

GENDER DIFFERENCES IN COGNITIVE ABILITIES IN HUMAN ADULTS

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Mini Review

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Abstract

Modern world of globalization and unification is of particular interest considering the rapid changes in men's and women's dispositions and engagement in societal institutions. According to these contemporary developments of the psychosocial context, cognitive differences between females and males may also be changing. The aim of this study was to update findings from the last two decades regarding gender differences in cognitive abilities.

Major updated results confirm earlier studies and demonstrate relevant gender differences in spatial abilities, verbal skills, emotional processing and executive functions. Like earlier studies, the new data also show small to trivial gender differences in mathematics performance, yet gender effects on complex problem solving are found to be smaller than in 1990 meta-analyses.

The updated data confirm that gender differences in cognitive abilities do exist despite the increasing unification of men's and women's involvement in psychosocial contexts. Moreover, new scientific approaches demonstrate that these gender-specific cognitive differences are grounded on hormonal, neuroanatomical and neurofunctional substrates emphasizing their biological origin. Although the psychosocial interaction is of relevance, the primary biological basis of gender differences should be very strongly and carefully considered.

Key words: cognitive abilities, gender differences, healthy adults

Introduction. Since long it has been recognized that females and males differ in their daily and preferred activities, as well as in their professional engagement [1]. In addition to long-standing societal traditions and stereotypes,

differences in cognitive abilities have been suggested to lead, at least partly, to the gender-specific domains. Indeed, controlled scientific exploration of adult humans and children has implicated gender differences in a variety of cognitive brain functions as responsible for the differential social engagement and preferences. Research has confirmed some societal stereotypes, finding reliable gender effects on specific cognitive tasks and disconfirmed others, finding evidence for similarities between males and females on other cognitive tasks. Faculties and behaviours most consistently linked to gender have been repeatedly associated with spatial information processing, verbal information processing, and emotional processes [1]. These conclusions have remained unchanged for years.

With this regard, modern world of globalization and unification is of particular interest considering rapid changes in men's and women's dispositions and participation in societal institutions. Nonetheless, issues such as the underrepresentation of women in the fields of engineering, higher education, and science are still present. According to these contemporary developments in the psychosocial context, cognitive differences between females and males may also be changing, decreasing for some tasks while remaining stable or increasing for others, suggesting that some earlier conclusions about gender differences and similarities in cognitive abilities need to be reexamined [2]. These new developments and possibilities have sparked new interest in, and debates about gender differences in cognitive abilities.

The aim of the present review was to update findings from the last two decades regarding gender differences in cognitive abilities. Cognition refers to all types of intellectual activity related to the acquisition, organization, processing, and use of information including basic cognitive processes such as sensation, perception, motor skills, attention, memory, learning, language, thinking, executive functions, and others. Yet, the major focus of the current review was on those functions in adults that have been previously most consistently recognized as gender-dependent: spatial processing, the effectiveness of verbal processing, and emotional processes. In addition, other fundamental cognitive processes essentially supporting performance in all cognitive control tasks – thinking, attention, and memory – were targeted to highlight better the specificity of gender-related cognition.

Methodology. The articles used to prepare this review were extracted by conducting a standard search in PubMed database (<https://pubmed.ncbi.nlm.nih.gov>) with keywords 'gender differences' and 'cognitive abilities' and 'healthy adults' with publication date since 2000 (231 articles found). Articles inconsistent with the scope of this study (topic, age range after 18 years of age, written in English) were excluded. After that, the reference lists of the related papers were checked, and other studies were collected through the 'Related Articles' function in the database. Thus, 44 articles published since 2000 are considered in the review.

Results. Gender differences in cognitive abilities.

Spatial processing. Consistent with earlier findings [3], males demonstrate better visual-spatial [4, 5] and auditory-spatial abilities [6]. The largest gender differences favouring men, are found for the mental rotation ability and especially for the 3D mental rotation [5, 7–11], which is evident across different cultures [7], with moderate to large effect size, and is present from infancy to old age [9].

