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Author(s): Spelke, Elizabeth S., Department of Psychology, Harvard University

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Abstract: This article considers 3 claims that cognitive sex differences account for the differential representation of men and women in high-level careers in mathematics and science: (a) males are more focused on objects from the beginning of life and therefore are predisposed to better learning about mechanical systems; (b) males have a profile of spatial and numerical abilities producing greater aptitude for mathematics; and (c) males are more variable in their cognitive abilities and therefore predominate at the upper reaches of mathematical talent. Research on cognitive development in human infants, preschool children, and students at all levels fails to support these claims. Instead, it provides evidence that mathematical and scientific reasoning develop from a set of biologically based cognitive capacities that males and females share. These capacities lead men and women to develop equal talent for mathematics and science.

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

Contents

By: Elizabeth S. Spelke
Department of Psychology, Harvard University

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Correspondence concerning this article should be addressed to: Elizabeth S. Spelke, Department of Psychology, Harvard University, 1130 William James Hall, 33 Kirkland Street, Cambridge, MA, 02138. Electronic mail may be sent to: spelke@wjh.harvard.edu

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 fewer women exhibit high talent in 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 research on the developmental and cognitive foundations of mathematical and scientific thinking.

Three claims for sex differences in intrinsic aptitude have received the greatest attention. One claim asserts that males and females are predisposed from birth to learn about different things: Male infants learn about objects and their mechanical relationships, whereas female infants learn about people, emotions, and personal relationships (Baron-Cohen, 2003; see also Browne, 2002). 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 have better command over these systems, for reasons that stem ultimately from genetic differences between the sexes (Geary, 1998; Kimura, 1999). A third claim focuses on gender disparities at the upper end of the ability distribution: Males show greater variability in inherent mathematical talent, and therefore they predominate in the pool of highly talented students from which future mathematicians and scientists will emerge (Benbow & Stanley, 1983; see also Benbow, 1988; Nowell & Hedges, 1998).

A review of the evidence from studies of infants, children, and adults yields little support for these claims. Infants show few cognitive sex differences and no male advantage in the processing of objects, space, or number. Although research on older children and adults has revealed differences between the performance of males and females on specific cognitive tasks, this research provides no evidence for sex differences in overall aptitude for mathematics or science at any point in development. Research on selected groups of highly talented students reveals some disparities in performance on speeded tests of quantitative reasoning, but highly selected male and female students also show equal abilities to learn mathematics. I focus on this evidence.

A number of well-studied topics in the literature on sex differences lie beyond my scope. Because formal science and mathematics are uniquely human endeavors, I do not consider cognitive sex differences in nonhuman animals. I also do not discuss sex differences in human preferences, motives, attitudes, temperament, or decisions. A complete account of men's and women's differing career paths must consider many kinds of sex differences, including differences in men's and women's attitudes toward science and desires to balance work and family. Thinking about these issues may benefit, however, from a review that asks a more restricted question: Do men and women have equal cognitive capacities for math and science careers?

Many discussions of the biological basis of men's and women's cognitive capacities focus on evidence that sex hormones modulate performance on specific cognitive tasks (for reviews, see Baron-Cohen, 2003; Halpern, 2000; and Kimura, 1999). The existence and nature of these effects would be relevant to this review, if performance on tasks influenced by hormones gave one sex a cognitive advantage in math and science disciplines. The evidence suggests, however, that men and women have equal aptitude for mathematics and science. For this reason, I do not review the extensive literature on hormones and cognition.

Instead, this review focuses on evidence of a different kind. Behavioral and neuroimaging studies of human cognition and cognitive development suggest that our species' talent for mathematical and scientific thinking has a considerable genetic basis in a set of core systems for representing objects, space, and number. These systems emerge early in infancy, remain present throughout life, are harnessed by children when they learn mathematics, and are used by adults when engaging in mathematical and scientific thinking (Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Spelke, 2003). The evidence to be reviewed suggests that these core systems are equally available to males and females. They provide the biological foundations for a set of cognitive capacities that men and women share.

Sex Differences in Infants' Processing of Objects?

Baron-Cohen (2003) proposed that males are predisposed to learn about objects and their mechanical interactions, whereas females are predisposed to learn about people and their emotional interactions. He cited as evidence an experiment conducted on newborn infants (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000). Infants viewed, side by side, an active and expressive person and a similarly sized inanimate object. Male infants looked longer at the object, whereas female infants looked longer at the person. Baron-Cohen suggested that male infants' focus on objects leads them to become *systemizers* who engage both with the mechanical world and with abstract systems like mathematics.

Claims that by nature men orient to objects and women orient to people are not new (see Maccoby & Jacklin, 1974, for a review of older claims and Browne, 2002, and Pinker, 2002, for recent statements), but Connellan et al.'s (2000) experiment seems to have given them compelling support. The experiment is unusual, however, in three respects. First, it stands alone. It is customary, in infant research, to replicate key findings and assemble multiple experiments in support of any claim. No replication of Connellan et al.'s experiment has been published, however, and no unpublished replications are mentioned in Baron-Cohen's (2003, 2005a) discussions of their finding.

The lack of replication is particularly curious, because a large, older literature suggests that male and female infants are equally interested in people and objects (Maccoby & Jacklin, 1974). Numerous experiments in the 1960s compared infants' visual attention to faces versus inanimate patterns. One study, for example, assessed infants' visual attention to a live person in a free play setting at one and three months and assessed their visual attention to pictures of faces and inanimate displays in a controlled setting at the latter age (Moss & Robson, 1968). Male and female infants looked equally at the live person at both ages. At three months, all infants looked longer at the face than the inanimate display, and this preference was greater for the male infants. These findings, like others from more recent research (see Rochat, 2001, for a review), provide no evidence that male infants are more focused on objects and female infants are more focused on people from birth onward.

