# 1

# Why So Few Women in Math and Science?

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It should go without saying that, along with most scientists I know, I would like to see equal representation of women in all areas of employment, including science and math. It distressed me greatly when I first became a Fellow of Trinity College, Cambridge, known for its long tradition in math and science, that of the two hundred or so fellows, only three were women. Like many people I assumed that this lack of equality—which still distresses me—had arisen as the result of some subtle form of discrimination or deterrent. The most common sociocultural explanations put forward for this outcome were some form of misogyny; a lack of same-sex role models for female applicants; and insufficient support during key stages of career development for women (especially with respect to pregnancy and childrearing).

Having been in this environment for over a decade, I am persuaded that any misogyny that may have existed is not currently evident, since the math and science professors I have met are liberal and fair-minded. The absence of same-sex role models remains a problem. In the math lectures, the sex ratio is at least three to one (male to female); it must certainly feel strange to be a female student in the minority, with the teachers also nearly all male. Similar sex ratios among math students are seen in most universities. While this might deter some women from joining these professions, however, it cannot be the whole story; a sex difference is seen in math scores in high school in the United States, long before such role-model factors at the university level

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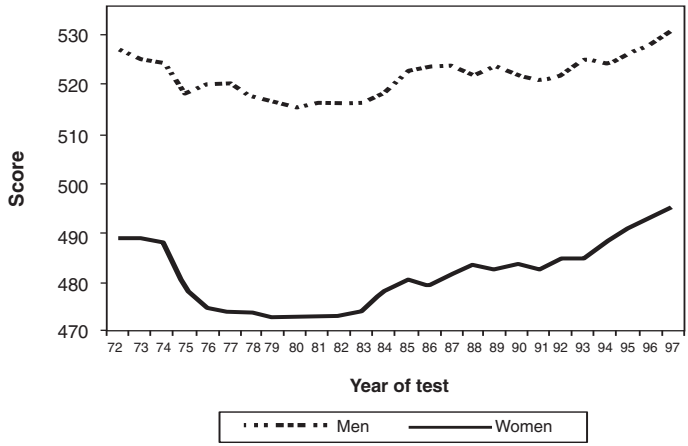
have had a chance to operate. Figure 1-1 shows, for example, the average scores on the SAT math test, year by year, from 1972 to 1997. Despite annual fluctuations, males outperform females consistently.

FIGURE 1-1
**SAT-MATH TEST RESULTS 1972–97**




SOURCE: Figure provided by Professor Steve Pinker with kind permission.

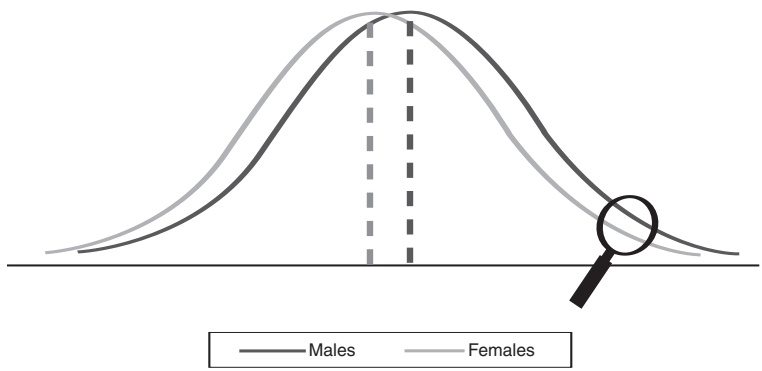
Finally, regarding the third of these sociocultural factors, the role of support around pregnancy and child care is much improved. In academia, the job is not a nine-to-five regular office job, but typically offers flexible hours. More fathers are involved in caring for their children, and parental leave following the birth of a child is funded not just for women, but for men, as well. In addition, more fellowships have been created just for female applicants. So, without denying a long history of discrimination against women, we can say that many of these sociocultural factors are lessening in importance in today's academic world. And yet, at higher levels in universities, the ratio of men to women in math continues to be around three males to every female. Why?

