Sex Differences in Intrinsic Aptitude for Mathematics and Science:

A Critical Review

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Abstract

This report considers three prominent claims that boys and men have greater natural aptitude for high-level careers in mathematics and science. According to the first claim, males are more focused on objects and mechanical systems from the beginning of life. According to the second claim, males have a profile of spatial and numerical abilities that predisposes them to greater aptitude in mathematics. According to the third claim, males show greater variability in mathematical aptitude, yielding a preponderance of males at the upper end of the distribution of mathematical talent. Research on cognitive development in human infants and preschool children, and research on cognitive performance by students at all levels, provides evidence against these claims. Mathematical and scientific reasoning develop from a set of biologically based capacities that males and females share. From these capacities, men and women appear to develop equal talent for mathematics and science.

Sex Differences in Intrinsic Aptitude for Mathematics and Science: A Critical Review

The academic faculties of U.S. universities are predominantly male, especially in the fields of mathematics, engineering, and science. Recent discussions of this disparity have focused attention on a pair of longstanding claims. First, there are fewer women on mathematics and science faculties, because few women are capable of academic work at the highest levels of these fields. Second, this sex difference has a genetic basis: women have less "intrinsic aptitude" for mathematics and science. The present review examines these claims in light of evidence from research in developmental and cognitive psychology.

Three claims for sex differences in intrinsic aptitude have received the greatest attention. One claim was given new life by the cognitive neuroscientist Simon Baron-Cohen in a recent book, *The Essential Difference* (2003). From the first day of life, Baron-Cohen suggests, male and female infants are predisposed to learn about different things: Male infants focus on objects and their mechanical relationships, whereas female infants focus on people, emotions, and personal relationships. From these beginnings, boys are more apt than girls to develop the knowledge and skills required by mathematics and science. A second claim focuses on the specific cognitive systems that give rise to effective reasoning in mathematics. Boys and men are said to have better command over these systems than do girls and women, for reasons that stem in part from genetic differences between the sexes (Geary, 1998; Kimura, 1999). A third claim, brought to

prominence by the educational psychologist, Camilla Benbow, focuses not on differences between the abilities of average males and females but rather on gender disparities at the upper end of the ability distribution. Males are said to show greater variability in their cognitive capacities, for reasons that are partly genetic. As a result, there are more males than females in the pool of extremely talented students from which future mathematicians and scientists will emerge (Benbow, 1988; see also Pinker, 2002).

Somewhat in contradiction to these three claims is a fourth: the role of genetic differences in producing the gender gap on math and science faculties is not known, because the relevant research has not been conducted. In our current state of ignorance, we should be open-minded and consider seriously the possibility that women are scarce on mathematics and science faculties because women have a genetic, cognitive disadvantage in these fields (Cronin, 2005; Pinker, 2005; Summers, 2005). Some commentators have suggested that it is unfair to women to neglect this possibility, because such neglect effectively denies to women the remediation they may need in order to succeed (Cronin, 2005).

A review of the evidence yields little support for these claims. Contrary to the last claim, a substantial amount of research has investigated the nature and development of sex differences in cognitive abilities. Although this research reveals a number of intriguing differences between males and females, it provides no evidence for sex differences in aptitude for mathematics or science. Instead, the research suggests that males and females have equal aptitude, both on average and at the highest levels of talent. Moreover, this research suggests that the cognitive differences between men and women are dwarfed by our common cognitive capacities. I review this research in this report. If males and females have equal aptitude for mathematics and science, questions concerning the genetic basis of cognitive sex differences do not bear on current discussions of the causes of the gender gap on faculties of science and mathematics. Nevertheless, this review considers briefly the evidence for a genetic contribution to human cognitive capacities for mathematics and science. This evidence suggests that our species' talent for mathematical and scientific thinking has a considerable genetic basis, in a set of capacities that men and women share.

Sex differences in infants' orientation toward objects?