Second, Connellan et al.'s (2000) experiment does not attempt to determine the basis for infants' preferences between the person 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. did not consider these questions.

Third, Connellan et al. (2000) did not discuss critical controls against experimenter bias. Because newborn infants cannot hold their heads erect, their visual preferences are influenced by the way in which they are positioned and supported; because one of the two stimuli was a live, expressive person, preferences also could be influenced by that person's behavior. Baron-Cohen (2005a) has indicated that the experimenters attempted to minimize bias, but a replication with more stringent controls would be desirable.

Connellan et al.'s (2000) experiment has received extraordinary attention in recent popular discussions of the origins and nature of cognitive sex differences (e.g., Baron-Cohen, 2005b; 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 its key prediction: If newborn male infants are predisposed to learn about mechanical objects, then we should expect older male infants to show superior knowledge of objects and their behavior. Over the past 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 televised science programs, but it has not figured in recent discussions of the origins of cognitive sex differences. Let us consider its findings.

Object perception begins at birth. Newborn human infants show clear, though limited, abilities to perceive the colors, shapes, sizes, and orientations of objects (e.g., Slater, Mattock, & Brown, 1990) and to perceive and extrapolate object motions (e.g., von Hofsten, 1982). Over the first six months, abilities to perceive and reach for objects develop rapidly (see Spelke, Vishton, & von Hofsten, 1995, and Johnson, 2004, for reviews). Infants also begin to represent objects that move fully out of view, to make inferences about mechanical interactions between objects, and to group objects into categories (e.g., Baillargeon, 2004; Hespos & Spelke, 2004; Quinn & Eimas, 1996). These findings are supported by multiple, converging experiments that test systematically both the existence and limits of infants' abilities, with displays that are systematically varied to pinpoint the basis of infants' responses and with methods that guard against potential sources of bias.

In most of these studies, the performance of male and female infants is compared systematically. Most studies find no sex differences. Some studies find an advantage for female infants, particularly in the domains of mechanical reasoning and the ages at which new abilities emerge (e.g., Baillargeon, Kotovsky, & Needham, 1995). For example, experiments have assessed infants' understanding that an object travels farther when hit by a heavier object; female infants achieve this understanding at 5.5 months, and male infants achieve it at 6.5 months (Kotovsky & Baillargeon, 1998). Such findings do not imply that female infants are superior to male infants at mechanical reasoning, because female infants develop somewhat more rapidly across the board, and so their superior performance is not likely to be specific to objects. Moreover, research on infancy has not been subjected to the powerful techniques of meta-analysis that are needed to evaluate positive findings of sex differences. Meta-analyses of cognitive sex differences are rare in infant research because they depend on significant effects, whereas the vast majority of studies of cognitive development in infancy report no significant sex differences.

If positive conclusions concerning sex differences are not warranted by this literature, however, negative conclusions can be offered with more confidence. Thousands of studies of human infants, conducted over three decades, provide no evidence for a male advantage in perceiving, learning, or reasoning about objects, their motions, and their mechanical interactions. Instead, male and female infants perceive and learn about objects in highly convergent ways. This conclusion accords well with that of Maccoby and Jacklin (1974), whose review of an older literature led them to characterize the notion that girls are more socially oriented and boys are more object oriented 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 about object mechanics is prone to errors and misconceptions (e.g., 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 in complex cultures develop and operate on natural number concepts and use numbers and geometry to map and measure their surroundings. Because formal mathematics has existed for only a few thousand years—a blink of the eye in evolutionary time—it must depend on older, more primitive systems that evolved for different purposes and that humans have harnessed to solve new problems (Geary, 1996; Kimura, 1999). Research in developmental and cognitive psychology and neuroscience serves to probe the nature and development of these systems and of the processes by which different systems come together to support new concepts and operations (Carey, 2001; Dehaene, 1997; Feigenson et al., 2004; Newcombe, 2002; Spelke, 2003).

Such research provides evidence for five different cognitive systems at the core of adults' mathematical thinking. One system serves to represent small, exact numbers of objects: the difference between *one, two,* and *three* (e.g., Butterworth, 1999; Trick & Pylyshyn, 1994). A second system serves to represent large, approximate numerical magnitudes: the difference in number (though not weight or volume) between, for example, 60 chickadees and 40 seagulls (Barth, Kanwisher, & Spelke, 2003; van Oeffelen & Vos, 1982). A third system consists of the quantifiers, number words, and verbal counting routine that children gain with the acquisition of a natural language (Wynn, 1992a). The fourth and fifth systems serve to represent environmental geometry and landmarks, respectively, for purposes of navigation, spatial memory, and geometrical reasoning (Newcombe & Huttenlocher, 2000; Wang & Spelke, 2002). When adults solve arithmetic problems, they activate areas of the brain that are involved in representing numerical magnitudes, language, and space (e.g., 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 these systems (see Dehaene, 1997, and Feigenson et al., 2004, for reviews). Are males and females biologically predisposed to develop one or more of the systems to different degrees, and is one sex better able to harness the systems for mathematical reasoning?