For me, the clearest clue regarding this sex ratio is the roster of winners of the Fields Medal, which is often referred to as "the Nobel Prize of

mathematics" and awarded to the most outstanding mathematicians under forty years of age. There has never been a female winner, despite this prize having been awarded regularly since 1950. This fact has prompted me to ask, what is going on at the extremes of the distribution of ability in math and science? To end up with a sex ratio of one to zero among Fields medalists, either the sociocultural factors are operating even more strongly in extreme groups, or we need also to consider some nonsocial factors. To my mind, these nonsocial factors include what we could call (for shorthand) personality type and biology. I will discuss each in turn and argue that they are not mutually exclusive. A certain personality type (namely, one that is more strongly drawn to "systemize") may, for partly biological reasons, be more common in males.

In making these arguments, I will be referring to *average* differences that are found in a small way when comparing males and females in the general population. And I will also refer to a statistical property of the normal distribution that has massive effects at its extremes.[1] Renowned Harvard psychologist Steve Pinker reminds us of a surprising mathematical property of the normal distribution (shown in figure 1-2): If two groups (such as males and females) differ a bit at the center of the range (in their

FIGURE 1-2
**TWO GROUPS (SUCH AS MALES AND FEMALES) DIFFER IN THEIR AVERAGE SCORES**

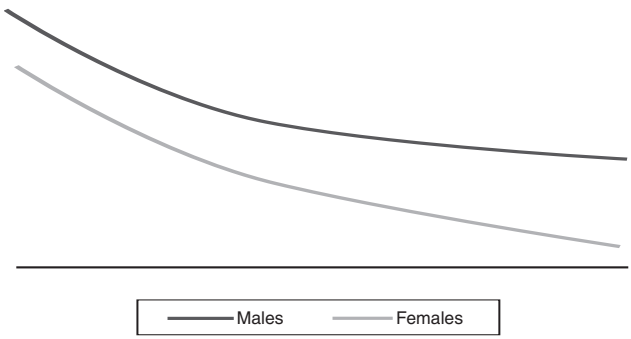



SOURCE: Figure provided by Professor Steve Pinker with kind permission.

means), then, because of the rate at which the slope of the curve falls off, the differences between them will be huge at the extremes. So, with height, for example, the two sexes differ by three inches on average. At five feet ten inches, the sex ratio is thirty to one (male to female). In people just two inches taller (six feet), the ratio jumps up to two thousand to one!

We can see quite why this is happening in figure 1-3, which blows up the portion of the distribution's right-hand tail that is indicated by the magnifying glass in figure 1-2. It becomes apparent that the gap between the sexes widens as we move to the extremes. This is a purely statistical property: The rate at which the slope falls off is a negative exponential of the square of the distance from the mean.

FIGURE 1-3
**AT THE EXTREMES, THE TWO GROUPS (E.G., MALES AND FEMALES) DIVERGE MUCH MORE**




SOURCE: Figure provided by Professor Steve Pinker with kind permission.

Since the statistical rule applies to any continuous dimension that is normally distributed, it will apply as much to psychological or personality traits as to height or blood pressure. Which psychological traits might be relevant, we may ask, when we think of typical sex differences in the population relevant to aptitude in science and math? And could a small sex difference in the center of the distributions become much bigger at the extremes? Finally, could these sex differences exist for partly biological reasons?

