Sex Difference Research and Cognitive Abilities

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Decades of research have investigated when and why females and males perform differently on cognitive tasks. This research has captured the attention of many people and has raised politically and emotionally charged questions. Overall, studies have not found evidence for a smarter sex. However, sex differences in some specific cognitive tasks are found, such as mental rotation (male advantage) or writing (female advantage). Importantly, these sex differences describe groups, *not individuals* (e.g., many women excel in mental rotation tasks, many men excel in writing tasks). Males and females also perform similarly on many other tasks, suggesting that focusing on differences may ignore the many ways in which the sexes are similar. Cognitive sex differences are sometimes substantial but often small in magnitude; both biological and environmental factors are necessary to explain these findings. Most research on cognitive sex differences has focused on three types of cognitive abilities: mathematical, spatial, and verbal. These abilities are multifaceted (e.g., some but not all spatial abilities show sex differences) and interrelated (e.g., some mathematical abilities require both spatial and verbal abilities).

EMPIRICAL EVIDENCE

Compared to males, females generally earn equal or higher grades in mathematics classes. In addition, average sex differences in mathematics test performance tend to be small. However, male advantages in mathematics test performance are sometimes found depending on factors such as age. For instance, small but notable male advantages in mathematics performance emerge in high school and college but are generally not found in earlier grades. Sex differences are also larger in highly selective samples, consistent with males being overrepresented in the higher-achieving "right tail" of the mathematics performance distribution (e.g., top 5 percent of test takers). These right-tail differences have been found in grades as early as kindergarten but vary substantially by children's ethnicity and socioeconomic status (Ceci, Williams, and Barnett 2009). These sex differences also vary substantially across nations. In a few nations, female advantages in average mathematics test performance are found and sex differences in the right tail of performance (e.g., top 5 percent) are not found (Halpern 2012). Male advantages among very highly performing students (higher than top 1 percent) are found globally but vary substantially in size across nations. In the United States, both average and right-tail differences have decreased during the 1970s to 1990s but have since remained constant; temporal changes in other nations are unclear. In sum, sex differences in average mathematics test performance tend to be small, although males outnumber females among high scorers in most nations.

Sex differences in spatial abilities strongly depend on the task considered. Males outperform females substantially in some spatial tasks such as mentally rotating 3-D objects but not consistently in other tasks such as mentally folding paper (Miller and Halpern 2014). Some spatial tasks such as remembering object locations moderately favor women.

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Many research studies have focused on mental rotation, perhaps because of the large sex differences found. One research synthesis found that sex differences in mental rotation emerged as early as middle school and increased during adolescence. Subsequent research with small to moderate sample sizes has found similar sex differences in second grade, preschool, and even infancy, although contradictory results are sometimes found. In one massive self-selected Internet sample, sex differences in mental rotation and spatial perception varied substantially across nations but favored males in all 53 nations analyzed. In sum, some spatial tasks such as mental rotation demonstrate remarkably robust and large male advantages. However, many other spatial tasks show no sex difference or, in one case, female advantage.

Research conducted before the 1990s suggested negligible sex differences in most verbal abilities. However, recent large international assessments of reading achievement reveal a different trend. In one recent analysis of the reading achievement of 1.5 million children, girls outperformed boys in all 75 nations in all four testing administrations (Miller and Halpern 2014). Sex differences in reading were moderately large in the majority of cases and three times as large as those in mathematics. Sex differences among low-performing students were also two times as large as among high-performing students; such findings are consistent with males being overrepresented in the "left tail" of the reading performance distribution and overrepresented among students with reading disabilities. These left-tail differences have been found in grades as early as kindergarten. Female advantages are even larger in writing achievement compared to reading achievement. Sex differences in reading and writing have not changed much in the United States during the 1970s to 1990s. However, according to some recent international research, female advantages in reading may have increased worldwide during the past decade. In sum, female advantages in reading and writing are moderate, global, and not decreasing.

