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Sex Differences in Math-Intensive Fields

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Abstract

Despite impressive employment gains in many fields of science, women remain underrepresented in fields requiring intensive use of mathematics. Here we discuss three potential explanations for women's underrepresentation: (a) male–female mathematical and spatial ability gaps, (b) sex discrimination, and (c) sex differences in career preferences and lifestyle choices. Synthesizing findings from psychology, endocrinology, sociology, economics, and education leads to the conclusion that, among a combination of interrelated factors, preferences and choices—both freely made and constrained—are the most significant cause of women's underrepresentation.

Keywords

sex differences; mathematic ability; spatial ability; discrimination; career aspirations

Since 1970, there has been exponential growth in women's representation in scientific careers. Today, half of all MD degrees are earned by women, as are 48% to 52% of PhDs in life sciences and the majority of doctorates to new psychologists (71%) and veterinarians (77%). However, in the most mathematically intensive fields—engineering, physics, mathematics, chemistry, economics, and computer science—women's progress has been much less dramatic. In the top 100 U.S. universities, only 9% to 16% of tenure-track positions in math-intensive fields are occupied by women (Nelson & Brammer, 2010). Among full professors, women number around or fewer than 10%: computer science, 10.3%; chemistry, 9.7%;economics, 8.7%; chemical engineering, 7.3%; mathematics, 7.1%;civil engineering, 7.1%;electricalengineering, 5.7%;physics, 6.1%; and mechanical engineering, 4.4%. In contrast, women are much better represented in the rest of the sciences and humanities, often making up one third or more of professorial posts.

Various explanations for the underrepresentation of women in math-intensive fields have been given. Here we review evidence for three: (a) sex differences in mathematical and spatial ability; (b) sex discrimination in publishing, funding, and hiring; and (c) occupational/lifestyle preferences and choices that reduce women's participation in math-intensive fields. The relevant data come from many areas of scholarship—endocrinology, economics, sociology, education, genetics, and psychology—and from different nations, age groups, and historical cohorts. (This evidence is reviewed in greater detail in Ceci & Williams, 2010, and Ceci, Williams, & Barnett, 2009.)

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Three Factors

I. Do sex differences in mathematical and spatial ability explain women's underrepresentation?

There are no systematic sex differences in *mean* mathematics scores, although male variances are 10% to 20% greater, resulting in disproportionately more males at both tails of the ability distribution. This is important because scientists in mathematical fields hail from the right tail of the quantitative distribution, not from the center, although how far out on the right tail is an open question. Figure 1 illustrates the GRE-Quantitative scores of Cornell graduate students in math-intensive fields. As can be seen, they come from the right tail, and the test actually underestimates this due to ceiling problems. Many achieve scores of 800, the highest score possible (15% achieve 750 and above); a test with a higher ceiling might spread these scores out, possibly accentuating the sex differences. Other sources of data agree with this claim (Ceci & Williams, 2010).

If professors in math-intensive fields come from the right tail of the quantitative distribution, then there are more men than women. Among the top 1% of scorers, there are 2 males for every female (e.g., Hyde, Lindberg, Linn, Ellis, & Williams, 2008; Wai, Cacchio, Putallaz, & Makel, 2010). Due to greater male variability, the farther out on either tail, the higher the ratio of males to females. During the 2006–2010 period, among 7th-grade perfect-800 scorers on the SAT-M, there were 6.58 males for every female (Wai et al., 2010). In the past 20 years, there have been nine perfect scorers among 7th graders on the ACT-Science test, eight of whom were male.

One could argue that the overabundance of males at the right tail explains women's underrepresentation: If there are twice as many males in the top 1%, then graduate admissions committees may admit more men. But this cannot be the whole story, or even most of it, because females get as good or better grades in math than do males (Gallagher & Kaufman, 2005). This has led some to suggest the SAT-M is biased against females, because the real measure of competence is mastering the curriculum, at which they excel. However, some claim that grading is biased against males because grades do not reflect their ability: In a study of 67,000 college calculus students, men receiving grades of D and F had SAT-M scores comparable to women receiving grades of B (Wainer & Steinberg, 1992). Putting aside which interpretation is correct, there is a reality that should not be overlooked. If scoring among the top 1% is required for success in math-intensive careers, there should be more women in these fields, because there is nowhere close to the 2-to-1 ratio in these careers. Something more than scoring at the right tail is responsible for the shortage of women. Furthermore, when analyses are restricted to those with high mathematical ability, fewer women than men choose these fields (Lubinski & Benbow, 2006).