Language function. Earlier studies have systematically found gender differences in verbal skills, overall favouring females, with small to trivial effect size. For example, a meta-analysis by [12] has demonstrated overall a small advantage towards females in all tests, with the largest gender difference found for speech production and programming a sequence of speech [13]. However, no gender differences have been shown for vocabulary, reading comprehension, analogies, or essay writing. Furthermore, contrary to stereotypes, males have exceeded females in total talking time [12]. Recent findings confirm in general these observations. Women are found to perform better in semantic fluency and verbal recognition [4]. According to a meta-analysis considering however mostly, but not only, adolescent studies, the female advantage in verbal skills is small, with the largest effect (small to moderate) being present for verbal fluency [9].

Emotional processing. A relevant number of updated studies confirm the previously detected effects of gender on emotional processing [14, 15]. Studies across-lifespan (from adolescence to old age) highlight female advantage in emotion recognition [16–19]. Females also demonstrate greater empathy [20–22] and emotional intelligence [23–25]. But even though it appears that males express less empathy than females, their higher discrimination in targeting helping behaviour (males discriminate better helping behaviour), supports the idea that males outperform females in the empathetic control [21]. Another meta-analysis of gender differences in the self-conscious emotions, like guilt and shame, also reveals differences favouring females [26]. Yet, data from both children and adults indicate that gender differences in emotional experience are small or, in many cases, trivial [9] and, contrary to stereotypes portraying women as the emotional ones, no gender differences are found for embarrassment and pride [26]. Moreover, the effect of mood congruence in observing faces (the emotion perceived from a face as being influenced by one's own mood) affects men more than women [27].

Thinking and abstraction. One domain that is mostly representative of thinking and abstraction is performance in mathematics. The stereotypes about female inferiority in mathematics stand in contrast to the scientific data on actual performance. In earlier studies, the gender difference in mathematics has been overall trivial in magnitude [28]. For complex problem solving, which is considered the highest cognitive level of mathematical tests, no effects of gender have been found in elementary and middle school, but a gender difference favouring males has presented in high school and college [28]. This difference, although small ($d = 0.29$), has been of concern because complex problem solving is cru-

cial for science, technology, engineering, and mathematics careers. According to an updated meta-analysis of Lindberg based on 242 publications in the period 1990–2007 and involving nearly 1.2 million people, males and females demonstrate similar processing in mathematics – with no overall gender difference and nearly equal variances in results [29]. The difference between males and females in complex problem solving is smaller than in the earlier studies ($d = 0.16$). During life cycle gender differences are negligible in elementary-school and middle-school-aged children, reach a peak in high school, and then decline for college-age and adults. Another meta-analysis, examining international data, indicates the presence of variability across nations in the magnitude and even in the direction of gender differences [30]. Generally, the gender difference is found to be trivial in magnitude, and it is found to be smaller than in 1990 meta-analyses or to even disappear in some cases in complex problem solving [9, 31]. Moreover, gender differences in mathematics performance have narrowed and remained negligible, with no gender effects being found in computation and in understanding of mathematical concepts in high school [29, 31].

Attention. According to updated research males demonstrate better processing in attention maintenance [32] and monitoring [33]. In selective attention tasks, gender differences depend on the type of specific cognitive operations needed for stimuli processing [34, 35]. For example, males show an advantage during Simon task performance, where spatial abilities are required [35], as well as in a task requiring locating sound source during distracting stimuli [6, 36]. In contrast, females demonstrate an advantage in Stroop task performance, where verbal abilities are used [37]. In general, females respond better to stimuli at the peripheral and local levels, while males respond better to stimuli at the central and global levels [38, 39]. Together, these observations imply a lack of major gender effects on executive attention and are rather indicative of specific differences in spatial and verbal processing.