Each of the five component systems emerges early in childhood. By six months of age, infants represent small numbers of objects, 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 also Feigenson et al., 2004, for a review). Six-month-old infants also distinguish between large, approximate numerosities when continuous variables are controlled, provided that the numbers differ by a large ratio (Brannon, 2002; Lipton & Spelke, 2003; Xu & Spelke, 2000). The detailed and contrasting limits on infants' performance with small versus large numbers provide evidence that the large- and small-number systems are distinct from one another and continuous with the systems found in older children and adults (Feigenson et al., 2004). Studies of these systems find no consistent sex differences at any age; the lone reported sex difference has favored females (van Marle, 2004). Infants, children, and adults are equally adept at representing small exact and large approximate numbers.

Toward the end of the second year, children begin to acquire the quantifier system of their language. For example, children learning English distinguish singular from plural (Kouider, Halberda, Wood, & Carey, in press) and master the workings of the counting routine (e.g., Sarnecka & Gelman, 2004; Wynn, 1992a). Studies of these achievements also find no sex differences favoring boys.

Sensitivity to geometric relationships, including distance and angle, begins early in infancy and grows rapidly in the preschool years. For example, 5-month-old infants represent the locations of hidden objects (Newcombe, Huttenlocher, & Learmonth, 1999) and engage in a form of mental rotation, imagining the orientation of an object that rotates to an unseen position (Hespos & Rochat, 1997). By 18 months, children use geometric properties of the surrounding layout to orient themselves (Hermer & Spelke, 1994; Learmonth, Nadel, & Newcombe, 2002) and to guide their manipulation of objects (von Hofsten, Rosander, & Ornkloo, 2005). 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 a review). Boys and girls show equal performance on all these tasks.

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 past decade, focusing on the emergence of the core systems supporting adults' mathematical thinking, confirm his conclusion. One could argue, however, that the above studies use sample sizes that are too small to detect subtle sex differences or that sex differences in core mathematical abilities emerge after infancy. Studies of core mathematical abilities in larger samples, and in older children, would be highly desirable.

For humans to engage in mathematical reasoning, the five core systems must come together. Three developmental transitions have been investigated in detail. Between 4 and 5 years of age, children first bring their understanding of number word meanings together with their nonsymbolic representations of small and large numerosities (e.g., Griffin & Case, 1996; Le Corre, 2004; Lipton & Spelke, in press). Between 3 and 7 years, children begin to use spatial language to combine their representations of landmark objects and geometry (Hermer & Spelke, 1994; Shusterman & Spelke, 2005). Between 6 and 10 years, children connect their representations of number and geometry by constructing and using a central device in elementary mathematics education: the *number line* (Gelman, 1991; Siegler & Booth, 2004; Siegler & Opfer, 2003). No sex differences have been reported at any of these transition points, even in studies with substantial sample sizes. Secondary mathematical abilities also develop similarly in boys and girls.

Sex differences emerge on more complex quantitative tasks. In most studies, these differences begin during or after elementary school and grow larger with increasing age (e.g., Beilstein & Wilson, 2000). A few studies find differences at younger ages in some but not all samples (e.g., Levine, Huttenlocher, Taylor, & Langrock, 1999; cf. Huttenlocher, Levine, & Vevea, 1998). Because the differences emerge well after infancy, it is difficult to tease apart the biological and social factors that produce them (see Halpern, 2000; Newcombe & Huttenlocher, in press). Nevertheless, let us consider the nature of the differences and their implications for achievement in mathematics.

Women are sometimes said to excel at verbal tasks and men at spatial tasks, but the literature on sex differences reveals a more nuanced pattern (for reviews, see Geary, 1998; Halpern, 2000; and Hyde, 2005). Girls and women tend to excel on tests of verbal fluency, arithmetic calculation, and memory for the spatial locations of objects. In contrast, boys and men tend to excel on tests of verbal analogies, mathematical word problems, and memory for the geometric configuration of an environment. Meta-analyses have revealed that some of these sex differences are reliable, although most are small. Indeed, most of the variables that have been tested in men and women have yielded sex differences that are small or close to zero in meta-analyses, leading Hyde (2005) to advance the *gender similarities hypothesis.* Although certain measures of motor behavior, sexuality, and aggression show large and reliable sex differences, few cognitive measures do so.

Let us consider the properties of the cognitive tasks that show sex differences. These tasks typically can be solved in multiple ways, and men and women tend to favor different solution strategies. In navigation tasks presenting both landmark and geometric information, for example, women tend to rely more on the former and men on the latter (e.g., Choi & Silverman, 1996; Saucier, Bowman, & Elias, 2003). In contrast, men and women perform equally when only one source of information is available (Hermer & Spelke, 1994; Wang & Spelke, 2002). In visual comparison tasks presenting two objects at different orientations, men are more apt to form an image of one object and turn it around in their minds to align it with the other (i.e., mental rotation), whereas women are more apt to compare features of the objects. This difference in strategies gives men an advantage on tasks in which feature-comparison strategies are ineffective (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) and gives women an advantage on tasks in which they are critical (see Hyde, 2005; Kimura, 1999). Finally, 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 apt 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). All these findings suggest that differing strategy choices underlie some of the sex differences in mature cognitive performance (e.g., Linn & Petersen, 1985).