Some argue that those who succeed in mathematical fields come from more rarified strata than the top 1%—perhaps the top .01% (1 in 10,000). There is no clear threshold beyond which extra mathematical prowess does *not* help; those in the top quarter of the top 1% outperform those in the bottom quarter of the top 1% on rates of landing tenure-track jobs, publishing articles and patents, and so on (Park, Lubinski, & Benbow, 2008). Thus, perhaps the sex ratio among prospective professors in these fields is greater than 2 to 1 and more in line with the sex asymmetries observed. Although it is possible, there exists no evidence to test this claim, and math-talented females are disproportionately less likely than matched males to enter these professions.

Males also excel in the ability to mentally rotate figures in three-dimensional space. This is a robust finding, with dozens of replications; Wai, Lubinski, and Benbow (2009) have shown that spatial ability in conjunction with mathematical ability has consistently predicted performance in math-intensive fields for more than half a century. In large meta-analyses, the effect size for spatial ability is substantial, .50 to .75 for male superiority. Male 4- to 5-month-olds mentally rotate better than females the same age. Playing with LEGOs, erector sets, blocks, and dynamic videogames, as well as attending graphics classes, boosts females' spatial skills, although not usually to males' levels (e.g., Baenninger & Newcombe, 1995; Terlecki, Newcombe, & Little, 2007). Notwithstanding the male advantage on three-dimensional spatial rotation, there is no direct evidence that this ability accounts for the shortage of women in math-intensive fields. This is not to assert it does not, but to point out that there is no compelling evidence it does. Relatedly, 46% of undergraduate mathematics majors are women, as are 30% of PhDs in mathematics, suggesting that whatever these women's spatial skills, they are compatible with high levels of achievement.

Finally, the omnipresent claim that sex differences in mathematics result from early socialization (i.e., parents and teachers inculcating a "math is for boys" attitude) fails empirical scrutiny. One cannot assert that socialization causes girls to opt out of math and science when girls take as many math and science courses as boys in grades K–12, achieve higher grades in them, and major in college math in roughly equal numbers to males. Moreover, survey evidence of parental attitudes and behaviors undermines the socialization argument, at least for recent cohorts (Ceci & Williams, 2010).

Thus, spatial and mathematical differences between the sexes are best viewed as secondary factors in women's under-representation in math-intensive fields.

II. Does sex discrimination account for the dearth of women?

Some have proffered "biases and barriers" as the cause of women's underrepresentation. But discussions on this topic often conflate two distinct phenomena—discrimination, on the one hand, and gendered outcomes resulting from biologically and socially influenced choices, on the other. In our framework, *discrimination* exists when women's successes are lower than men's for comparable achievements, such as when a manuscript submitted to a journal has a lower chance of acceptance if it bears a female name, a given CV is downrated by search committees when it bears a woman's name, or a woman's grant has to be superior in quality to a man's to earn a comparable score. In contrast to discrimination, biologically and socially influenced choices—either freely made or constrained—may lead to outcome differences favoring one gender but need not involve discrimination. Often-mentioned examples of gendered outcomes resulting from choices include reduced likelihood of earning tenure and increased likelihood of opting out of full-time tenure-track work by women raising young children (since they work fewer hours at their jobs than both male counterparts and childless females), and reduced productivity by women due to their greater likelihood of working at teaching-intensive institutions with fewer resources for research. Such gender-linked conditions do not involve discrimination in our framework, but they can nevertheless make things more difficult for women (e.g., coincidence of tenure clock with fertility clock). Unlike discrimination, such gendered outcomes emanate from personal choices—both freely made and constrained—such as the choice to have children, take care of elderly parents, or seek jobs within a limited geographic area to remain with partners or extended family.

