, may account for the lack of such enhancement in another recent study [23]. Even in that study, however, a masculine pattern of abilities (spatial rotation relatively better than verbal fluency) is seen.

Given the influence of early androgen levels on spatial ability, one might expect a relation also between adult androgen levels and spatial scores. Several studies relating levels of testosterone (T) and measures of spatial ability, across and within sex, have found a nonlinear relationship [12••,24–26]. In women, it is those with higher testosterone, and in men those with lower testosterone, who excel. This has given rise to the suggestion that there is an optimal level of testosterone for certain kinds of spatial function, and that this optimal level is in the low male range (Figure 3).

As in nonhuman animals, human behaviour is subject to activational fluctuations in sex hormones, evident also in cognitive functioning. The most thoroughly investigated influence of activational hormones on cognition has employed the natural variations in estrogen across the menstrual cycle [27,28]. Women performed better on spatial tests in the low-estrogen (menstrual) phase of the cycle than in the high-estrogen (late follicular or midluteal) phase. In contrast, their performance on articulatory-verbal and fine manual skills was better in the high-estrogen phase.

Hormone-related variations in cognitive function appear also in men. In Europe and North America, men have higher testosterone levels in autumn than in spring. Since spatial ability tends to be better in men with lower T levels, it was predicted, and found, that spatial tasks would be performed better by men in spring than in autumn

Figure 3



Schematic diagram of the relation between testosterone levels and spatial ability. The mean of all groups is depicted at 0. Division into high and low testosterone groups is done by splitting at the median level within each sex. Women with higher testosterone achieve better scores than women with lower levels, but in men, the reverse is true.

[29•]. Performance on nonspatial tasks was uninfluenced by season. Recently, diurnal fluctuations in T levels were also associated with variation in spatial function [12••]. T levels are highest in men in early morning, and spatial performance was worst in early morning, consistent with the findings from the seasonal study. Since both of the preceding studies yield correlational data, we cannot be certain that T levels are the direct cause of the cognitive changes. However, when testosterone was administered to older men with presumptively lower-than-optimal T levels, the effects were consistent with the above studies [30•]. The group who received testosterone improved performance on a visuospatial constructional task, relative to placebo controls. Similarly, androgen administration improved performance selectively on a spatial task in female-to-male transsexuals [31•].

The susceptibility of cognitive pattern to variations in sex hormones is consistent with the idea that these hormones played a role in organizing the pertinent neurocognitive systems, and thus that some of the sex differences are due to early organizing influences. It must also be true that some of the variability in the size of cognitive sex differences from study to study is due to variation in the time of day, the season, and the menstrual phase.

Sexual orientation and cognitive pattern

Sexual orientation is another biological variable that might be expected to relate to cognitive pattern. Although the determinants of sexual orientation are by no means fully understood, animal neurohormonal models of partner preference [32], and genetic and neuroanatomical studies in humans [33] suggest an early contribution of these factors to variation in sexual orientation in at least some males. A few studies on cognitive differences between homosexual and heterosexual men (reviewed in [10••]) found variable effects, but if anything, homosexual men scored lower on mental rotation tasks and on tasks sampling perception of the horizontal.

Most studies on cognitive function in homosexuals have, because of the difficulties in recruiting subjects, employed small sample sizes. Moreover, the unknown factors in recruitment make it problematic whether those subjects tested are representative of the homosexual population. For these reasons, it is important that samples be large enough, and that results be replicated reliably across studies, before accepting the findings. In a study employing the largest samples to date (72 homosexual men and 68 homosexual women), no significant differences between homosexual and heterosexual subjects appeared on two commonly used paper-and-pencil spatial tasks, after adjusting for age and education [10••]. The authors conclude that if differences related to sexual orientation exist, they are relatively small.

In contrast to such paper-and-pencil tasks sampling spatial orientation, reliable differences have been found between homosexual and heterosexual men on targetting tasks. One method employed an overhanded dart throw at a board (G Sanders, abstract SY068.4, 25th International Congress of Psychology, Brussels, July 1992), and the other, underhand throwing of a velcro-covered ball at a vertical carpet marked out in squares [14••]. Both of these throwing tasks show large sex differences favouring men [14••,34]. In both the Sanders and the Hall and Kimura [14••] studies, heterosexual men made smaller errors than homosexual men, who did not differ significantly from heterosexual women. On a finger dexterity task that favours women (Purdue Pegboard), homosexual men did not differ from heterosexual men. Earlier studies employing traditional spatial tests had suggested that homosexual men might show a pattern intermediate between heterosexual men and women. Hall and Kimura [14••] have suggested, instead, that homosexual men may show either a male-typical or a female-typical pattern, depending on the function in question. Moreover, since adult levels of sex hormones do not differ between homosexual and heterosexual men, any hormonal explanation must invoke differences earlier in life.