Memory function. Similar to earlier reports [40], females demonstrate a general advantage in semantic [4] and episodic memory [4, 41, 42]. Notably, in episodic memory gender differences are modified by the material to be remembered, so that in females this is manifested as better performance (small effect size) in episodic memory related to verbal abilities (e.g., remembering a story or nameable images) [42]. But women also have an advantage in episodic memory tasks that are neither verbal nor spatial, such as faces, possibly indicating a general advantage in episodic memory [4, 42–45]. Also, they manifest a rather large advantage in the sensory memory for odour, taste, and colour ($g = 0.37$) [42]. The updated data further show that females remember better the identity and location of objects, lists of words and numbers [7, 44–48]. Males excel in episodic memory relying on spatial processing tasks (e.g., routes) and non-nameable images [42], and in object location memory for masculine objects and measures of distance [47].

Importantly, according to updated results, males demonstrate better performance than women in both spatial and verbal working memory [49–53].

Discussion. Consistent with earlier studies, updated research demonstrates better (with moderate to large effect size) spatial processing of males compared to females. Gender differences in verbal skills confirm earlier observations about overall small female advantage, with the largest effect (small to moderate) being present for verbal fluency. Accordingly, the related executive functions manifest gender effects. Specifically, like earlier reports females have a general advantage in semantic and episodic memory associated with verbal abilities whereas males excel in spatial and verbal working memory and in episodic memory relying on spatial processing and in some kinds of object location memory. Some new data point to males' superiority in attention maintenance and monitoring. Updated findings agree with the previously detected small to trivial advantage of females in emotional processing. However, although the new data confirm the trivial gender differences in mathematics performance, gender effects favouring males in complex problem-solving conditions are found to be smaller than in the 1990 meta-analyses or even absent in some cases.

It is to be emphasized that these comparisons do not identify the smarter gender, because differences are not deficiencies. Another important note is that the reviewed results are derived from average between-group differences. Even when the gender effect is large, it cannot be used to assess single individuals and the individual level of evaluation may disconfirm these group descriptions.

A most critical issue concerns the source of gender differences in cognitive abilities. Factors, that are proposed as explanations fall into two broad categories – biological and social-environmental [1]. There are two research approaches that have been recently developed and employed to address this critical issue.

One acknowledged approach to test biological and social-environmental explanations of psychological gender differences is to assess the cross-cultural consistency of the differences [5, 54]. If gender differences are consistent across different cultures, then biological influences are bolstered. In contrast, if the direction of gender differences varies across societies – men exceeding women in some societies, women exceeding men in others, or no differences in still others, then the predictions of biological theories of gender differences are contradicted. With these hypotheses in mind, a study using mental rotation and line angle judgment in more than 90 000 women and 111 000 men from 53 nations found that in all nations the average performance of men exceeded that of women [5]. Such results suggest a biological predisposition to these spatial abilities.

Another recognized approach is based on studies of younger human populations (neonates/infants/children) where social-environmental influences are minimized as well as on nonhuman animals. Gender differences in toy preference are correlated with mental rotation skills in 6- to 12-month-old boys, but not girls [10, 55]. Although environmental factors can still play a role in toy predilections

by 6 months of age, the authors argue for a biological explanation based on related findings in nonhuman primates [56] and in newborn infants [57]. A mechanism for the toy preference is proposed according to which higher levels of prenatal androgen exposure in males may modulate the development of magnocellular and parvocellular layers of the thalamus [58–60]. This would favour the earlier development of the dorsal stream in male infants and perhaps lead to a male preference for objects with moving parts such as trucks. The interest, in turn, is hypothesized to lead to enhanced mental rotation ability, although details are lacking about how this would unfold. In typically developing females, in contrast, prenatal androgen exposure may be too small to affect the relative timing of development of these neural systems, and thus females may not have a preference for moving parts and thus may have less developed mental rotation ability. However, this hypothesis needs further empirical support. Likewise, studies of infants/children offer converging evidence that gender differences in empathy have phylogenetic and ontogenetic roots in biology, and are not merely cultural as determined by products driven by socialization [21].

Thus, both earlier research [61–63] and new data on spatial cognition [11, 64] and cognitive abilities in general [11] point to the biological underpinnings of gender differences. Although gender influences on cognitive skills can be modulated by many variables, yet the biological sex seems to exert the strongest effects. Several biological sources have currently been identified as the main factors.