Baron-Cohen (2003) proposed that from the first day of life, human males are primarily interested in objects and their mechanical interactions, whereas human females are primarily interested in people and their social and emotional interactions. He cited as evidence an experiment conducted in his laboratory on newborn infants (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000). Infants were propped up in a crib or on a parent's lap and shown, side by side, a live, active and expressive person and a similarly sized inanimately moving object. Male infants looked longer at the object than the person, whereas female infants looked longer at the person than the object. Baron-Cohen concluded that male infants are predisposed to learn about mechanical systems, whereas female infants are predisposed to learn about mechanical systems, whereas female infants are predisposed to learn about mechanical source predisposition leads boys to become "systematizers" who engage both with the mechanical world and with abstract systems like mathematics.

Baron-Cohen is not the first to claim that men are rational and women are emotional, but the experiment by Connellan et al. (2000) seems to give that claim its first clear support. This experiment, however, is unusual in three respects. First, it stands alone. It is customary, in research on cognition in infancy, to replicate key findings and assemble multiple experiments in support of any given hypothesis. For example, early reports that newborn infants were capable of imitation (e.g., Meltzoff & Moore, 1977) were not accepted until they had been replicated in scores of further experiments from multiple laboratories (e.g., Field, Woodson, & Greenberg, 1982; Reissland, 1988; see Meltzoff & Moore, 1999, for a review). In contrast, no replication of Connellan et al.'s (2000) experiment has been published, and no unpublished replications are mentioned in Baron-Cohen's (2003) report of this finding. The lack of replication is particularly curious, because there is a long, older literature that contradicts Connellan et al's (2000) finding and provides evidence that male and female infants attend equally to people and objects (Maccoby & Jacklin, 1974).

Second, the experiment does not attempt to determine the basis for infants' preference between the face and object. Assertions that infants prefer one category of entities to another must address a range of critical questions. Does the preference depend on the categorical distinction between the entities or on other differences between the two displays, such as their rate of motion or distribution of color or contrast? Does the preference generalize to other members of the two categories, or is it specific to the tested pair? (For recent discussions of these issues, see Cohen, 2003; Mandler, 2004; Quinn & Oates, 2004; Shutts & Spelke, 2004.) Connellan et al. (2000) and Baron-Cohen (2003) do not raise these questions. Indeed, neither report describes the two stimuli in enough detail to evaluate the possible bases of infants' preferences.

Third, the experiment lacks critical controls against experimenter bias. Because newborn infants cannot hold their heads erect independently, their visual preferences can be influenced by the way in which the parent or experimenter supports them. There is no indication that Connellan et al. (2000) guarded against this potential source of bias by ensuring that the parent who held the infant, or the assistant who positioned the infant in his or her crib, was ignorant of the locations of the two objects or the infant's gender. There is also no discussion in Connellan et al. (2000) of the possibility that the person who served as the stimulus--who was also first author on the paper--might have biased infants' preferences by behaving differently toward male and female infants. The lack of attention to these sources of bias is unusual in infant research.

Despite its limitations, this experiment has received considerable attention (e.g., Cronin, 2005; Hauser, 2005; Sax, 2005). Because of the breadth and force of the arguments that have been based on it, it is important to evaluate a key prediction of its findings, and of Baron-Cohen's claims. If male infants orient primarily to mechanical objects from the first day of life, then we should expect them to show superior learning about objects and their properties. Over the last three decades, many experiments have investigated infants' perception of and learning about objects. This literature has received wide attention by experimental psychologists, popular science writers, and television science programs. Curiously, Baron-Cohen (2003) does not mention this work, and it has not figured in the recent discussions of sex differences. Let us consider its findings.

Object perception begins at birth: newborn human infants perceive the colors, shapes, sizes, and orientations of objects (e.g., Slater, Mattock & Brown, 1990), and they

perceive and extrapolate object motions (e.g., von Hofsten, 1982). Newborn infants also perceive the complete shapes of partly hidden objects under a limited set of conditions (Valenza, Gava, Leo & Simion, 2004). Over the first four months, abilities to perceive and reach for objects develop rapidly (see von Hofsten, 1991, Johnson, 2004, and Spelke, 1990, for reviews). Moreover, infants begin to represent objects that move fully out of view, they make inferences about mechanical interactions between objects, and they begin to group objects into categories (Baillargeon, 2004; Hespos & Spelke, 2004; Quinn & Eimas, 1996). By six months, for example, infants reason about the forces that influence object motion (Kotovsky & Baillargeon, 1998; Leslie, 1982). All of these conclusions are supported by multiple, converging experiments that test systematically both the existence and limits of infants' abilities, with displays that are described in detail and are systematically varied to pinpoint the basis of infants' responses, and with methods that guard against potential sources of bias.