The demonstration of a sexual-orientation effect on throwing accuracy is interesting for two reasons: first, it shows an association with sexual orientation of an arguably more ecologically valid spatial task than the typical paper-and-pencil tasks, and second, it refutes the often invoked explanation of the sex difference on targetting, that men are better because they have a physical/structural advantage.

Sex differences in relevant brain organization

Although some morphological sex differences in the brain have been found, notably in the size of commissural systems [35–37], these have yet to be related directly to the cognitive sex differences. The most commonly adopted hypothesis about functional brain sex differences is that the left and right hemispheres of the brain are more asymmetrically organized in men than in women [1]. That is, speech is less dependent on the left hemisphere, and spatial and visuoperceptual functions are less dependent on the right hemisphere in women than in men. The hypothesis of lesser functional asymmetry in women is based largely on studies of perceptual asymmetry in normal subjects. For example, when two different words are presented to the two ears simultaneously, the right-ear input, having better access to the opposite (speech) hemisphere, is reported more accurately than the left ear. This is true of both men and women, but the ear differences are often smaller in women [38].

New brain imaging techniques make it possible to record activity in each hemisphere while actually performing a task, and thus the degree of functional asymmetry can be studied more directly. However, although imaging techniques are of undoubted value in examining individual differences, they must be constrained by information about what happens when presumptively critical regions are lost. Thus, a recent study asked subjects to determine whether two nonsense words rhymed, that is, to make a phonological comparison. In men, activation on functional magnetic resonance imaging was limited to a frontal area of the left hemisphere, whereas in women, this region was activated in both hemispheres [39•]. The reasonable inference, that phonological processing is more asymmetrically organized in men, however, needs to be vetted against data from pathology to this region. Until we know that damage to the left or right brain region has different effects in men and women, it may be premature to conclude that the imaging data represent primary functional differences.

It is also often claimed that the superior performance by men on visuospatial tasks is due to enhanced development of the right hemisphere, or greater dependence on right-hemisphere function. Yet, actual studies comparing the effects of left-hemisphere or right-hemisphere damage in men and women do not support this position. One study [40] found that pathology to the right hemisphere adversely affected spatial rotation ability equally in men and women. Another study [41•] suggested that women with right-hemisphere strokes were more affected than were men on visuospatial tasks such as line orientation.

A second hypothesis concerning brain sex differences is that men and women differ in dependence of speech and related manual control functions, on anterior and posterior regions. Women are more likely to suffer speech disorders (aphasia) and motor programming disorders (apraxia) after anterior damage, whereas men are more likely to incur these symptoms after posterior damage [40,42,43•]. This arrangement has been speculatively linked to the male advantage on throwing accuracy, and to the female advantage on certain fine motor tasks [14••,40].

Conclusions

Cognitive profile varies consistently with sex, albeit with substantial overlap between men and women. A new task requiring detection of changes in an array of object locations yields a sex difference favouring women, an unexpected finding. Studies relating cognitive pattern to sexual orientation report more consistent findings on a real-world targetting task than on paper-and-pencil spatial tests. The probable influence of early exposure to androgens in organizing adult spatial ability is supported by additional studies on spatial performance in girls with congenital adrenal hyperplasia (CAH). Fluctuations in sex hormones continue to affect cognitive pattern in adulthood, as evidenced by diurnal, menstrual and seasonal variations. Imaging techniques have begun to uncover possible functional brain differences between men and women, but these need to be rigorously vetted in future against the effects of relevant brain lesions. Brain sex differences in left–right, anterior–posterior, and interhemispheric functional organization may exist.

Acknowledgements

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Halpern DF: *Sex Differences in Cognitive Abilities*, edn 2. Hillsdale, New Jersey: Lawrence Erlbaum Associates; 1992.
2. Kimura D: **Sex differences in the brain.** *Sci Am* 1992, **267**:119–125.
3. •• Eals M, Silverman I: **The hunter-gatherer theory of spatial sex differences: proximate factors mediating the female advantage in recall of object arrays.** *Ethology Sociobiol* 1994, **15**:95–105.
This paper follows up the authors' original findings [17] showing better object location memory in women, with familiar objects. Here, they present unfamiliar objects, both in a real-world room situation and by a test using line drawings. Again, women show better recognition of object locations. This series of experiments is novel in showing better performance by women on a spatial task.
4. Geary DC: **Sexual selection and sex differences in mathematical abilities.** *Behav Brain Sci* 1996, in press.
5. Hamburg BA: **The psychobiology of sex differences: an evolutionary perspective.** In *Sex Differences in Behavior.* Edited by Richart RM, Van de Wiele RL. New York: Wiley & Sons; 1974:373–392.
6. • Lynn R: **Sex differences in intelligence and brain size: a paradox resolved.** *Pers Individ Diff* 1994, **17**:257–271.
Among other things, this paper summarizes sex differences favouring males on spatial tasks in six different countries.
7. Mann VA, Sasanuma S, Sakuma N, Masaki S: **Sex differences in cognitive abilities: a cross-cultural perspective.** *Neuropsychologia* 1990, **28**:1063–1077.