## Sex Differences in the General Population

There are interesting differences between the *average* male and female mind. In using the word "average," I am, from the outset, recognizing that such differences may have little to say about individuals. As we will see, the data actually require us to look at each individual on his or her own merits, as individuals may or may not be typical for their sex. The two relevant psychological processes in which we observe sex differences on average are *systemizing* and *empathizing*. Empathy is less relevant to the question about sex ratios in math and science, and is reviewed later. "Systemizing" is the drive to analyze the variables in a system to derive the underlying rules that govern its behavior. Systemizing also refers to the drive to construct systems. Systemizing allows one to *predict* the behavior of a system and to control it. I review the evidence indicating that, on average, males spontaneously systemize to a greater degree than do females.[2]

As systemizing is a new concept, it needs a little more definition. By a "system" I mean something that takes inputs and delivers outputs. To systemize, one uses "if–then" (correlation) rules. The brain focuses on a detail or parameter of the system and observes how this varies—that is, it treats a feature of a particular object or event as a variable. Alternatively, a person actively or systematically manipulates a given variable. One notes the effect(s) of performing an operation on one single input in terms of its effects elsewhere in the system (the output). The key data structure used in systemizing is [input–operation–output]. If I do $x$, $a$ changes to $b$. If $z$ occurs, $p$ changes to $q$. Systemizing therefore requires an exact eye for detail.

As shown in table 1-1, the human brain can analyze or construct at least six kinds of systems. Systemizing is an inductive process. One watches what happens each time, gathering data about an event from repeated sampling, often quantifying differences in some variables within the event and observing their correlation with variation in outcome. After confirming a reliable pattern of association—that is, generating predictable results—one forms a rule about how a particular aspect of the system works. When an exception occurs, the rule is refined or revised. Otherwise, the rule is retained. Systemizing works for phenomena that are ultimately lawful, finite, and deterministic. The explanation is exact, and its truth-value is testable. ("The light went on because the switch was in the up position.")

Systemizing is of almost no use for predicting moment-to-moment changes in a person's behavior, but it is our most powerful way of understanding and predicting the law-governed, inanimate universe.

TABLE 1-1
**MAIN TYPES OF SYSTEMS**

| Systems | Examples |
|---|---|
| Technical | A computer, a musical instrument, a hammer |
| Natural | A tide, a weather front, a plant |
| Abstract | Mathematics, a computer program, syntax |
| Social | A political election, a legal system, a business |
| Organizable | A taxonomy, a collection, a library |
| Motoric | A sports technique, a performance, a musical technique |

The relevant domains to explore for evidence of systemizing include any fields that are, in principle, rule-governed. Thus, chess and football are good examples of systems. As noted above, systemizing involves monitoring three elements: input, operation, and output. The operation is what was done or what happened to the input in order to produce the output.

So, what is the evidence for a stronger drive to systemize in males?

- *Toy preferences.* Boys are more interested than girls in toy vehicles, weapons, building blocks, and mechanical toys, all of which are open to being "systemized."[3]
- *Adult occupational choices.* Some occupations are almost entirely male. These include metalworking, weapon-making, the manufacture of musical instruments, and the construction industries, such as boatbuilding. The focus of these occupations is on creating systems.[4]
- *Predominantly male disciplines.* Math, physics, computer-science, and engineering all require high systemizing and are largely male-dominated.

- *Test scores.* The SAT Reasoning Test (formerly the Scholastic Aptitude Test and Scholastic Assessment Test), which is administered nationally to college applicants in the United States, is, in part, a test of math skills. Males on average score 50 points higher than females on this portion of the test.[5] Among individuals who score above 700 (out of a possible 800) points, the sex ratio is thirteen to one (men to women).[6]
- *Constructional abilities.* On average, men score higher than women in an assembly task in which people are asked to put together a three-dimensional (3-D) mechanical apparatus. Boys are also better at constructing block buildings from two-dimensional blueprints, and they show more interest than girls in playing with LEGO bricks, which can be combined and recombined into an infinite number of systems. Boys as young as three years of age are also faster at copying 3-D models of outsized LEGO pieces. Older boys, from the age of nine years, are better than girls at imagining what a 3-D object will look like if it is laid out flat, and at constructing a 3-D structure from just an aerial and frontal view in a picture.[7]
- *The water-level task.* Originally devised by the Swiss child psychologist Jean Piaget, the water-level task involves a bottle that is tipped at an angle. Individuals are asked to predict the water level. Women more often draw the water level aligned with the tilt of the bottle and not horizontally, as is correct.[8]
- *The rod-and-frame test.* The rod-and-frame test features a movable rod inside a movable frame. As the frame is moved, the subject is asked to adjust the rod to keep it in a vertical position. A person whose judgment of vertical orientation is influenced by the tilt of the frame is said to be "field-dependent"—that is, his or her judgment is easily swayed by extraneous input in the surrounding context. One who is not influenced by the tilt of the frame is said to be "field-independent." Most studies indicate that females are more field-dependent—that is, women are relatively more distracted by contextual cues, and they tend not to consider each variable within a system separately. They are more likely than