In all these studies, male and female infants are tested. In most studies, the performance of the two genders is compared systematically. Most studies find no gender differences. Some studies find an advantage for female infants, particularly in the domain of mechanical reasoning and at ages when new abilities emerge (e.g., Baillargeon, Kotovsky & Needham, 1995, for review). At about 6 months of age, for example, infants take the first steps toward understanding that the distance an object travels depends on the force with which it is hit; female infants pass this milestone at 5.5 months, and males at 6.5 months (Kotovsky & Baillargeon, 1998). These findings do not support Baron-Cohen's thesis that male infants are predisposed to learn more readily about the workings of the world. Male infants have no systematic advantage over

females in their capacities to perceive, represent, or reason about objects, their motions, and their mechanical interactions.

The large literature on infants' perception, learning, and cognitive processing in of objects therefore suggests that male and female infants focus on objects, and learn about their mechanical interactions, in highly convergent ways. This literature accords well with the conclusions of Maccoby and Jacklin (1974), whose review of an older literature on infants' preferences and attentional patterns led them to characterize the notion that "girls are more social than boys" as the first of many "unfounded beliefs about sex differences" (p. 349).

One might argue, however, that scientific reasoning does not depend on commonsense knowledge about objects, because intuitive reasoning of object mechanics is prone to errors and misconceptions (e.g., McCloskey, Washburn & Felch, 1983; Gentner & Stevens, 1983). True scientific reasoning may emerge when students begin to use mathematics--both number and geometry--to structure their understanding of the physical world. Let us turn, therefore, to the second claim for a male advantage in science and mathematics: males are better endowed than females with specific cognitive mechanisms that are critical for successful learning of mathematics.

Sources of mathematical thinking

Formal mathematics is a recent achievement in the history of life on earth. Only humans develop and operate on natural number concepts, and we have done so only for a few thousand years: a blink of the eye in evolutionary time. Our capacity for mathematical reasoning therefore must depend on older, more primitive systems that evolved for different purposes: systems that we harness to solve new problems (Geary, 1996; Kimura, 1999). A primary goal of my research, and that of many other cognitive psychologists and neuroscientists, is to probe the nature and development of each of these component systems and of the processes by which they come together to permit new kinds of thinking (Carey, 1985, 2001; Dehaene, 1997; Feigenson, Dehaene & Spelke, 2004; Newcombe, 2002; Spelke, 2000, 2003).

Research provides evidence for five different cognitive systems at the foundation of mathematical thinking. The first system serves to represent small, exact numbers of objects: the difference between *one, two,* and *three* (e.g., Butterworth, 1999; Trick & Pylyshyn, 1994). The second system serves to represent large, approximate numerical magnitudes. This system allows us to determine, without counting or calculation, that a flock of sixty chickadees is more numerous (though less voluminous) than a flock of forty seagulls (Barth, Kanwisher & Spelke, 2003; van Oeffelin & Vos, 1982). The third system consists of the quantifiers, number words, and verbal counting routine that children gain with the acquisition of a natural language (Hurford, 1987; Wiese, 2003; Wynn, 1992a). The fourth and fifth systems underlie navigation and spatial memory. One focuses on geometrical properties of the environment, and the other on environmental landmarks (Newcombe & Huttenlocher, 2000; Wang & Spelke, 2002).