The gonadal hormones account. A critical biological factor implicated in gender differences in cognitive functions is based on the gonadal hormones testosterone, estrogen, and progesterone [11]. In a number of publications, the influence of sex hormones on cortical maturation, the structure and function of the auditory analyzer, the size of corpus callosum, and accordingly on a variety of cognitive abilities (verbal, spatial, manual dexterity) is demonstrated. Sex hormones that emerge at critical periods of development (in utero, immediately after birth, through puberty) are hypothesized to have long-lasting, organizing effects on brain development, while sex hormones that are differentially emphasized during adulthood have short-term activating action on brain functioning [65–67]. Studies in mammalian animals [68] as well as pathological and nonclinical human populations provide evidence that prenatal hormones have an influence on cognition [2, 10, 69–71]. Prenatal hormones are considered determining factors for female and male brain organization [72], influencing brain lateralization [73], the size of corpus callosum [74, 75], as well as some auditory structures [76]. Further, it is reported that women suffering from the genetic disease congenital adrenal hyperplasia (CAH, characterized by production of large amount of androgen starting from the third embryonic month) have enhanced spatial skills compared to unaffected females [10, 70]. Studies also show that young girls with CAH are more often involved in aggressive games, play more with stereotypical male-type toys (cars and trucks), and prefer male playmates compared to girls from the control

group, even though parents strongly encourage CAH girls to play with female-type toys, such as dolls [71, 77]. These preferences persist into adolescence and adulthood [78]. According to other studies, however, exposure and sensitivity to androgens may not be a major determinant of sexual dimorphism in neonatal brain structures [79–82]. Data on the influence of postnatal sex hormones on brain development and functioning related to cognitive abilities are mixed. Spatial processing is suggested to be enhanced in the presence of medium levels of androgens [67, 83–85], although disconfirming results also exist [48, 83, 84, 86–91]. Female cognitive abilities (e.g., verbal skills, manual dexterity, and spatial skills) have been shown to vary across the menstrual cycle, depending on the levels of gonadal hormones estrogen and progesterone [72, 92]. Estrogen is suggested to be responsible for the improvement in auditory function in women [93–96], because it enhances synaptic transmission and improves neuronal conduction [97, 98]. A longitudinal study shows that cortical maturation in adolescents is determined by androgen sensitivity [99]. The size of gray matter in some brain regions (parahippocampal gyrus, parietal cortex) is found to be related to sexual maturation. There are specific sexually dimorphic regions in the brain that contain significant populations of sex hormone receptors, such as the hypothalamus, amygdala, hippocampus, basal ganglia, cerebellum [100]. Sex hormone receptors are found in many cortical areas, like parts of the frontal lobe, motor cortex, posterior parietal cortex, insular cortex, and parahippocampus [101, 102], which provides an opportunity for direct effect of sex hormones on cortical development. Together, these observations support a critical role of gonadal hormones in modulating cognitive abilities and preferences.

The neuroanatomical account. Another factor, implicated in gender differences in cognitive abilities are the gender variances in brain structure. It is shown that males compared to females have 9–12% larger brain size (post-mortem [103, 104] and in vivo [105–107]). Gender differences of cortical density yield conflicting results: some studies report a denser cortex in males [108, 109], others report a denser cortex in females [110–112], and there are studies that report equal density in the two genders [106, 113]. Females have relatively thicker cortex and greater cortical complexity than males, after accounting for differences in the overall brain size [112, 114–117] and for a better network efficiency between cortical areas [118]. Gender variants are also found in cortical morphological networks and their functioning [119]. Males demonstrate higher percentage of white matter and greater intra-hemispheric connectivity, as well as enhanced modularity and transitivity, and higher glucose metabolism in limbic regions, compared with higher rates of cerebral blood flow, higher percentage of gray matter tissue, higher inter-hemispheric connectivity and cross-module participation that are predominant in females [120, 121]. Gender differences are also found in cortical cytoarchitecture – males have higher total neuronal and synaptic density, more numerous and smaller nerve cells [108, 109, 122, 123]. In contrast, females have more neuropil,

fewer but larger nerve cells, and larger bodies of neurons in the left hemisphere. It is suggested that male brains are structured to facilitate connectivity between perception and coordinated action, whereas female brains are designed to facilitate communication between analytical and intuitive processing modes [120].