men to state erroneously that a rod is upright if it is aligned with its frame.[9]

- *The embedded-figures test.* Attention to relevant detail, which is a general feature of systemizing and clearly a necessary part of it, is superior in males. One measure of this is the embedded-figures test. On average, males are quicker and more accurate than women in locating a target object in a larger, complex pattern.[10] Males, on average, are also better at detecting a particular feature (static or moving).[11]
- *The mental rotation test.* The mental rotation test involves systemizing because it is necessary to treat each feature in a display as a variable that can be transformed (for instance, rotated) and then predict the output, or how it will appear after transformation. Again, men are quicker and more accurate than women in performing the task.[12]
- *Reading maps.* Map-reading is an everyday test of systemizing in that it requires features from 3-D input to be transformed to a two-dimensional representation. In general, boys perform at a higher level than girls in map-reading. Men can also learn a route by looking at a map in fewer trials than women, and they are more successful at correctly recalling details about direction and distance. This observation suggests that men treat features in a map as variables that can be transformed into three dimensions. When children are asked to make a map of an area that they have only visited once, boys' maps have a more accurate layout of the features in the environment. More of the girls' maps make serious errors in the location of important landmarks. Boys tend to emphasize routes or roads, whereas girls tend to emphasize specific landmarks (the corner shop, the park, and so on). These strategies of using directional cues versus using landmark cues have been widely studied. The directional strategy represents an approach to understanding space as a geometric system. Similarly, the focus on roads or routes is an example of considering space in terms of another system, in this case a transportation system.[13]

- *Motoric systems performance.* When asked to throw or catch moving objects (target-directed tasks), such as playing darts or intercepting balls flung from a launcher, males tend to perform better than females. In addition, men are, on average, more accurate than women in their ability to judge which of two moving objects is traveling faster.[14]
- *The Systemizing Quotient.* A questionnaire that has been tested among adults in the general population, the Systemizing Quotient includes forty items that ask about a subject's level of interest in a range of different systems existing in the environment, including technical, abstract, and natural systems. Males score higher than females on this measure.[15]
- *Mechanics test.* The Physical Prediction Questionnaire (PPQ) is based on an established method for selecting applicants to study engineering. The task involves predicting in which direction levers will move when an internal mechanism of cogwheels and pulleys is engaged. Men score significantly higher on this test than women.

### Female Advantage in Empathy

We have summarized the evidence for a stronger interest in systems in males, but there is also a body of evidence suggesting that females have a stronger interest in and aptitude for empathy. As summarized below, sex differences of a small but statistically significant magnitude have been found by studies in a number of areas:

- *Sharing and turn-taking.* On average, girls show more concern for fairness in sharing, while boys share less. In one study, boys showed a propensity for competition fifty times greater than that of girls, while girls were twenty times more likely than boys to take turns.[16]
- *Rough-and-tumble play, or "rough-housing."* Boys engage in more wrestling, mock fighting, and other such activities than girls. While often playful, rough-housing can cause injuries or be

intrusive, suggesting that higher levels of empathy may tend to discourage it.[17]