Research in cognitive psychology and cognitive neuroscience suggests that each of these systems contributes to adults' mathematical thinking. When adults solve arithmetic problems, for example, we activate areas of the brain that are involved in the tasks of representing numerical magnitudes, language, and space (Dehaene, Spelke, Pinel, Stanescu & Tsivkin, 1999). Adult patients with damage to one or more of these systems typically show distinctive impairments in mathematical reasoning and calculation (e.g., Butterworth, 1999; Lemer, Dehaene, Spelke & Cohen, 2003). When college students are given a host of mathematical tasks, their performance shows signatures of the systems (see Dehaene, 1997, for a review). These converging lines of evidence allow us to evaluate whether males and females are biologically predisposed to develop one or more of the systems to different degrees, and whether one sex is better able to harness the systems for mathematical reasoning.

Each of the five component systems emerges early in childhood. By 6 months of age, infants represent small numbers of objects (up to about three), perform simple additions and subtractions on these small-number representations, and compare one small set to another on the basis of number (Feigenson & Carey, 2003; Wynn, 1992b; see Feigenson et al., 2004, for review). By 6 months, infants also distinguish between large, approximate numerosities when they are presented with arrays of objects or sequences of actions or sounds: they discriminate arrays of 8 objects from arrays of 16 objects, for example, even when other properties of the array (such as the density of elements or their summed area) are controlled. Large-number discrimination is approximate; infants succeed at number-discrimination tasks only when numbers differ by a large ratio (Brannon, 2002; Lipton & Spelke, 2003; Wood & Spelke, in press; Xu & Spelke, 2000). The contrasting limits on infants' performance with small vs. large numbers provide evidence that the large- and small-number systems are distinct (see Feigenson, et al., 2004, for review).

Toward the end of the second year, children begin to acquire the quantifier system of their language: English-learning infants distinguish singular from plural, for example, by 20 months of age (Kouider, Halberda, Wood & Carey, in press). Over the next two years, children learn the meanings of the number words and other quantifiers like "some" and "many," and they master the workings of the counting routine (e.g., Sarnecka & Gelman, 2004; Wynn, 1990, 1992a). Sensitivity to geometric relationships including distance and angle begins early in infancy and grows rapidly in the preschool years. For example, five-month-old infants represent linear distance and use distance representations to keep track of the locations of hidden objects (Newcombe, Huttenlocher & Learmonth, 1999). At this age, infants also engage in a form of mental rotation, imagining the orientation of an object that rotates to an unseen position (Hespos & Rochat, 1997). By about 18 months of age, children are sensitive to geometric properties of the surrounding surface layout and use those properties to orient themselves in navigation tasks (Hermer & Spelke, 1994; Learmonth, Nadel & Newcombe, 2002). Infants also become sensitive to landmarks toward the end of the first year (Acredolo, 1978; Rieser, 1979), and toddlers use landmarks to locate objects and find routes through the environment (Gouteux & Spelke, 2001; see Newcombe & Huttenlocher, 2000, for review).

None of these studies reveals sex differences, early in development, that favor males. In tasks assessing infants' representations of small numbers of objects, the only reported gender difference favors females (vanMarle, 2005). Infants' discrimination of large, approximate numerical magnitudes shows no gender differences. Studies of the acquisition of number words and verbal counting have found no gender differences favoring males in children's acquisition of the English singular-plural distinction, of number words, or of the counting routine. Finally, no gender differences have been reported in infants' representations of environmental geometry or landmarks. In particular, young girls and boys show equal abilities to use both landmarks and geometric properties of the environment to locate objects, to navigate, and to learn from maps and models (DeLoache, 1987; Hermer & Spelke, 1996; Huttenlocher & Vasilyeva, 2003). In his review of the subset of these findings that was available ten years ago, the evolutionary psychologist and sex-difference researcher David Geary (1996) concluded from such evidence that girls and boys show equal "primary abilities" for mathematics. Findings of the last ten years continue to support this conclusion.

In order for humans to engage in mathematical reasoning, these five component systems must come together. Three developmental transitions have been investigated in detail. One transition occurs between 4 and 5 years of age, when children first bring their understanding of number word meanings together with their non-symbolic representations of small and large numerosities (e.g., Griffin & Case, 1996; LeCorre, 2004; Lipton & Spelke, in press). A second transition occurs between the ages of 3 and 7 years, when children first use spatial language to combine their representations of objects and geometrical relations (for example, representing that a given object is located "left of the red box": Hermer & Spelke, 1996; Shusterman & Spelke, in press). A third transition occurs between the ages of 6 and 10 years, when children first connect their representations of number and geometry by constructing and using a central device in elementary mathematics classrooms: the "number line" (Gelman, 1991; Siegler & Booth, 2004; Siegler & Opfer, 2003).

