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Current Opinion in Neurobiology

Sex and cognition: gender and cognitive functions

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Gender stereotypes hold that males outperform females in mathematics and spatial tests, and females outperform males on verbal tests. According to meta-analyses, however, among both children and adults, females perform equally to males on mathematics assessments. The gender difference in verbal skills is small and varies depending on the type of skill assessed (e.g., vocabulary, essay writing). The gender difference in 3D mental rotation shows a moderate advantage for males, but this gender difference occurs in the absence of a spatial curriculum in the schools. Meta-analyses of gender differences across a wide array of psychological qualities support the Gender Similarities Hypothesis, which states that males and females are quite similar on most — but not all — psychological variables.

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Current Opinion in Neurobiology 2016, **38**:53–56

This review comes from a themed issue on **Neurobiology of sex**

Edited by **Barry J Dickson** and **Catherine Dulac**

For a complete overview see the Issue and the Editorial

Available online 5th March 2016

http://dx.doi.org/10.1016/j.conb.2016.02.007

Background: the history of psychological research on gender differences

From the time of the founding of scientific psychology around 1879, researchers have investigated psychological gender differences [1]. Authoritative reviews in the 1960s and 1970s by the eminent Stanford psychologist Eleanor Maccoby framed the field, as well as related neurobiology research, for the next several decades [2,3]. These reviews concluded that gender differences in verbal ability, spatial ability, and mathematical ability were well established, with girls scoring higher on verbal tests and boys scoring higher on spatial and mathematical tests. In the 1974 review, Maccoby also dismissed as unfounded beliefs in certain other cognitive gender differences, concluding that research failed to find that (a) girls excel at simple rote learning whereas boys are better at tasks that require higher-level cognitive processing; and (b) that boys are more analytic. The conclusions about gender differences were taken up eagerly by researchers, whereas the conclusions about gender similarities were largely ignored.

At the same time as researchers sought to investigate psychological gender differences scientifically, gender stereotypes pervaded the culture at large in the U.S. and many other Western nations. Women are viewed as having stronger verbal skills and men are seen as stronger in mathematics and science [4]. Contemporary research using the Implicit Attitudes Test (IAT) continues to show that, at a nonconscious level as measured by reaction times, people associate math with males [5•]. Similarly, there is a stereotyped link between male and science and the strength of this stereotype varies across nations and cultures [6].

The role of meta-analysis in research on gender differences

A new era in research on psychological gender differences began in the early 1980s with the development of the statistical method of meta-analysis, which is a quantitative method for aggregating research findings across many studies of the same question [7]. Because of this quantitative integration across a large number of studies, meta-analysis provides much stronger evidence about a phenomenon than any individual study can. Individual studies on a question may arrive at inconsistent conclusions, allowing researchers to cherry pick studies that conform to their research agenda. Meta-analysis synthesizes across all studies, thus discerning patterns that are reliable. Moreover, meta-analysis provides an estimate of the magnitude of an effect, such as the gender difference in math performance.

Central to meta-analysis is the concept of effect size. Several alternative effect size statistics are available, depending on the research design [7]. Here I focus on the statistic d, which assesses the magnitude of difference in two-group designs. For gender differences, the formula is $d = (M_M - M_F)/s_w$, where M_M is the mean (average) score for males, M_F is the mean score for females, and s_w is the within-groups standard deviation. That is, d reflects the difference between the male average and the female average, in standard deviation units. Positive values reflect higher average scores for males and negative values indicate higher average scores for females. Cohen [8] provided the following guidelines for the interpretation of effect sizes: 0.20 is a small effect, 0.50 is moderate, and 0.80 is a large effect.

To provide a visual representation of a small effect size of $d = 0.20$, Figure 1 shows two normal distributions that are