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

How can researchers evaluate this claim? In the literature on cognitive sex differences, one common strategy is to focus on performance on standardized tests of mathematical reasoning such as the SAT-M. Boys score higher than girls on the SAT-M and similar tests (Gallagher & Kaufman, 2005), although the difference is small, and the distributions of male and female scores are highly overlapping (Hyde, 2005). The strategy of inferring sex differences in mathematical ability from sex differences in the SAT-M is problematic, however, for several reasons. First, more girls take the SAT-M, and so the sample of boys is more highly selected. Second, and more deeply, tests such as the SAT-M are themselves in need of explanation and justification (see Gallagher & Kaufman, 2005). The SAT-M and similar tests consist of a variety of items assessing a complex mix of capacities and strategies. Because different items show different performance disparities by sex (Gallagher et al., 2002), such tests can be made to favor either boys or girls by suitable choice of items (see Browne, 2002; Halpern, 2002). How can we determine whether the particular mix of items composing the SAT-M provides a fair measure of the relative mathematical abilities of boys and girls?

This problem may be illustrated by a specific example. Girls consistently perform better than boys on items in which the student must determine if the data provided in a problem are sufficient to answer the problem. Such data-sufficiency items once appeared on the SAT-M, but they have been eliminated. According to Chipman (2005), the decision to eliminate these items was justified on pragmatic grounds, because performance on the items benefits considerably from coaching. Removing a class of items on which girls score better nevertheless has the effect of lowering the scores of girls, relative to boys, and it raises a question: Did this change increase or decrease the fairness of the SAT-M as a measure of mathematical ability in men and women? If boys are more talented than girls, then this change may have increased the fairness of the test. If boys and girls are equally talented, then this change increased the test's bias against girls. Evaluation of the SAT-M therefore requires an independently motivated account of the nature of mathematical talent, its component processes, and its distribution across boys and girls (Willingham & Cole, 1997). On pain of circularity, SAT-M scores cannot, in themselves, reveal whether boys or girls have greater aptitude for mathematics.

A second strategy for evaluating men's and women's aptitude for science and mathematics is to ask how performance on tests of specific cognitive abilities showing sex differences, 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). This strategy is problematic, however, for two reasons. First, such studies typically find that many cognitive measures, including those favoring boys and those favoring girls, predict later accomplishment to some degree (see Byrnes, 2005). Second, the decision to major in physics or to become a mathematician is affected by many factors, including preferences, motivations, and expectations of success. The differing cognitive profiles of men and women may be associated with any of these factors (see Shea et al., 2001).

Given these problems, I suggest two ways to evaluate and compare the mathematical talents of males and females. One approach is to analyze mature mathematical thinking into its core foundations and their interactions and then to compare the core abilities of males and females. We have seen that this approach, to date, yields no evidence for sex differences. The second approach is 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 males are more gifted at learning mathematics, then boys should perform better than girls when they are challenged to learn new, advanced mathematical concepts and procedures. Because 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 thus predicts that male students will gravitate toward more demanding mathematics classes and will get better grades.

Although high school calculus classes once drew more boys than girls, that gender gap has closed. Boys and girls take equally demanding math classes in high school, and girls get better grades (Gallagher & Kaufman, 2005; Xie & Shauman, 2003). In U.S. colleges, the academic pursuits of male and female students begin to diverge, but men and women get equal grades in math classes that are matched for difficulty (Bridgeman & Lewis, 1996), and they major in math in nearly equal numbers. In 2000, for example, women earned 47% of bachelor's degrees in mathematics (Chipman, 2005). By the most meaningful measure—the ability to master new, challenging mathematical material over extended periods of time—college men and women show equal aptitude for mathematics.

The contrast between the performance of high school students on the SAT-M and the performance of college students in mathematics classes suggests that the SAT-M systematically underpredicts the performance of high school girls, relative to boys. Further analyses support that suggestion. When the SAT-M scores of boys and girls are matched, girls go on to earn higher grades in college mathematics classes (see Royer & Garofoli, 2005, for a review). The SAT-M's underprediction of girls' mathematics performance is widely known (e.g., Gallagher & Kaufman, 2005; Nature Neuroscience Board of Editors, 2005; Willingham & Cole, 1997) but is rarely mentioned in popular discussions of males' and females' aptitude for mathematics (e.g., Cronin, 2005; Pinker, 2002; Summers, 2005).

In summary, males and females show somewhat different cognitive profiles when presented with complex tasks that can be solved by multiple strategies, but they show equal performance on tasks that tap the core foundations of mathematical thinking. Moreover, males and females show equal abilities to learn advanced, college-level mathematics. Insofar as mathematical ability is central to students' progress in the sciences, males and females would seem to be equally capable of learning science.

Sex 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 aptitudes for math and science, on average, and 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 mathematical ability than do females, more males show extreme mathematical talent.

This claim received wide attention in the early 1980s, with the publication of initial findings from the long-term study of mathematically precocious youth (the SMPY; Benbow & Stanley, 1983). Adolescents were screened for talent in mathematics and were given the SAT-M. Many girls and boys took the test, but more boys received the highest scores. Considering just the top 1% of SAT-M scores, there were over 12 boys for every girl (Benbow & Stanley, 1983; Lubinski & Benbow, 1992). Subsequent research has shown that the preponderance of boys stems both from a difference in the variability of test scores and from a difference in means, and that it appears both on the SAT-M and on other, similar tests (Deary, Thorpe, Wilson, Starr, & Whalley, 2003; Feingold, 1992; Hedges & Nowell, 1995; Hyde, Fennema, & Lamon, 1990; Nowell & Hedges, 1998).

After the screening, boys and girls entered the SMPY program in large numbers (the cutoff for admission was well below the 1% level where the sex disparity was greatest) and 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 boys 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 few sex 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).