Do gender differences emerge at the point when children bring their core quantitative systems together and harness them for new purposes? Studies of these transition points have tested both girls and boys and have compared their performance. They find no evidence for sex differences in any of the transitions (e.g., Lipton & Spelke, in press; Shusterman & Spelke, in press; Siegler & Opfer, 2003;). Males and females do not only show equal primary abilities for mathematics; their earliest-developing secondary abilities are equal as well.

Sex differences do appear on a variety of more complex quantitative tasks. In most studies, these differences begin at adolescence and grow larger with increasing age; in some studies, they start in elementary school (e.g., Beilstein & Wilson, 2000). A few studies find differences at the start of formal schooling in some samples (e.g., Levine, Huttenlocher, Taylor, & Langrock, 1999), though not in all samples (Huttenlocher, Levine & Vevea, 1998). Because the differences begin to emerge well after infancy, it is difficult to tease apart the biological and social factors that produce them (see Halpern, 2000; Kimura, 1999; Newcombe & Huttenlocher, in press). Before we ask what causes these differences, however, we must consider what the differences are, and what implications they have for achievement in mathematics and science.

Although it is frequently said that women excel at verbal tasks and men excel at spatial tasks (following Maccoby & Jacklin, 1974), the literature on sex differences reveals a more nuanced pattern. First, men and women do not perform differently on all verbal and spatial tasks. In most cases, differences appear in tasks that allow for multiple solution strategies. When a navigation task can be solved only by representing the geometry of the surface layout or only by representing landmarks, for example, no sex differences appear at any age (Hermer & Spelke, 1996; Wang & Spelke, 2000). When both sources of information are available, however, adult males tend to rely more on geometry whereas females tend to rely more on landmarks (see Halpern, 2000, for a

review). Similarly, males and females tend to favor different strategies in solving mathematical word problems on speeded tests such as the quantitative portion of the Scholastic Assessment (formerly, Aptitude) Test (SAT-M). When a problem can be solved either by verbal computation or by spatial imagery, males are more likely to use the latter (Geary, Saults, Liu, & Hoard, 2000), and they perform better on problems that lend themselves to this strategy (Gallagher, Levin & Cahalan, 2002). The gender gap on tests of mathematical reasoning is narrowed when all students are encouraged to use the spatial strategy (Geary, 1996). These findings suggest that differing strategy choices, rather than differing cognitive abilities, underlie some of the sex differences in mature cognitive performance.

Second, the pattern of sex differences is more fine-grained than a simple claim of female superiority on verbal tasks, and male superiority on spatial tasks, would imply. Some verbal, mathematical, and spatial tasks favor females, whereas others favor males (see Halpern, 2000, for review). Girls and women often outperform boys and men on tests of verbal fluency, arithmetic calculation, and memory for the spatial locations of objects. In contrast, boys and men often excel on tests of verbal analogies, mathematical word problems, and memory for the geometric configuration of a route or environment. When navigating through complex environments in which both landmarks and geometric information are available, women tend to rely more on the former and men on the latter. Men also outperform women on tasks where they must compare the forms of two objects that appear at different orientations. Men may be more apt to form an image of one object and turn it around in their minds to align it with the other ("mental rotation"), whereas women may be more apt to compare features of the two objects: another difference in strategy.

Because females are better at some cognitive tasks and males are better at others, most investigators of sex differences have concluded that males and females have equal cognitive ability, with somewhat different profiles (Halpern, 2000, Halpern, Wai & Saw, 2005; Pinker, 2002). In Halpern's words (2000, p. 8), "differences are not deficiencies." Nevertheless, some psychologists have suggested that the differing profiles of men and women predispose males to better learning of advanced mathematics (Baron-Cohen, 2003; Casey, Nuttal, Pezaris & Benbow, 1995; Geary, 1998; Kimura, 1999). On this view, the verbal, mathematical and spatial tasks that show a male advantage matter more to the practice of formal mathematics than the verbal, mathematical and spatial tasks that show a female advantage.