Three studies are frequently cited as evidence for discrimination against women in gaining admission to programs, winning funding for fellowship applications, and getting hired by search committees: Wenneras and Wold (1997), Trix and Psenka (2003), and Steinpreis, Anders, and Ritzke (1999). Elsewhere we have analyzed these findings and concluded they are unable to explain the low numbers of women in math-intensive fields, nor are other studies alleging discriminatory manuscript acceptances, hiring, and grant awarding (see Ceci & Williams, 2010; Ceci et al., 2009). For example, persuasive counterevidence reveals no discrimination against women's grant applications (e.g., Marsh, Bornmann, Mutz, Daniel, &

O'Mara, 2009) or likelihood of being hired. A National Academy of Science task force found that, among new PhDs applying for tenure-track jobs, women were slightly *more* likely to be invited to interview than men, and there were no sex differences in job offers or resources:

> For the most part, men and women faculty in science, engineering, and mathematics have enjoyed comparable opportunities within the university. ... Women fared well in the hiring process at Research I institutions, which contradicts some commonly held perceptions of research universities. If women applied for positions at RI institutions, they had a better chance of being interviewed and receiving offers than male job candidates had. (Committee on Gender Differences, 2010, p. 5)

Others have a found a similar lack of discrimination. Ginther and Kahn (2006) analyzed promotion and pay data, noting that historic asymmetries favoring males disappeared by the early 2000s, with current asymmetries resulting from nongender factors. Others have also found that after controlling for structural variables such as status of the university, discipline, and presence of young children before tenure—all of which penalize women disproportionately—there is no evidence of discriminatory treatment, because men in the same circumstances fare equivalently. Again, these variables certainly disadvantage women more than men, but they result from choices made by women, and when women make other choices they fare equivalently to men.

Structural variables that impede progress, although correlated with gender, can be just as detrimental to men. For example, although electing to have children early in one's career may lead to subsequent productivity issues, not all women make this choice, and it also presents a challenge for men caring for children (e.g., divorced fathers sharing custody), sick partners, or elderly parents. Women without children fare equivalently to men with or without children (men with or without children fare similarly because those with children have partners who do most of the childrearing; Ceci & Williams, 2010; Hill, Corbett, & St. Rose, 2010). If choosing to have children reduces scientific productivity (and causes the pay and promotion consequences), this does not represent discrimination, despite the fact that women are disproportionately affected. In sum, it is essential to distinguish between claims of outright discrimination against women and gendered outcomes that may affect more women than men because of women's choices but not because they are women per se. The evidence shows that sex discrimination does not account for women's underrepresentation in math-intensive fields.

III. Do gender differences in interest, preferences, and lifestyle choices explain the underrepresentation of women?

If neither ability differences nor discrimination is a primary cause of the dearth of women in math-intensive fields, what is? Evidence points to sex differences in preferences and choices, with the caveat that choices can be either freely made or constrained by biology and society. In adolescent surveys, it is less common for girls to name math-intensive career aspirations. For example, one recent poll of 8- to 17-year-olds reported 24% of boys interested in engineering versus only 5% of girls; a survey of 13- to 17-year-olds reported 74% of boys interested in computer science versus only 32% of girls. Some have suggested that females are more interested in careers involving social relations, such as law and medicine, and males are more interested in fields involving systematizing inanimate objects. A recent meta-analysis revealed sex differences in the people-versus-things dimension of educational/vocational interests (Su, Rounds, & Armstrong, 2009). As we noted earlier, females with high math aptitude are less interested in math-intensive careers than are comparable males (Lubinski & Benbow, 2006).

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One overlooked factor is that, among males and females of comparably outstanding mathematical aptitude, females are more likely to also have outstanding verbal ability (Park et al., 2008). This gives them more career choices than males, who are aware their strength is only math, whereas females can consider math-oriented fields as well as law, social sciences, humanities, and medicine. Finally, surveys show sex differences in desire to work 50 or more hours per week, in desire to focus on career over family, and in preference for part-time positions. These factors are not unique to math-intensive fields, but they become relevant when the pipeline leading to PhDs lacks women to begin with, as in mathematical fields. Here, small perturbations matter in the desire to pursue academic jobs requiring long hours and delayed fertility choices, further reducing an already undersized pool.