Because these conclusions depend on students' scores on the SAT-M, they are open to two interpretations: Either more boys than girls have extreme talent in mathematics, or SAT-M scores overestimate the abilities of talented boys, relative to girls. The SMPY data provide a wealth of information bearing on these interpretations. Benbow and her collaborators (Lubinsky & Benbow, 1992; Lubinski, Webb, Morelock, & Benbow, 2001; Webb, Lubinski, & Benbow, 2002) looked at the school performance of talented girls and boys. In early samples, more boys than girls entered the SMPY program, and boys went on to take more demanding high school 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 boys outnumbered girls at the upper tail of the SAT-M, the SMPY girls got better grades in high school mathematics, as they have in less selected samples. In college, male and female SMPY veterans continued to take equally demanding classes and got equally good grades, as do college women and men generally. They also graduated at equal rates and obtained an equal number of doctoral degrees (Lubinski & Benbow, 1992; Lubinski et al., 2001; Webb et al., 2002). Sex differences were found in students' fields of concentration: Men received more degrees in engineering and physics, whereas women received more degrees in biology and medicine. Nevertheless, male and female students received degrees in mathematics at nearly equal rates. In one SMPY cohort, for example, 10.3% of men and 9.7% of women received bachelor's degrees in mathematics, and 2.2% of men and 2.1% of women went on to receive master's degrees in mathematics

(Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000).

The conclusion from these findings is clear. Although most SMPY students with high scores on the SAT-M are male, male and female veterans of that program learn advanced mathematics at equal rates and with equal success. If one gauges students' talent at mathematics by their successful mastery of the demanding material required of college mathematics majors, one will conclude that men and women have equal aptitude for mathematics, not only in the general population of college students but in selected samples of students with high talent.

These findings reduce the urgency of questions concerning the contribution of genes and experience to the gender gap on SAT-M scores. If the genetic contribution were strong, however, then males should predominate at the upper tail of performance in all countries and at all times, and the male-female ratio should be of comparable size across different samples. Contrary to this prediction, the preponderance of high-scoring males is far smaller in some countries (e.g., Deary et al., 2003) and altogether absent in others (Feingold, 1994). Moreover, the preponderance of boys with high scores on the SAT-M has declined substantially in U.S. samples. In one sample of students selected for high talent, it declined from 10.7:1 in the 1980s to 2.8:1 in the 1990s (Goldstein & Stocking, 1994). The performance of boys and girls on standardized tests likely reflects a complex mix of social, cultural, and biological factors.

Conclusions

Research on the cognitive abilities of males and females, from birth to maturity, does not support the claim that men have greater intrinsic aptitude for mathematics and science. Male and female infants do not differ in the cognitive abilities at the foundations of mathematical and scientific thinking; they have common abilities to represent and learn about objects, numbers, language, and space. Male and female children harness these abilities in the same ways, at the same times, to master the concepts and operations of elementary mathematics. Although older boys and girls show somewhat different cognitive profiles, the differences are complex and subtle (it is not the case, e.g., that women are verbal and men are spatial). These differences tend to be small, and they stem primarily from differing strategy choices. Above all, these differing profiles do not add up to a male or female advantage in learning advanced mathematics. High school boys show both higher mean scores and greater variability on the SAT-M, but high school and college men and women are equally proficient in mathematics classes, both on average and within the pool of the most talented students.

The finding that men and women show equal aptitude for mathematics and science does not imply that humans' genetic endowment is irrelevant to these 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 uniquely 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; Pepperberg, 1994). All these abilities contribute to the learning of science and mathematics, most likely through a complex process in which intrinsic capacities are tuned both by everyday experience and by instruction (e.g., Dehaene, 1997; Newcombe, 2002; Spelke & Newport, 1998). 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.

It remains the case that university faculties have many more male than female mathematicians and scientists. Moreover, male and female undergraduates are not equally likely to major in physics or engineering (Xie & Shauman, 2003), and mathematically gifted men and women tend to gravitate toward different sorts of careers (Benbow et al., 2000). Might there be some genetically determined cognitive difference, not yet discovered, that accounts for these disparities?

The questions addressed in this review are empirical, and so the answer to every *Might there be …?* question is *yes*. Nevertheless, the wealth of research on cognition and cognitive development, conducted over 40 years, provides no reason to believe that the gender imbalances on science faculties, or among physics majors, stem from sex differences in intrinsic aptitude. To be sure, there are more men than women who major in physics and engineering today. A generation ago, however, many more men than women majored in biology, medicine, and mathematics, and many more men became economists or accountants. A century ago, far more men attended college. Those disparities, we now know, had social causes, for they have been eliminated or reversed (see Halpern et al., 2005). Studies of cognitive sex differences suggest that today's gender disparities have causes similar to those of past disparities. If that is the case, then studies of cognitive development and of its biological basis will not explain the preponderance of men on academic faculties of mathematics and science. We must look beyond cognitive ability to other aspects of human biology and society for insights into this phenomenon.

References

1. Acredolo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology*, 13, 1-8.

2. Baillargeon, R. (2004). Infants' reasoning about hidden objects: Evidence for event-general and event-specific expectations. *Developmental Science*, 7, 391-424.

3. Baillargeon, R., Kotovksy, L. & Needham, A. (1995). The acquisition of physical knowledge in infancy. In D. Sperber & D. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 79–116). New York: Clarendon Press/Oxford University Press.