How can we evaluate this claim? In the literature on cognitive sex differences, one common strategy is to focus on performance on standardized tests such as the SAT-M. This strategy is problematic, however, because standardized tests such as the SAT-M are themselves in need of explanation and justification (see Gallagher & Kaufman, 2005). The SAT-M consists of a variety of items that require a complex mix of capacities and are open to different solution strategies. Because different items show different performance disparities by sex (Gallagher, et al., 2002), the SAT-M could be made to favor either males or females by suitable choice of items (Chipman, 2005). Creating a fair test requires an independently motivated account of the nature of mathematical talent and its distribution across males and females. The test itself therefore cannot serve as an

independent measure of the relative mathematical talents of girls and boys (Willingham & Cole, 1997).

A second strategy is to ask how performance on tests of specific abilities, such as mental rotation, correlates with later achievement in mathematics and science (e.g., Casey et al., 1995; Kimura, 1999; Shea, Lubinski & Benbow, 2001; Xie & Shauman, 2003). Such studies typically find that a wide range of cognitive measures, including those favoring males and those favoring females, predict later accomplishment to some degree (see Byrnes, 2005). This method is problematic, however, because the decision to major in physics or to become a mathematician is affected by multiple factors other than intrinsic aptitude, and the cognitive profiles of men and women may influence several of these factors (see Shea et al., 2001).

Given these problems, the best way to evaluate the roles of male vs. female cognitive profiles on mathematics aptitude may be to ask what goes on in real high school and college classrooms, before differing interests and social forces begin to influence men's and women's academic pursuits. If achievement in mathematics depends more on facility with verbal analogies, mathematical word problems, and geometric navigation tasks than on facility with word production, mathematical calculation, and landmark navigation, then boys should perform better than girls when they are challenged to learn new, advanced mathematical concepts and procedures. Since the differing cognitive profiles of boys and girls begin to emerge by adolescence, if not earlier, the claim that the male profile favors mathematical talent predicts that male students will gravitate toward more demanding math classes and get better grades. Although high school calculus classes used to draw more males than females, that gender gap has closed. Boys and girls take equally demanding math classes in high school, and girls get better grades (Xie & Shauman, 2003; Gallagher & Kaufman, 2005). In college, the academic pursuits of male and female students begin to diverge, but men and women get equal grades in math classes (Bridgeman & Wendler, 1991) and they major in math in nearly equal numbers: in 2000, 47% of undergraduate math majors were women (Chipman. 2005). This evidence supports the view that cognitive differences between males and females do not translate into cognitive deficiencies for females in mathematics. From adolescence onward, males and females show somewhat different cognitive profiles, but they are equally able to learn mathematics. If difficulties with mathematics pose the main obstacle to students' progress in the sciences, then males and females would seem to be equally capable of learning science.

If girls and boys do not differ in their overall aptitude for mathematics and science, then this review need not take on the difficult project of teasing apart genetic and environmental influences on cognitive sex differences. Very briefly, however, it is likely (a) that genetic differences between males and females contribute to their differing cognitive profiles, and (b) that the contribution is indirect and culture-dependent (Halpern, 2000; Newcombe & Huttenlocher, in press).

Consider, for example, the most robust cognitive sex difference favoring males, on mental rotation tasks. Performance on mental rotation tasks shows some modulation by exposure to sex hormones, both before birth and at the time of testing (see Halpern, 2000, for review). Infants and young children, however, do not show performance differences on mental rotation tasks. For example, male and female infants are equally able to extrapolate the orientation of a rotating object that moves from view (Hespos & Rochat, 1977), and male and female toddlers are equally apt to rotate the objects that they manipulate into orientations that are appropriate for building block structures (von Hofsten & Rosander, 2005). Middle class children with exposure to blocks in homes and preschool settings begin to show this sex difference at the start of schooling, but less fortunate children do not, probably because of their limited opportunities for blocks play (Levine, Vasilyeva, Lourenco, Newcombe & Huttenlocher, 2005). In middle-class preschool classrooms, blocks tend to be located in boys' play areas, associated with boys' games. Prenatal hormones may influence children's play styles in ways that make girls with higher testosterone levels more likely to want to play with boys and to be accepted by them. Such girls therefore will gain the extra experience with blocks that builds mental rotation skills (Nuttal, Casey & Pezaris, 2005). This speculation is plausible, because spatial abilities are enhanced in all students by training and practice (Baenninger & Newcombe, 1989).