- *Responding empathically to the distress of other people.* Girls from the age of one year show greater concern for others through sad looks, sympathetic vocalizations, and comforting behavior than do boys. More women than men report frequently sharing the emotional distress of their friends and demonstrate more comforting behavior, even toward strangers, than men do.[18]
- *Using a "theory of mind."* As early as three years of age, little girls are ahead of boys in their ability to infer what people might be thinking or intending.[19]
- *Sensitivity to facial expressions.* Women are better at decoding nonverbal communication, picking up subtle nuances from tone of voice or facial expression, or judging a person's character.[20]
- *Tests of empathy.* Women score higher than men on questionnaires designed to measure empathic response.[21]
- *Values in relationships.* More women than men value the development of altruistic, reciprocal relationships, which by definition require empathizing. In contrast, more men than women value power, politics, and competition.[22] Girls are more likely to endorse cooperative items on a questionnaire and to rate the establish-ment of intimacy as more important than the establishment of dominance. In contrast, boys are more likely than girls to endorse competitive items and to rate social status as more important than intimacy.[23]
- *Disorders of empathy.* Disorders such as psychopathic personality disorder and conduct disorder are far more common among males.[24]
- *Aggression.* Aggression can occur only with reduced empathizing. Here again, there is a clear sex difference. Males tend to display far more "direct" aggression (such as pushing, hitting, and punching), while females tend to show more "indirect" (relational, covert) aggression (such as engaging in gossip, excluding others,

and making cutting remarks). Engaging in direct aggression may involve a lower level of empathy than engaging in indirect aggression, while indirect aggression may call for better mind-reading skills because its impact is strategic.[25]

- *Murder.* The deliberate taking of life is the ultimate demonstration of a lack of empathy. Daly and Wilson analyzed homicide records dating back over seven hundred years, from a range of different societies. They found that "male-on-male" homicide was thirty to forty times more frequent than "female-on-female" homicide.[26]
- *Establishment of "dominance hierarchies."* Males are quicker than females to establish forms of social organization in which members compete over resources by means of aggression. Typically, a dominance hierarchy is established by one or more individuals pushing others around to become the leaders, which in part may reflect lower empathizing skills.[27]
- *Language style.* Girls' speech is more cooperative, reciprocal, and collaborative than that of boys. In concrete terms, this difference is reflected in girls' ability to continue a conversational exchange with a partner for a longer period. When girls disagree, they are more likely to express their differing opinions sensitively, in the form of questions rather than assertions. Boys' talk is more "single-voiced discourse"—that is, the speaker presents only his own perspective. The female speech style is more "double-voiced discourse"—a girl will spend more time negotiating with her partner, trying to take the other person's wishes into account.[28]
- *Language abilities.* Females have been shown to have better language skills than males. It seems likely that good empathizing would promote language development,[29] and vice versa, so these factors may not be independent.
- *Talk about emotions.* Women's conversations involve much more talk about feelings than men, while men's conversations tend to be more object- or activity-focused.[30]
- *Parenting style.* Fathers are less likely than mothers to hold their infants in a face-to-face position. Mothers tend to go along with

their children's choices in play, while fathers are more likely to impose their own choices. Also, mothers more often fine-tune their speech to match their children's understanding.[31]

- *Face preference and eye contact.* From birth, females look longer at faces, particularly at people's eyes, whereas males are more likely to look at inanimate objects.[32]

## Culture and Biology

At one year of age, boys strongly prefer to watch a video of cars going past, an example of predictable mechanical systems, than to watch a film showing a human face. Little girls show the opposite preference. Girls also engage in more eye contact than boys at this age.[33] Some investigators argue that differential socialization may cause such sex differences, even at a very early age.