8. Bohlin CF: **Learning style factors and mathematics performance: sex-related differences.** *Int J Educ Res* 1994, 21:387–398.

9. Lubinski DL, Benbow CP: **The study of mathematically precocious youth: the first three decades of a planned 50-year study of intellectual talent.** In *Beyond Terman: Contemporary Longitudinal Studies of Giftedness and Talent.* Edited by Subotnik RF, Arnold KD. Norwood, New Jersey: Ablex; 1994:255–281.

10. •• Gladue BA, Bailey JM: **Spatial ability, handedness, and human sexual orientation.** *Psychoneuroendocrinology* 1995, **20**:487–497.

With larger-than-usual samples of subjects, this study finds no significant effect of sexual orientation on mental rotations or the water level task, though they do find sex differences. The authors conclude that either there are no orientation differences, or they are small, and thus show up unreliably. The paper has a useful discussion of the sampling and recruitment problems to be overcome in studies of this kind.

11. Hamilton CJ: **Beyond sex differences in visuo-spatial processing: the impact of gender trait possession.** *Br J Psychol* 1995, **86**:1–20.

12. •• Moffat SD, Hampson E: **A curvilinear relationship between testosterone and spatial cognition in humans: possible influence of hand preference.** *Psychoneuroendocrinology* 1996, in press.

In addition to confirming a strong sex difference favouring males on a spatial rotation task, and a nonlinear relation between testosterone levels and spatial ability, this study provides the first definitive data on diurnal variation in cognitive function. Men perform worst on spatial tasks early in the morning, when testosterone levels are highest.

13. Hammer RE, Hoffer N, King WL: **Relationships among gender, cognitive style, academic major, and performance on the Piaget water-level task.** *Percept Mot Skills* 1995, **80**:771–778.

14. •• Hall JAY, Kimura D: **Sexual orientation and performance on sexually dimorphic motor tasks.** *Arch Sex Behav* 1995, **24**:395–407.

Two motor tasks showing opposite sex differences are employed, a spatiomotor targetting task that favours men, and a finger dexterity task (Purdue Pegboard) that favours women. The typical sex differences are confirmed. A group of homosexual men does not differ from women on the targetting task, and does not differ from men on the Pegboard task. The suggestion is that homosexual males may show male-typical or female-typical behaviour, depending on the function studied, rather than an intermediate pattern. Neither the sex difference nor the sexual orientation difference is accounted for by finger size, hand strength, or sports history.

15. Greene KS, Gynther MD: **Blue versus periwinkle: color identification and gender.** *Percept Mot Skills* 1995, **80**:27–32.

16. Stumpf H, Jackson DN: **Gender-related differences in cognitive abilities: evidence from a medical school admissions testing program.** *Pers Individ Diff* 1994, **17**:335–344.

17. Silverman I, Eals M: **Sex differences in spatial abilities: evolutionary theory and data.** In *The Adapted Mind.* Edited by Barlow JH, Cosmides L, Tooby J. New York: Oxford University Press; 1992:533–549.

18. Goy RW, McEwen BS: *Sexual Differentiation of the Brain.* Cambridge, Massachusetts: MIT Press; 1980.

19. Williams CL, Barnett AM, Meck WH: **Organizational effects of early gonadal secretions on sexual differentiation in spatial memory.** *Behav Neurosci* 1990, **104**:84–97.

20. Collaer ML, Hines M: **Human behavioral sex differences: a role for gonadal hormones during early development?** *Psychol Bull* 1995, **118**:55–107.

21. Hampson E: **Spatial cognition in humans. Possible modulation by androgens and estrogens.** *J Psychiatry Neurosci* 1995, **20**:397–404.

22. Resnick SM, Berenbaum SA, Gottesman IJ, Bouchard TJ: **Early hormonal influences on cognitive functioning in congenital adrenal hyperplasia.** *Dev Psychol* 1986, **22**:191–198.

23. Helleday J, Bartfai A, Ritzen EM, Forsman M: **General intelligence and cognitive profile in women with congenital adrenal hyperplasia (CAH).** *Psychoneuroendocrinology* 1994, **19**:343–356.

24. Gouchie C, Kimura D: **The relationship between testosterone levels and cognitive ability patterns.** *Psychoneuroendocrinology* 1991, **16**:323–334.

25. Hampson E, Moffat SD: **Is testosterone related to spatial cognition and hand preference in humans?** *Brain Cogn* 1994, **26**:255–266.