Gender differences in the variability of intrinsic aptitude for math and science?

The third and final claim of a male advantage for academic careers in math and science accepts the conclusion that males and females have equal aptitude for math and science, on average. It focuses instead on the performance ranges of males and females. According to this claim, the distribution of male talent shows greater spread. Because males show greater variability in cognitive abilities than do females, there are more talented males at the upper end of the ability distribution.

This claim received wide attention in the early 1980s, with the publication of initial findings from a long-term study of mathematically precocious youth (SMPY; Benbow & Stanley, 1980, 1983). Adolescents were screened in middle school, typically in 7th grade, for talent in mathematics. They were screened, in part, by the SAT-M. Although almost as many girls as boys took the screening test, there were many more boys at the upper end of the distribution of SAT-M scores. Considering just the top 1% of scores, there were over 12 boys for every girl (Benbow & Stanley, 1983; Lubinski & Benbow, 1992). Subsequent research has shown that the preponderance of males stems more from a difference in the variability of test scores than from a difference in means, both for the SAT-M and for other, similar tests (Feingold, 1992; Hedges & Nowell, 1995; Hyde, Fennema & Lamon, 1990; Nowell & Hedges, 1998). Mean scores on the SAT-M also favor boys, however, by a consistent margin (Willingham & Cole, 1997).

After the screening, boys and girls entered the program in large numbers (the cutoff for admission was well below the 1% level where the sex difference was greatest), and they were given accelerated exposure to mathematics. At the end of high school, the students from the SMPY sample took the SAT-M again as part of the process of applying to college, and again there was a preponderance of males at the upper tail of test scores (Benbow & Stanley, 1983). The investigators concluded that there were more boys than girls in the pool from which future scientists and mathematicians are drawn. Because the initial difference was obtained before students began to select their courses, and because the students showed little gender differences in their reported attitudes toward mathematics, the investigators suggested that the sources of the sex difference were, in part, genetic (Benbow, 1988; Benbow & Stanley, 1983; see also Pinker, 2002). As in the case of the differing cognitive profiles discussed in the last section, I defer the question of genetic differences and first consider whether more boys than girls show extreme talent in mathematics. The SMPY data provide a wealth of information on this point, and SAT-M test scores are only the tip of the iceberg. Benbow and her collaborators also looked at the high school performance of these talented girls and boys. In early samples, more boys than girls entered the SMPY program, and boys went on to take more demanding mathematics classes. In the later samples, however, the numbers of male and female participants were nearly equal, as were the numbers of boys and girls in high school mathematics classes. Although the boys outnumbered the girls at the upper tail of the SAT-M, the girls got better grades in high school mathematics, as they do in less selected samples (Willingham & Cole, 1997). Benbow (1988) suggested that the girls were less gifted, but more diligent, at learning mathematics.

The investigators went on to study the college performance of SMPY students. In college, male and female SMPY veterans continued to take equally demanding classes. They majored in math at equal rates and got equally good grades, as do college women and men generally (Willingham & Cole, 1997; Chipman, 2005). They also graduated at equal rates and obtained equally many doctoral degrees (Lubinski & Benbow, 1992; Lubinski, Webb, Morelock & Benbow, 2001; Webb, Lubinski & Benbow, 2002). Although sex differences were found both in students' fields at the time of graduation and in their advanced degrees, the students received bachelor's degrees in mathematics at equal rates. The biggest sex differences were found within science and engineering fields: men received more degrees in engineering and physics, whereas women received more degrees in biology and medicine.