4. Baron-Cohen, S. (2003). The essential difference: The truth about the male and female brain. New York: Basic Books.

5. Baron-Cohen, S. (2005a). The assortative mating theory: A talk with Simon Baron-Cohen. Retrieved April 3, 2005, from http://www.edge.org/3rd_culture/baron-cohen05/baron-cohen05_index.html

6. Baron-Cohen, S. (2005b, August 8). Op-ed: The male condition. *The New York Times*, 15

7. Barth, H., Kanwisher, N. & Spelke, E. (2003). The construction of large number representations in adults. *Cognition*, 86, 201-221.

8. Beilstein, C. D. & Wilson, J. F. (2000). Landmarks in route learning by girls and boys. *Perceptual & Motor Skills*, 91, 877-882.

9. Benbow, C. P. (1988). Sex differences in mathematical reasoning ability in intellectually talented preadolescents: Their nature, effects, and possible causes. *Behavioral & Brain Sciences*, 11, 169-232.

10. Benbow, C. P., Lubinski, D., Shea, D. L. & Eftekhari-Sanjani, H. (2000). Sex differences in mathematical reasoning ability at age 13: Their status 20 years later. *Psychological Science*, 11, 474-480.

11. Benbow, C. P. & Stanley, J. C. (1983, December 2). Sex differences in mathematical reasoning ability: More facts. *Science*, 222, 1029-1030.

12. Brannon, E. M. (2002). The development of ordinal numerical knowledge in infancy. *Cognition*, 83, 223-240.

13. Bridgeman, B. & Lewis, C. (1996). Gender differences in college mathematics grades and SAT-M scores: A reanalysis of Wainer & Steinberg. *Journal of Educational Measurement*, 33, 257-270.

14. Browne, K. R. (2002). Biology at work: Rethinking sexual equality. New Brunswick, NJ: Rutgers University Press.

15. Butterworth, B. (1999). The mathematical brain. London: Macmillan.

16. Byrnes, J. P. (2005). Gender differences in math: Cognitive processes in an expanded framework. In

A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics.* New York: Cambridge University Press.

17. Carey, S. (2001). Evolutionary and ontogenetic foundations of arithmetic. *Mind and Language*, 16, 37-55.

18. Casey, M. B., Nuttal, R., Pezaris, E. & Benbow, C. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, 31, 679-705.

19. Chipman, S. F. (2005). Research on the women and mathematics issue: A personal case history. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics* (pp. 1–24). New York: Cambridge University Press.

20. Choi, J. & Silverman, I. (1996). Sexual dimorphism in spatial behaviors: Applications to route learning. *Evolution & Cognition*, 2, 165-171.

21. Cohen, L. B. (2003). Unresolved issues in infant categorization. In D. Rakison & L. M. Oakes (Eds.), *Early category and concept development* (pp. 193–209). New York: Oxford University Press.

22. Connellan, J., Baron-Cohen, S., Wheelwright, S., Batki, A. & Ahluwalia, J. (2000). Sex differences in human neonatal social perception. *Infant Behavior & Development*, 23, 113-118.

23. Cronin, H. (2005, March 12). The vital statistics: Evolution, not sexism, puts us at a disadvantage in the sciences. *The Guardian*, 21

24. Deary, I. J., Thorpe, G., Wilson, V., Starr, J. M. & Whalley, L. J. (2003). Population sex differences in IQ at age 11: The Scottish mental survey 1932. *Intelligence*, 31, 533-542.

25. Dehaene, S. (1997). The number sense: How the mind creates mathematics. Oxford, England: Oxford University Press.

26. Dehaene, S., Spelke, E., Pinel, P., Stanescu, R. & Tsivkin, S. (1999, May 7). Sources of mathematical thinking: Behavioral and brain-imaging evidence. *Science*, 284, 970-974.

27. Feigenson, L. & Carey, S. (2003). Tracking individuals via object-files: Evidence from infants' manual search. *Developmental Science*, 6, 568-584.

28. Feigenson, L., Dehaene, S. & Spelke, E. S. (2004). Core systems of number. *Trends in Cognitive Sciences*, 8, 307-314.

29. Feingold, A. (1992). Sex differences in variability in intellectual abilities: A new look at an old controversy. *Review of Educational Research*, 62, 61-84.

30. Feingold, A. (1994). Gender differences in variability in intellectual abilities: A cross-cultural perspective. *Sex Roles*, 30, 81-92.

31. Gallagher, A. M. & Kaufman, J. C. (2005). Gender differences in mathematics. New York: Cambridge University Press.

32. Gallagher, A. M., Levin, J. Y. & Cahalan, C. (2002). Cognitive patterns of gender differences on mathematics admissions tests (ETS Research Report No. 02-19). Princeton, NJ: Educational Testing Service.

33. Geary, D. C. (1996). Sexual selection and sex differences in mathematical abilities. *Behavioral &*

Brain Sciences, 19, 229-284.

34. Geary, D. C. (1998). Male, female: The evolution of human sex differences. Washington, DC: American Psychological Association.

35. Geary, D. C., Saults, S. J., Liu, F. & Hoard, M. K. (2000). Sex differences in spatial cognition, computational fluency, and arithmetical reasoning. *Journal of Experimental Child Psychology*, 77, 337-353.

36. Gelman, R. (1991). Epigenetic foundations of knowledge structures: Initial and transcendent constructions. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 293–322). Hillsdale, NJ: Erlbaum.