26. Shute VJ, Pellegrino JW, Hubert L, Reynolds RW: **The relationship between androgen levels and human spatial abilities.** *Bull Psychonom Soc* 1983, **21**:465–468.

27. Hampson E: **Estrogen-related variations in human spatial and articulatory-motor skills.** *Psychoneuroendocrinology* 1990, **15**:97–111.

28. Hampson E: **Variations in sex-related cognitive abilities across the menstrual cycle.** *Brain Cogn* 1990, **14**:26–43.

29. • Kimura D, Hampson E: **Cognitive pattern in men and women is influenced by fluctuations in sex hormones.** *Curr Directions Psychol Sci* 1994, **3**:57–61.

Fluctuations in estrogen levels across the menstrual cycle and across on–off phases of hormone replacement therapy in postmenopausal women were related to variations in cognitive pattern. In men, seasonal fluctuations in testosterone related to variations in spatial, but not other abilities.

30. • Janowsky JS, Oviatt SK, Orwoll ES: **Testosterone influences spatial cognition in older men.** *Behav Neurosci* 1994, **108**:325–332.

Testosterone was administered to a group of older men whose endogenous levels were presumably below the 'optimal' level for spatial ability. Their performance on a visuoconstructional task improved relative to a matched placebo control group. Estrogen levels were also assayed, and found to relate inversely to performance on this task.

31. • Van Goozen SHM, Cohen-Kettenis PT, Gooren LJG, Frijda NH, Van de Poll NE: **Activating effects of androgens on cognitive performance: causal evidence in a group of female-to-male transsexuals.** *Neuropsychologia* 1994, **32**:1153–1157.

A battery of cognitive tests was administered twice, once before and again three months after the onset of androgen treatment. Improvement was seen selectively on a test of rotated figures; verbal reasoning was unaffected, and verbal fluency tests were depressed.

32. Bakker J, Van Ophemert J, Slob AK: **Postweaning housing conditions and partner preference and sexual behavior of neonatally ATD-treated male rats.** *Psychoneuroendocrinology* 1995, **20**:299–310.

33. LeVay S, Hamer DH: **Evidence for a biological influence in male homosexuality.** *Sci Am* 1994, **270**:44–49.

34. Watson NV, Kimura D: **Nontrivial sex differences in throwing and intercepting: relation to psychometrically-defined spatial functions.** *Pers Individ Diff* 1991, **12**:375–385.

35. Allen LS, Gorski RA: **Sexual dimorphism of the anterior commissure and massa intermedia of the human brain.** *J Comp Neurol* 1991, **312**:97–104.

36. Holloway RL, DeLacoste MC: **Sexual dimorphism in the human corpus callosum.** *Hum Neurobiol* 1986, **5**:87–91.

37. Steinmetz H, Staiger JF, Schlaug G, Huang Y, Jäncke L: **Corpus callosum and brain volume in women and men.** *Neuroreport* 1995, **6**:1002–1004.

38. McGlone J: **Sex differences in human brain asymmetry: a critical survey.** *Behav Brain Sci* 1980, **3**:215–263.

39. • Shaywitz BA, Shaywitz SE, Pugh KR, Constable RT, Skudlarski P, Fulbright RK, Bronen RA, Fletcher JM, Shankweiler DP, Katz L, Gore JC: **Sex differences in the functional organization of the brain for language.** *Nature* 1995, **373**:607–609.

During a phonological speech processing task, functional magnetic resonance imaging techniques showed brain activation limited to the left inferior frontal region in men, whereas in women, activation was more diffuse, involving both left and right frontal regions.

40. Kimura D: *Neuromotor Mechanisms in Human Communication.* New York: Oxford University Press; 1993:139–159.

41. • Desmond DW, Glenwick DS, Stern Y, Tatemichi TK: **Sex differences in the representation of visuospatial functions in the human brain.** *Rehabil Psychol* 1994, **39**:3–14.

Equal numbers of male and female patients with right-hemisphere stroke were compared with same-sex control subjects on several visual perceptual tasks. Impairments on all tasks were at least as great in female subjects, suggesting that right-hemisphere dependence for such functions is at least as great in women as in men. This is one of the rare studies comparing the effects of brain lesions in men and women on tasks that depend primarily on the right hemisphere.

42. Cappa SF, Vignolo LA: **Sex differences in the site of brain lesions underlying global aphasia.** *Aphasiology* 1988, **2**:259–264.

43. • Hier DB, Yoon WB, Mohr JP, Price TR, Wolf PA: **Gender and aphasia in the stroke data bank.** *Brain Lang* 1994, **47**:155–167.

In patients with left-hemisphere stroke, infarct lesions producing aphasia were more posteriorly placed in men, more anterior in women.