BIOLOGICAL THEORIES

Some theoretical approaches have focused on biological factors such as hormones and brains to explain these complex patterns of cognitive sex differences. Although the term *biological* is often conflated with *innate* and *immutable*, these ideas are conceptually distinct. Environmental factors such as poor nutrition can cause biological differences (differentiating *biological* and *innate*) and biological traits such as hair color can be easily altered (differentiating *biological* and *immutable*). Hence, evidence for biological factors does not contradict the considerable evidence that cognitive sex differences are malleable and that all cognitive abilities can improve if nurtured and supported (Ceci, Williams, and Barnett 2009).

Early biological theories hypothesized that genes occurring on sex-linked chromosomes explain cognitive sex differences. Although sex-linked genes may partly explain the higher rates of mental retardation among males, genetic theories have failed to explain most other cognitive sex differences (Halpern 2012).

Some evidence exists that prenatal androgen exposure (e.g., exposure to testosterone in utero) may partly explain sex differences in mental rotation performance. Results have been inconsistent in studies using crude measures of prenatal androgens (e.g., the ratio of the index finger to ring finger) but have been more consistent in other studies. For instance, females with abnormally high prenatal androgen exposure (either because of having a genetic condition or a male fraternal twin) tend to have moderately superior mental rotation ability compared to control females (Miller and Halpern 2014). Hence, higher prenatal androgen exposure likely increases women's mental rotation performance, but the mechanisms of *how* remain unclear. Effects of prenatal androgens on any other cognitive abilities (spatial or non-spatial) also remain unclear.

Sex hormones encountered in adulthood may affect some cognitive abilities, but this evidence is mixed. For instance, in one well-controlled but small experimental study ($n = 26$), a single dose of testosterone improved women's mental rotation performance ($d \sim 0.4$). In some other small studies, circulating levels of testosterone predicted mental rotation performance both within and across adults. However, many other experimental and correlational studies (some with larger sample sizes) have failed to replicate these effects, sometimes even finding contradictory results (Ceci, Williams, and Barnett 2009). These inconsistencies have led some biologically oriented researchers, who believe in the cognitive effects of prenatal androgens, to conclude that the cognitive effects of postnatal hormones are either small or nonexistent.

Influential theories, with mixed empirical support, explain cognitive sex differences on the basis of brain lateralization (that is, the extent to which an individual's left or right brain hemisphere is more dominant for particular cognitive functions). According to these theories, prenatal androgens "organize" brain development resulting in men being more dominant in the right hemisphere and women being equally dominant in both. Based on other cognitive neuroscience research, right hemispheric dominance is thought to support spatial abilities and bilaterality is thought to support verbal abilities. Some evidence exists for these claims. For instance, during some spatial tasks, sex differences in brain lateralization have been found as early as 5 years of age. However, other evidence is inconsistent. For instance, during language tasks, sex differences in lateralization have not been found according to research syntheses (Miller and Halpern 2014).

Sex differences in the brain certainly exist (e.g., men have 10 percent larger brains). The bundle of fibers, called the corpus callosum, that connect the two hemispheres may be more bulbous in females, perhaps suggesting greater inter-hemispheric connectivity in females. However, many neuroscience researchers intensely debate this claim regarding the corpus callosum. Other researchers also point out that structural brain differences do not necessarily imply functional advantages (e.g., better verbal abilities) because women and men may use the same brain regions differently. Furthermore, such brain differences could reflect the accumulation of environmental experiences rather than the organizational effects of prenatal sex hormones. Differences in brain activation can even reflect the situational effects of making gender stereotypes salient (Halpern 2012). In sum, brain research has promise in helping to explain cognitive sex differences. However, the causal relationships between hormones, brains, and behavior are currently ambiguous.

Evolutionary theories propose that cognitive sex differences evolved in response to the demands of hunter-gatherer societies. For instance, men are thought to have better spatial ability because they had to track and hunt animals over long distances. Other scholars disagree, pointing out that women likely had to also navigate long distances to find edible crops that ripened in different locations throughout the year (Halpern 2012). These evolutionary theories are generally difficult to test empirically but offer interesting perspectives to consider.

ENVIRONMENTAL THEORIES

Environments contribute to cognitive sex differences, as evidenced by the substantial variability of cognitive sex differences across nations and across time. Researchers have proposed that specific environmental factors such as gender equity, sex-typed activities, and stereotypes explain this variability. Understanding these environmental causes offers promise to maximize the cognitive potential of both men and women.