Gender effects are found in subcortical and cortical structures responsible for transfer and processing of sensory and motor information (hearing, vision, movement), cognitive information (language, memory, attention, learning, cognitive control), emotional information (emotions, motivation), wakefulness, sleep, etc. [124]. For example, male brains are larger than female brains bilaterally in the occipital cortex and in the motion-sensitive area of the primary visual cortex, i.e., males possess more tissue to process visual information [125]. Concerning hearing, female cochlear canals are found to be shorter than male, leading to gender differences in the neuronal pathway, corresponding to shorter cochlear pass times in females [94,96,126,127]. Gender differences are found in language-related areas such as the temporal cortex and Broca's area, which are larger in females [128].

The frontal and medial paralimbic cortex, hippocampus, and caudate nucleus are reported to be larger in females [100,129]. On the other hand, the medial frontal cortex, hypothalamus and amygdala have larger sizes in males [100]. There are inconsistent reports that the thalamus and some temporal lobe regions are larger in females [130]. Overall, the results indicate complementarity between females and males that would result in greater adaptive diversity [121]. The data show that male/female brain differentiation may vary in pattern and scale, and in some respects (relative local gray matter volumes) it can be substantial, taking the form of sexual dimorphism and involving large areas of the brain (the cortex in particular) [131]. Some sex differences can produce cognitive gender differences, but other sex differences in the brain may serve to prevent (in the case where they are maladaptive) differences at the behavioural/skill level. Specifically, some differences might result from compensatory mechanisms aimed at maintaining similar intellectual capacities across the sexes, despite for example, the smaller average volume of the brain in females compared with males.

The neurophysiological account. Another factor implicated in gender differences in cognitive abilities are the gender differences in brain function [132, 133]. By applying fMRI, gender differences are found in brain areas that are activated during memory [134–136], spatial [137–141] and language processing [136, 137, 142–144], cognitive control [145]. The results demonstrate differential patterns of brain activation in males and females during a variety of cognitive tasks even though performance in these tasks may not vary, and variability in performance may not be reflected in these differences in brain activation [136]. It is assumed that different functional activation between females and males is related to gender differences in the neuro-functional involvement, in the maturation of relevant brain areas or in the use of different strategies by the representatives of the two genders in solving the same task. Clinical data on sex-dependent

prevalence of mental illness also demonstrate the existence of a sex-dimorphic functional organization of the brain [63, 146].

In summary, the research on the sex-related variations supported by hormonal, neuroanatomical and neurofunctional sources strongly suggests that gender differences in behavioural abilities are grounded on neurobiological influences. Neurobiological factors appear to be involved at the neurogenetic and early hormonal level and determine the occurrence of different properties of neural structure and function (transmission of information in all or separate systems, organization of neuronal networks, neuroplasticity, etc.). This can lead to different modes of information processing and a subsequent occurrence of different abilities in the two genders even on the background of identical or similar psychosocial influences. However, the neurobiological differences can certainly be further modulated and potentiated/depotentiated by socio-environmental factors, which finally underpin an integrated source of gender differences.

Conclusions. The updated data confirm that gender differences in cognitive abilities exist. They appear overall similar to those previously established, despite the increasing changes in recent decades in men's and women's participation in social institutions. Hence, the updated data demonstrate that the dramatic changes in the social environment have not led to substantial changes in gender effects on cognitive abilities emphasizing the leading role of biological factors. Moreover, this conclusion is strongly supported by new hormonal, neuroanatomical and neurofunctional studies demonstrating the biological origin of gender-specific cognitive abilities. Although the psychosocial interaction is of relevance, the primary biological basis of gender differences should be very strongly and carefully considered.

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