Table 1

Summary of effect sizes for cognitive gender differences

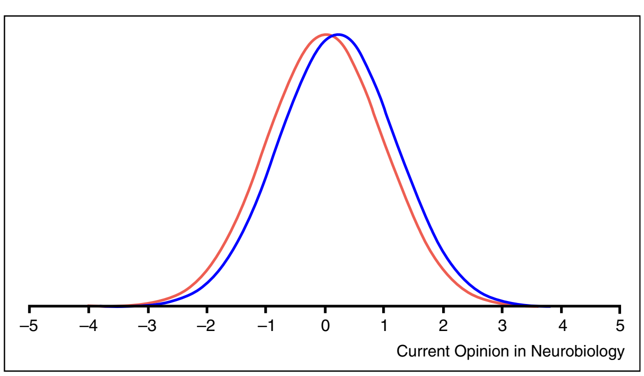
	Ages	*d*
Mathematics performance		
Hyde *et al.* [10]	Grades 2–11	0.0065
Lindberg *et al.* [11••]	Children and adults	0.05
Else-Quest *et al.* [12]	14-year to 16-year-olds	−0.01 to 0.11
Spatial skills, 3D mental rotation		
Linn and Petersen [13]	Children and adults	0.73
Voyer *et al.* [14]	Children and adults	0.51
Verbal skills		
Hyde and Linn [17]	Children and adults	−0.11
Hedges and Nowell [18] reading comprehension	Adolescents	−0.18 to 0.002

0.20 standard deviations apart, which is the meaning of $d = 0.20$. With a small effect size such as this, there is great overlap between the distribution of scores for males and the distribution of scores for females.

A meta-analysis proceeds in several steps. First, all prior research with data relevant to the question (e.g., gender differences in math performance) is identified. Second, statistics are extracted from each article and d is computed for each article. Third, a weighted mean value of d is computed, averaging across all studies and weighting by sample size. Fourth, moderator analyses can be conducted to examine whether there are systematic variations in the effect size depending on various features of the study; for example, is the gender difference in math performance smaller in childhood and larger in adolescence?

At this point, multiple excellent meta-analyses are available on cognitive gender differences, and these meta-analyses, rather than individual studies, form the basis for this review. See Table 1 for a summary.

Figure 1



Two normal distributions, for males and females, that are 0.20 standard deviations apart (i.e., $d = 0.20$). These illustrate a small effect size for gender differences.

Mathematics performance

Although a 1990 meta-analysis found some evidence of gender differences in math performance [9], more recent meta-analyses indicate that, in general, the gender difference has disappeared, while also revealing more complex variations in the magnitude of the gender difference. This change over time may be due to changes in girls' patterns of course-taking. Before 1990, girls were less likely than boys to take a full 4 years of math in high school, whereas today girls take as much math as boys do.

One meta-analysis synthesized data from state assessments of U.S. children's math skills; these data represented the testing of more than 7 million children in grades 2 through 11 [10]. There was no systematic variation across grade levels in the effect size for gender differences and, overall, $d = .0065$, that is, there was no gender difference in math performance.

A second meta-analysis synthesized data from 242 studies appearing between 1990 and 2007, representing data from 1.2 million children and adults [11••]. Again, there was no gender difference in math performance, $d = 0.05$.

A third meta-analysis examined data from two major international data sets, the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA), which tested 14-year to 16-year-olds in 69 participating nations [12]. For TIMSS, $d = -0.01$ and for PISA $d = 0.11$, both values that are very close to zero or no gender difference. Variation across nations in the magnitude of the gender difference was substantial, though. For example, for TIMSS, $d = -0.04$ in both Romania and Norway, but $d = 0.18$ in Chile and Morocco. Multiple regression analyses indicated that these variations across nations could be accounted for, in part, by measures of the nations' levels of gender equality. Larger gender differences favoring males were found in nations characterized by more gender inequality in matters such as women's representation in parliament and women's share of research jobs. These findings are consistent with the gender stratification hypothesis, which maintains that gender differences in outcomes such as math performance are closely related to opportunity structures for girls and women in their culture [12].

Overall, then, findings from meta-analyses indicate that females have reached parity with males in math performance today, although there are variations in this pattern as a function of factors such as nation and culture.

Spatial skills

A variety of types of spatial skills exist. Here I focus on one particular skill, three-dimensional (3D) mental rotation, which involves the ability to mentally rotate an object in three-dimensional space to see if it matches another object. Spatial skills are important in everyday tasks such as map reading and navigation, in academic courses such as organic chemistry, and in occupations such as architecture and engineering.

Among the types of spatial skills, 3D mental rotation shows the largest gender difference, favoring males. In an early meta-analysis, the gender difference in 3D mental was large, $d = 0.73$ [13]. A later meta-analysis found that the gender difference was moderate in magnitude, $d = 0.51$ [14].