The conclusion from these findings is clear. If the purpose of the SAT is to predict students' performance in college, the SAT-M is flawed: It underpredicts the performance of female students, and it overpredicts the performance of male students, both in the college-going population at large (Bridgeman & Wendler, 1991) and in more selected samples matched for institutions and math classes (Bridgeman & Lewis, 1996). Although most of the high scorers on the SAT-M are male, there is no preponderance of males among high-performing math majors in American universities. This discrepancy between SAT scores, and college achievement, is well known (Gallagher & Kaufman, 2005; Willingham & Cole, 1997; *Nature Neuroscience*, 2005). Like the other evidence presented in this review, however, recognition of the SAT-M's key shortcoming has not figured in current, public discussions of men's and women's intrinsic aptitude for mathematics and science.

These findings reduce the urgency of questions concerning the contribution of genes and experience to the gender gap at the high end of performance on standardized tests like the SAT-M. If the genetic contribution were strong, however, then we might expect that males would predominate at the upper tail of performance in all countries and at all times. Contrary to this expectation, the preponderance of high-scoring males has declined substantially over the last twenty years in U.S. samples (Monastersky, 2005; Willingham & Cole, 1997) and it is altogether absent in some countries (Feingold, 1994). The performance of boys and girls on standardized tests, like their performance in schools, likely reflects a complex mix of social, cultural, and biological factors.

Conclusions

Contrary to popular assertions, a great deal of evidence sheds light on the cognitive abilities of males and females from birth to maturity. This evidence does not support the claim that men have greater intrinsic aptitude for mathematics and science. Male and female infants, preschool children, and elementary school children do not differ in the cognitive abilities at the foundations of mathematical and scientific thinking: they have similar abilities to represent and learn about objects, numbers, language, and space. Although older boys and girls show somewhat different cognitive profiles, the profiles are complex and subtle (it is not the case, for example, that women are "verbal" and men are "spatial"), and they do not add up to a male or female advantage either in general intelligence or in the specific abilities that mathematics classes demand. American high school boys show greater variability on the quantitative SAT, but American college men and women are equally proficient at learning advanced mathematics, both on average and within the pool of the most talented students.

It remains the case that university faculties have many more male than female mathematicians and scientists. What is more, male and female undergraduates are not equally likely to major in physics and engineering. Might there be some genetically determined cognitive difference, not yet discovered, that accounts for these discrepancies?

The questions addressed in this review are empirical, and so the answer to every "might there be...?" question is "yes." A more useful question, however, is this: Does the wealth of research on cognition and cognitive development, assembled over the last 40 years, provide any reason to believe that the gender imbalances on science faculties, or among physics majors, stem from sex differences in intrinsic aptitude? The present

review suggests that it does not. To be sure, there are more males than females who major in physics and engineering today. A generation ago, however, many more males than females majored in biology or medicine, and many more males became economists or accountants. A century ago, far more males than females attended college. Those differences, we now know, had social, not genetic, causes, for they no longer exist (see Halpern et al., 2005). Studies of cognitive sex differences suggest that today's gender disparities have similar causes to those of the past. Studies of cognitive development, and of its biological basis, do not explain the preponderance of men on academic faculties of mathematics and science. We must look to studies of our society for insights into this phenomenon.

The research reviewed in this report does not suggest, however, that our genetic endowment is irrelevant to our cognitive achievements. On the contrary, infants' abilities to represent and understand objects, number, and space depend in part on capacities that are present and functional from the beginning of life. Preschool children's abilities to construct natural number concepts and to learn verbal counting also depend, in part, on our human biological endowment: Humans in all cultures attain these skills to some degree (Pica, Lemer, Izard & Dehaene, 2004), whereas no other animal has done so even after extensive training (Matsuzawa, 1985, 2000; Pepperberg, 1994). All of the cognitive abilities that underlie achievements in science and mathematics likely develop through a complex interplay of intrinsic capacities, tuned both by everyday experience and by instruction (e.g., Dehaene, 1997; Spelke & Newport, 1998; Newcombe, 2002). The negative conclusions of this review imply only that our considerable gifts for mathematics and science have been bestowed, in equal measure, on males and females.

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