A historical perspective is revealing. In 1960, only 5.9% of all doctorates in mathematics went to women. Some concluded this was because women were not up to the challenge of high-level mathematics or that their disposition was not cut out for the grueling world of 60 hours/week science (assuming these careers were somehow more grueling than other scientific and medical careers—an assumption for which no data exists). In a very short time, however, women increased their representation in most fields of science 3- to 10-fold; by 2006, women earned 29.6% of PhDs in mathematics, and similarly impressive gains occurred in engineering and physics. This rapid growth dis-abused those who believed women were not cut out for science. Interestingly, women made these gains without an abundance of female role models. Consider: In 1963, fewer than 5% of veterinary students were female, but today 77% of DVM recipients are women. Similarly, in 1976, only 8% of biology PhDs went to women, but by 2006, 48% to 52% went to women. These gains occurred while male professors did most of the supervision. Although this does not prove same-sex mentors are unimportant (cf. Blau, Currie, Croson, & Ginther, 2010), it seems premature to assume they are essential.

Another historical insight concerns the fluidity of elite mathematics performance. In the early 1980s, 13 male 7th graders for every 1 female scored at the top 0.01%, or 1 in 10,000, (i.e., scoring ≥700 on the SAT-M in 7th grade; Benbow & Stanley, 1983). Lest one think this ratio reflects strict biological determinism, by the mid-1990s it had shrunk to 4-to-1, where it has remained (Wai et al., 2010). And international comparisons contain occasional instances of women outperforming men in mathematics.

In sum, women's preferences and choices—freely made and constrained—play a preeminent role in their under-representation.

Conclusion

The relatively small numbers of women in math-intensive careers result from many factors, one of which seems primary and should be accorded the greatest weight. Sex differences in mathematical and spatial ability, although substantial, appear unable to explain most of the shortage. Nor can the shortage be attributed to current discrimination, although historic discrepancies may be explained in such terms. The primary factor in women's underrepresentation is choices both freely made and constrained by biology and society. Women choose at a young age not to pursue math-intensive careers; few adolescent girls express desires to be engineers or physicists, preferring instead to be medical doctors, veterinarians, biologists, psychologists, and lawyers. Females make this choice despite earning higher math and science grades than males throughout schooling. Although women earn a large portion of baccalaureate degrees in all fields of science, including mathematics, disproportionately fewer enter graduate school in these fields, preferring biology, social sciences, law, medicine, and the humanities—even when they possess math ability comparable to males. Of those who enter graduate school in math-intensive fields, more women than men drop out or change fields, and of those who complete doctorates, fewer women apply for tenure-track positions. Women drop out of scientific careers—especially math and physical sciences—after entering them as assistant professors at higher rates than men, and this remains true as women advance through the ranks. Although the reasons for this attrition are not well understood, it appears to have less to do with discrimination or ability than with fertility decisions and lifestyle choices, both freely made and constrained. The tenure structure in academe demands that womenhavingchildrenmaketheir greatest intellectual contributions contemporaneously with their greatest physical and emotional achievements, a feat not expected of men. When women opt out of full-time careers to have and rear children, this is a choice—constrainedbybiology—thatmen arenot required to make.

Recommended Reading

Ceci, S.J., & Williams, W.M. (2010). (See References). Provides a comprehensive, highly accessible overview of what is known about sex differences in math-intensive fields, based on more than 400 published studies, and containing the references for many of the claims made in this article.

Committee on Gender Differences in the Careers of Science, Engineering, and Mathematics Faculty; Committee on Women in Science, Engineering, and Medicine; National Research Council. (2010). (See References) An in-depth analysis of the academic interviewing, hiring, institutional resources, climate, and tenure and promotion statistics of top research universities in six areas of natural science.

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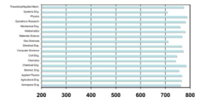

Fig. 1.

Mean GRE-Quantitative scores of 480 Cornell graduate students in math-intensive fields for the year 2006. (Overall mean = 760)

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