This gender difference exists in the absence of a spatial curriculum in American schools, in contrast to the extensive math curriculum. It may be that the gender difference in spatial performance results from gender differences in informal, extracurricular learning experiences, such as involvement in sports and video game playing. Scores on spatial tests can be improved with training [15•]. Research now is focusing on boys' greater participation in video games, some of which improve spatial skills. In one experiment, college students were given 10 hours of training on an action video game [16]. Afterward, women in the experimental group performed as well as men in the control group that had not had the training.

Overall, then, 3D spatial skills show a moderate gender difference favoring males. However, this gender difference may result from the absence of a spatial curriculum in the schools, and girls' average performance might be brought up to the level of boys' with well-designed training.

Verbal skills

An early meta-analysis found that the female advantage in verbal skills is quite small, $d = -0.11$ [17]. There are multiple types of verbal ability, though, and patterns of gender differences vary across these different abilities. In this meta-analysis, for example, there were no gender differences for vocabulary ($d = -0.02$), reading comprehension ($d = -0.03$), or essay writing ($d = -0.09$), but verbal fluency showed a moderate difference favoring females ($d = -0.33$).

Another meta-analysis examined data from several large, well-sampled studies of U.S. adolescents [18]. For reading comprehension, d ranged between -0.18 and 0.002 across the studies. For vocabulary, effect sizes ranged between -0.06 and 0.25. Overall, most effect sizes were close to zero, so there was no evidence of a substantial female advantage in these tests of verbal skills.

Other cognition functions

Gender differences in other aspects of human cognition have been studied meta-analytically as well. These findings are beyond the scope of the current review, but are noted briefly here. These meta-analyses include research on gender differences in moral reasoning [19], interests [20], and working memory [21]. Gender differences in attitudes about mathematics (e.g., math self-concept) have also been studied meta-analytically [12].

The Gender Similarities Hypothesis

Readers will have noticed that, despite stereotypes about male superiority in the math domain and female superiority in the verbal domain, actual gender differences evaluated meta-analytically are quite small and often close to zero. These meta-analyses and others like them led me to propose the Gender Similarities Hypothesis, which holds that males and females are similar on most, but not all, psychological variables [22•].

Evidence for the Gender Similarities Hypothesis came from a synthesis of 46 meta-analyses of research on psychological gender differences, for a wide array of outcomes, including cognitive abilities, multiple aspects of communication, aggression, sexuality, leadership, personality, self-esteem, and depression. A total of 124 effect sizes were extracted from the 46 meta-analyses. Overall, 30% of the effect sizes were close to zero (between 0 and 0.10) and an additional 48% were in the small range (0.11–0.35). 78% of the effect sizes, then, were small or close to zero, that is, they showed gender similarities. Exceptions to the pattern of gender similarities occurred for certain aspects of motor performance (e.g., throwing distance), aggressive behavior, and some aspects of sexuality.

Ten years later, other scientists tested the Gender Similarities Hypothesis by aggregating 106 meta-analyses and found generally the same result: 39% of the effect sizes were close to zero and an additional 46% were in the small range [23•]. Overall, then, and contrary to stereotypes, males and females are more similar than they are different across a broad spectrum of psychological attributes.

Conclusion

Gender stereotypes hold that men outperform women in mathematics and spatial tests, and that women outperform men on verbal tests. Psychological research from the 1930s through the 1970s indicated that these stereotypes were accurate. Meta-analyses changed these views, however, and it may be that the phenomena themselves changed over time. For example, the gender difference in math performance may have narrowed from the 1970s to the present. Today, females perform equally to males on mathematics assessments, in both K-12 data and data including adults. The gender difference in verbal skills, too, is small and varies depending on the type of verbal skill that is assessed (e.g., vocabulary, essay writing). The gender difference in 3D mental rotation shows a moderate advantage for males, but this gender difference occurs in the absence of a spatial curriculum in the schools. Surveying meta-analyses of gender differences in cognitive abilities, as well as a wide array of other psychological qualities, leads to the Gender Similarities Hypothesis, which states that males and females are quite similar on most — but not all — psychological variables. It is important that neurobiologists who do work related to cognitive gender differences update themselves on the latest findings in the field.

Conflict of interest statement

Nothing declared.

Acknowledgements

Funding was provided by the National Science Foundation, REC 0635444. The author thanks the many individuals who have collaborated with her over the years on meta-analyses of cognitive gender differences, including, especially, Nicole Else-Quest, Sara Lindberg, Jennifer Petersen, and Marcia Linn.

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