Some sociocultural theories propose that national gender equity partly causes cognitive sex differences. Consistent with predictions, male advantages in mathematics are smaller and sometimes even reversed in nations with greater gender equity in education and in the workforce (e.g., percent women among students enrolled in school or among employed workers). However, these relationships are far less clear for sex differences in spatial and verbal abilities (Miller and Halpern 2014).

Other theories, for varied reasons, predict that economic prosperity should increase some cognitive sex differences. Consistent with predictions, sex differences in mathematical and spatial abilities tend to be larger in families with higher socioeconomic status and nations with more economic prosperity. These relationships are less clear for sex differences in verbal abilities.

Sex differences may increase with economic prosperity because the prevalence of sex-typed activities may also increase. For instance, some male-typical spatial activities (e.g., playing action video games) have been experimentally shown to increase spatial abilities. Males' more frequent engagement in these activities may therefore partly explain sex differences in some spatial abilities. Evidence for the effects of sex-typed activities on other cognitive abilities is less clear.

Much research has investigated whether the negative consequences of gender stereotypes may partly explain cognitive sex differences. For instance, women often perform worse if reminded of their gender before taking a mathematics test; this phenomenon is known as *stereotype threat*. Dozens of studies have replicated this basic effect. Other researchers have debated this evidence, arguing that these threat effects are small or not robust, according to a recent research synthesis. Stereotype threat researchers responded by arguing that the selection criteria of that research synthesis was biased and that a subsequent synthesis found threat effects that were both robust and meaningful (Miller and Halpern 2014). Research also suggests that gender stereotypes may partly explain male advantages in some spatial tasks (according to more than a dozen studies) and female advantages in some verbal tasks (according to a small handful of studies). Scholars continue to debate whether these stereotype threat effects exist in "real-world" settings such as when taking high-stakes standardized tests (e.g., the SAT).

Individuals tend to persist on tasks in which they expect and value success. Sex differences in these task expectancies and values might partly explain cognitive sex differences (Halpern 2012). For instance, females from across the world expect less academic success in mathematics than males, even when no sex differences in test performance are found. This lower confidence could cause women to avoid mathematics activities or underperform as the mathematics material becomes more challenging in high school and beyond. Extensive longitudinal evidence supports these claims, but these theories are generally difficult to test experimentally. Sex differences in other psychosocial constructs may also be important (e.g., women report higher math anxiety).

Some socialization theories propose that teachers and parents contribute to cognitive sex differences by influencing children's values and expectancies for success. For instance, teachers and parents may give boys more encouragement to pursue mathematics than girls because of biased perceptions of boys' abilities. Much evidence exists for some of these claims, but other evidence is inconsistent (Ceci, Williams, and Barnett 2009). For instance, in a recent nationally representative study, US elementary and middle school teachers rated girls' math achievement higher than boys' even when empirical data showed the opposite trend. Of course, teachers and parents may influence cognitive sex differences in many other ways than through differential treatment and biased perceptions. For instance, consistent with recent longitudinal and quasi-experimental evidence, female teachers' math anxiety could influence girls' math achievement by shaping girls' beliefs about which gender is good at math.

BIOLOGICAL AND ENVIRONMENTAL INTERACTIONS

Biopsychosocial theoretical frameworks describe biological and environmental factors as inseparable because they exert reciprocal effects on each other. Effects of biology can be mediated or moderated by environments and vice versa (Halpern 2012). For instance, higher prenatal androgen exposure could cause females to engage in male-typical activities (e.g., playing action video games) that are likely to enhance spatial cognition. In this way, effects of biology would be mediated by females' choices of activities and moderated by the availability of such activities. Recent research provides some direct evidence for this mediational pathway. Furthermore, environments cause biological changes. Effects of gender stereotypes on mental rotation performance are likely explained, in part, by changes in brain activation and perhaps circulating levels of testosterone. Hence, both prenatal androgens and gender stereotypes likely influence sex differences in mental rotation, and both factors interact with biology and environment. In other words, biology influences environments and environments influence biology in a continuous causal loop. Understanding how both biological and environmental factors interact is likely to identify strategies that can maximize both sexes' cognitive potential.

SEE ALSO: Educational Testing and Gender; Gender Difference Research; Psychology of Gender: History and Development of the Field

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