37. Gentner, D. & Stevens, A. L. (1983). Mental models. Hillsdale, NJ: Erlbaum.

38. Goldstein, D. & Stocking, V. B. (1994). TIP studies of gender differences in talented adolescents. In K. A. Heller & E. A. Hany (Eds.), *Competence and responsibility* (Vol. 2, pp. 190–203). Ashland, OH: Hofgreve.

39. Gouteux, S. & Spelke, E. S. (2001). Children's use of geometry and landmarks to reorient in an open space. *Cognition*, 81, 119-148.

40. Griffin, S. & Case, R. (1996). Evaluating the breadth and depth of training effects when central conceptual structures are taught. *Monographs of the Society for Research in Child Development*, 61, 83-102.

41. Halpern, D. (2000). Sex differences in cognitive abilities (3rd ed.). Mahwah, NJ: Erlbaum.

42. Halpern, D. (2002). Sex differences in achievement scores: Can we design assessments that are fair, meaningful, and valid for girls and boys? *Issues in Education*, 8, 1-19.

43. Halpern, D., Wai, J. & Saw, A. (2005). A psychobiosocial model: Why females are sometimes greater than and sometimes less than males in math achievement. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics* (pp. 48–72). New York: Cambridge University Press.

44. Hauser, M. D. (2005). Comments on Baron-Cohen's “The assortative mating theory.” *Edge: The Reality Club*, 158 Retrieved April 4, 2005, from http://www.edge.org/

45. Hedges, L. V. & Nowell, A. (1995, July 7). Sex differences in mental test scores, variability, and numbers of high-scoring individuals. *Science*, 269, 41-45.

46. Hermer, L. & Spelke, E. S. (1994). A geometric process for spatial reorientation in young children. *Nature*, 370, 57-59.

47. Hespos, S. J. & Rochat, P. (1997). Dynamic representation in infancy. *Cognition*, 64, 153-189.

48. Hespos, S. J. & Spelke, E. S. (2004). Precursors to spatial language. *Nature*, 430, 453-456.

49. Huttenlocher, J., Levine, S. & Vevea, J. (1998). Environmental input and cognitive growth: A study using time-period comparisons. *Child Development*, 69, 1012-1029.

50. Hyde, J. S. (2005). The gender similarities hypothesis. ***American Psychologist***, 60, 581-592.

51. Hyde, J. S., Fennema, E. & Lamon, S. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bulletin*, 107, 139-155.

52. Johnson, S. P. (2004). Development of perceptual completion in infancy. *Psychological Science*, 15, 769-775.

53. Kimura, D. (1999). Sex and cognition. Cambridge, MA: MIT Press.

54. Kotovsky, L. & Baillargeon, R. (1998). The development of calibration-based reasoning about collision events in young infants. *Cognition*, 67, 311-351.

55. Kouider, S., Halberda, J., Wood, J. N. & Carey, S.Acquisition of English number marking: The singular-plural distinction. *Language Learning and Development* in press

56. Learmonth, A. E., Nadel, L. & Newcombe, N. S. (2002). Children's use of landmarks: Implications for modularity theory. *Psychological Science*, 13, 337-341.

57. Le Corre, M. (2004). The construction of the positive integers: A case study of human cognition as a product of evolution and culture. Unpublished doctoral dissertation, New York University.

58. Lemer, C., Dehaene, S., Spelke, E. & Cohen, L. (2003). Approximate quantities and exact number words: Dissociable systems. *Neuropsychologia*, 41, 1942-1958.

59. Levine, S. C., Huttenlocher, J., Taylor, A. & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology*, 35, 940-949.

60. Linn, M. C. & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, 56, 1479-1498.

61. Lipton, J. S. & Spelke, E. S. (2003). Origins of number sense: Large number discrimination in human infants. *Psychological Science*, 14, 396-401.

62. Lipton, J. S. & Spelke, E. S.Preschool children master the logic of the verbal counting routine. *Cognition* in press

63. Lubinski, D. & Benbow, C. P. (1992). Gender differences in abilities and preferences among the gifted: Implications for the math/science pipeline. *Current Directions in Psychological Science*, 1, 61-66.

64. Lubinski, D., Webb, R. M., Morelock, M. J. & Benbow, C. P. (2001). Top 1 in 10,000: A 10-year follow-up of the profoundly gifted. *Journal of Applied Psychology*, 86, 718-729.

65. Maccoby, E. E. & Jacklin, C. N. (1974). Psychology of sex differences. Stanford, CA: Stanford University Press.

66. Mandler, J. M. (2004). The foundations of mind: Origins of conceptual thought. New York: Oxford University Press.

67. Matsuzawa, T. (1985). Use of numbers by a chimpanzee. *Nature*, 315, 57-59.

68. Moss, H. A. & Robson, K. S. (1968). Maternal influences in early social visual behavior. *Child Development*, 39, 401-408.

69. Nature Neuroscience Board of Editors (2005). Separating science from stereotype *Nature Neuroscience*, 8, 253 [Editorial].

70. Newcombe, N. S. (2002). The nativist-empiricist controversy in the context of recent research on spatial and quantitative development. *Psychological Science*, 13, 395-401.

71. Newcombe, N. S. & Huttenlocher, J. (2000). Making space: The development of spatial representation and reasoning. Cambridge, MA: MIT Press.

72. Newcombe, N. S. & Huttenlocher, J.Development of spatial cognition. in press In D. Kuhn & R. S. Siegler (Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language* (6th ed.). New York: Wiley.