While evidence does exist for socialization contributing to these differences, this is unlikely to be a sufficient explanation. Connellan and colleagues have shown that among *one-day-old* babies, boys look longer at a mechanical mobile, which is a system with predictable laws of motion, than at a person's face, an object that is next to impossible to systemize. One-day-old girls show the opposite profile.[34] These sex differences are, therefore, present earlier in life than can be plausibly explained by socialization, raising the possibility that, while culture and socialization may to some extent determine the development of a brain prone to a stronger interest in systems or empathy, biology may also play a part. Evidence supporting both cultural determinism and biological determinism is ample.[35] For example, one's score on the Systemizing Quotient (SQ) questionnaire is positively correlated with the prenatal level of testosterone.[36]

## Conclusions

We have reviewed much evidence suggesting significant sex differences in the drive to systemize and empathize. While on some tests this is expressed in terms of ability, my own view is that these differences are fundamentally

a reflection of *drives* or *interests* rather than ability, per se. That is, on average, more boys than girls are attracted to systems from an early age, and this difference leads more boys to pursue activities (such as math or music or skateboarding) that involve systemizing. Increased practice can lead to stronger ability, but it remains plausible that these are primarily differences in personality, with differences in ability being secondary. Equally, we have reviewed evidence that, on average, more girls than boys are attracted to people and the emotional lives of others, which involves empathizing.

The causes of these fundamental differences remain unclear, but over and above the role of experience and the postnatal environment (including differences in socialization), candidates for prenatal biological factors that may be implicated include both genetic differences and testosterone levels in utero.[37] We can find another clue that systemizing and empathizing may have a partly genetic basis in the fact that in the neurodevelopmental condition of autism, which is genetic, the drive to systemize is even stronger than in the general population, while empathy is impaired. Indeed, it is possible that autism exemplifies "extreme maleness."[38]

The research reviewed above suggests we should not expect the sex ratio in occupations such as math or physics ever to be fifty-fifty if the workplace is left simply to reflect the numbers of applicants of each sex who are drawn to such fields. If we want a particular field to have an equal representation of men and women, which I think may be desirable for reasons other than scientific, we need to put in place social policies that will produce that outcome.

Finally, and most importantly, the research teaches us that there is no scientific justification for stereotyping, since none of the studies allows one to predict an individual's aptitudes or interests on the basis of his or her sex. This is because—at risk of repetition—the studies only capture differences between groups on average. Individuals are just that: They may be typical or atypical for their group. Prejudging an individual on the basis of his or her sex is, as the word "prejudge" suggests, mere prejudice.

## Notes

1. For this second argument, I am grateful to Steve Pinker both for pointing it out and for giving permission to reproduce figures 1-2 and 1-3 from his files.
2. Baron-Cohen et al. 2002.
3. Jennings 1977.
4. Geary 1998.
5. Benbow and Stanley 1983.
6. Geary 1996.
7. Kimura 1999.
8. Wittig and Allen 1984.
9. Witkin et al. 1954.
10. Elliot 1961.
11. Voyer et al. 1995.
12. Collins and Kimura 1997.
13. Galea and Kimura 1993.
14. Schiff and Oldak 1990.
15. Baron-Cohen et al. 2003.
16. Charlesworth and Dzur 1987.
17. Maccoby 1999.
18. Hoffman 1977.
19. Happe 1995.
20. Davis 1994.
21. Baron-Cohen and Wheelwright 2004.
22. Ahlgren and Johnson 1979.
23. Knight et al. 1989.
24. Dodge 1980; Blair 1995.
25. Crick and Grotpeter 1995.
26. Daly and Wilson 1988.
27. Strayer 1980.
28. Smith 1985.
29. Baron-Cohen et al. 1997.
30. Tannen 1990.
31. Power 1985.
32. Connellan et al. 2001.
33. Lutchmaya and Baron-Cohen 2002.
34. Connellan et al. 2001.
35. Eagly 1987; Gouchie and Kimura 1991.
36. Lutchmaya et al. 2002. For a review of the evidence for the biological basis of sex differences in the mind, see Baron-Cohen 2003.
37. Bailey, Bolton, and Rutter 1998.
38. Baron-Cohen 2003.

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