73. Newcombe, N. S., Huttenlocher, J. & Learmonth, A. (1999). Infants' coding of location in continuous space. *Infant Behavior and Development*, 22, 483-510.

74. Nowell, A. & Hedges, L. V. (1998). Trends in gender differences in academic achievement from 1960–1994: An analysis of differences in mean, variance, and extreme scores. *Sex Roles*, 39, 21-43.

75. Pepperberg, I. M. (1994). Numerical competence in an African grey parrot (Psittacus erithacus). *Journal of Comparative Psychology*, 108, 36-44.

76. Pica, P., Lemer, C., Izard, V. & Dehaene, S. (2004, October 15). Exact and approximate arithmetic in an Amazonian indigene group. *Science*, 306, 499-503.

77. Pinker, S. (2002). The blank slate: The modern denial of human nature. New York: Viking.

78. Quinn, P. C. & Eimas, P. D. (1996). Perceptual organization and categorization in young infants. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 10, pp. 1–36). Norwood, NJ: Ablex.

79. Quinn, P. C. & Oates, J. M. (2004). Early category representations and concepts. In J. M. Oates & A. Grayson (Eds.), *Cognitive and language development in children,* (2nd ed., pp. 21–60). Oxford, England: Blackwell.

80. Rieser, J. (1979). Spatial orientation in six-month-old infants. *Child Development*, 50, 1078-1087.

81. Rochat, P. (2001). The infant's world. Cambridge, MA: Harvard University Press.

82. Royer, J. M. & Garofoli, L. M. (2005). Cognitive contributions to sex differences in math performance. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics* (pp. 99–120). New York: Cambridge University Press.

83. Sarnecka, B. W. & Gelman, S. A. (2004). Six does not just mean a lot: Preschoolers see number words as specific. *Cognition*, 92, 329-352.

84. Saucier, D., Bowman, M. & Elias, L. (2003). Sex differences in the effect of articulatory or spatial dual task interference during navigation. *Brain and Cognition*, 53, 346-350.

85. Sax, L. (2005). Why gender matters. New York: Doubleday.

86. Shea, D. L., Lubinski, D. & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology*, 93, 604-614.

87. Shusterman, A. & Spelke, E. S. (2005). Language and the development of spatial reasoning. In P. Carruthers, S. Laurence, & S. Stitch (Eds.), *The innate mind: Structure and content* (pp. 89–108). New York: Oxford University Press.

88. Shutts, K. & Spelke, E. S. (2004). Straddling the perception-conception boundary. *Developmental Science*, 7, 507-511.

89. Siegler, R. S. & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development*, 75, 428-444.

90. Siegler, R. S. & Opfer, J. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, 14, 237-243.

91. Slater, A., Mattock, A. & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology*, 49, 314-322.

92. Spelke, E. S. (2003). Core knowledge. In N. Kanwisher & J. Duncan (Eds.), *Attention and Performance: Vol. 20. Functional neuroimaging of visual cognition* (pp. 29–56). New York: Oxford University Press.

93. Spelke, E. S. & Newport, E. (1998). Nativism, empiricism, and the development of knowledge. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Handbook of child psychology: Vol. 1: Theoretical models of human development.* (5th ed., pp. 275–340). New York: Wiley.

94. Spelke, E. S., Vishton, P. & von Hofsten, C. (1995). Object perception, object-directed action, and physical knowledge in infancy. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 165–179). Cambridge, MA: MIT Press.

95. Summers, L. (2005, January 14). Remarks at NBER conference on diversifying the science and engineering workforce. Retrieved April 5, 2005 from http://www.president.harvard.edu/speeches/2005/nber.html

96. Trick, L. & Pylyshyn, Z. W. (1994). Why are small and large numbers enumerated differently? A limited capacity preattentive stage in vision. *Psychological Review*, 101, 80-102.

97. van Marle, K. (2004). Infants' understanding of number: The relationship between discrete and continuous quantity. Unpublished doctoral dissertation, Yale University, New Haven, CT.

98. van Oeffelen, M. P. & Vos, P. G. (1982). A probabilistic model for the discrimination of visual number. *Perception & Psychophysics*, 32, 163-170.

99. von Hofsten, C. (1982). Eye-hand coordination in the newborn. *Developmental Psychology*, 18, 450-461.

100. von Hofsten, C., Rosander, K. & Ornkloo, H. (2005). Young children's predictive manipulation of blocks in a form-fitting task. Manuscript submitted for publication.

101. Voyer, D., Voyer, S. & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117, 250-270.

102. Wang, R. F. & Spelke, E. S. (2002). Human spatial representation: Insights from animals. *Trends in Cognitive Sciences*, 6, 376-382.

103. Webb, R. M., Lubinski, D. & Benbow, C. P. (2002). Mathematically facile adolescents with math/science aspirations: New perspectives on their educational and vocational development. *Journal of Educational Psychology*, 94, 785-794.

104. Willingham, W. W. & Cole, N. S. (1997). Gender and fair assessment. Mahwah, NJ: Erlbaum.

105. Wynn, K. (1992a). Addition and subtraction by human infants. *Nature*, 358, 749-750.

106. Wynn, K. (1992b). Children's acquisition of the number words and the counting system. *Cognitive*

Psychology, 24, 220-251.

107. Xie, Y. & Shauman, K. (2003). Women in science: Career processes and outcomes. Cambridge, MA: Harvard University.

108. Xu, F. & Spelke, E. S. (2000). Large number discrimination in 6-month-old infants. *Cognition*, 74, B1-B11.

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