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Assessing Women and Men in Engineering
In Partnership with the Society of Women Engineers

Literature Overview Critically Thinking About the Brain and Gender Differences

CASEE

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Why is it so widely believed that humans use only 10% of their brain, that personality is determined by the degree to which the logical "left" brain interacts with the artistic "right" brain, and that exposing babies to classical music will make them smarter? These statements are all fundamentally untrue (Herculano-Houzel, 2002; Beyerstein, 1999) and represent just a few of the myths that obscure public understanding of human behavior. While misconceptions about the brain and behavior are often based on fact, misinterpretations can turn facts into distorted beliefs that influence how we approach science, technology, engineering, and mathematics (STEM) education and outreach. Neuroscience is inundated with myths and of particular concern are those that negatively influence views about cognitive and behavioral differences between genders. This review provides educators with a way to translate myths about neuroscience into educational applications and help students and others develop the critical thinking skills needed to distinguish scientific facts from mainstream opinion.

Myth 1: Men have larger brains than women have and are therefore more intelligent.

In 1806, Carl Linneaus, the father of modern taxology, proposed that the larger an organism's brain, the more advanced the organism's behavior. Soon after, scientists began investigating the relationship between human brain size and intelligence, and the belief emerged that because men possess larger brains than woman do, men are, on average, more intelligent. German anatomist Frederick Tiedmann articulated the claim in 1836 stating, "There is an indisputable connection between the size of the brain and the mental energy displayed by the individual" (Hamilton, 1935). Since Tiedmann, many researchers have examined the relationship between brain size and gender, and like him, most have applied highly flawed methods and interpretations (Morton, 1849; Hooton, 1926; Von Bonin, 1934; Blinkov & Glezer, 1968; Haack & Meihoff, 1971; Rushton, 1991; Nooranipour & Farahani, 2008).

Historically, brain size was determined by obtaining external measurements of the head, such as the circumference of the skull (McDaniel, 2005). This technique led early scientists to conclude that men do indeed have larger brains than women have, but in reality, external dimensions of the skull reveal little about brain size. The amount of space between the inside of the skull and the outer layers of the brain can vary significantly from person to person. Between the skull and the brain is a dense protective layer known as the meninges, and the thickness of the meninges can be substantially different between men and women. Additionally, the space between the skull and the brain is home to the body's cerebrospinal fluid, a liquid cushion that allows the brain to freely float in the skull, and men and women can possess different levels of this fluid (Paolini, Danelson, Geer, & Stitzel, 2009; Gur, Gunning-Dixon, Turetsky, Bilker, & Gur, 2002; Reina et al., 1999; Grant et al., 1987). Furthermore, there are gender differences in the thickness of our skulls that would affect the overall size of an individual's head yet have no bearing on brain size (Moreira-Gonzalez, Papav, & Zins, 2006; Ross, Jantz, & McCormick, 1998). It is now known that measurements of skull size are poor indicators of brain size.

A more accurate way to estimate brain size is by measuring brain volume through imaging techniques such as magnetic resonance imaging (MRI). This method provides a highly detailed image of the brain by using a powerful magnetic field. Nopoulos, Flaum, O'Leary, and Andreasen (2000) obtained average brain volume measurements of 1254 cm^3 for men and 1130 cm^3 for women; Raz and colleagues (2004) reported average male and female brain volumes of 1272 cm^3 and 1156 cm^3; and Sowell and colleagues (2007) measured mean brain volumes of 1363 cm^3 for men and 1188 cm^3 for women. Based on these studies, the average difference in brain volume between men and women is about 150 cm^3, roughly the size of half a can of soda.

Measuring brain size through MRI does not control for the fact that the average male body is proportionately larger than the average female body. According to the Centers for Disease Control and Prevention, based on data collected in the United States between 1999 and 2002, the average U.S. man weighs 191 pounds, while the average woman weighs 164 pounds. This means the average man weighs nearly 27 pounds (about 16%) more than the average woman. The MRI studies cited in the previous paragraph demonstrated that the average difference in brain volume between men and women is about 150 cm^3 (about 12%), showing that the gender difference in brain size is less than the gender difference in body weight.

Determining the mass, or weight, of the brain is another common measure of overall brain size. Pakkenberg and Voigt (1964) found average male and female brain weights of 3.0 pounds and 2.7 pounds, respectively; Ankney (1992) measured mean weights of 3.1 pounds for men and 2.8 pounds for women; and Nooranipour and Farahani (2008) found a 3.1-pound average in men and a 2.7-pound average in women. These studies reveal that an approximately .33-pound average difference exists between male and female brain weights. The larger body size of men would be expected to translate into a larger average brain weight, but even controlling for the difference in overall body weight between men and women, the average male brain is about .22 pounds heavier than the average female brain (Schoenemann, 2002;4 Ankney, 1992; Ho, Roessmann, Straumfjord, & Monroe, 1980). This is about the weight of a bar of soap.

So why might gender difference in brain size exist? One hypothesis is that men and women lose brain cells at different rates as they age. Over the age span of 25 to 80, researchers have found that the male brain shrinks significantly, while age affects the size of the female brain very little (Ho et al., 1980; Cowell et al., 1994; Murphy et al., 1996; Gur, Turetsky, et al., 1999). A study by Witelson, Beresh, and Kigar (2006) dramatically documents this phenomenon, finding male brain volumes decreasing by 50 mL a decade (roughly the weight of a golf ball): a rate ten times that of the female brain.

Another hypothesis for gender disparity of brain size is that neural communication may occur more efficiently in a smaller brain. This idea is based on the fact that the corpus callosum, a brain structure responsible for transferring neural signals, is significantly larger in women than in men. The human brain is divided bilaterally, meaning that each neurological structure exists in both the left and right hemisphere. The corpus callosum is a thick band of fibers that essentially connects the two halves, or hemispheres, of the brain. Studies have shown that key sections of the corpus callosum are significantly larger in the average female brain than in the average male brain (Dubb, Gur, Avants, & Gee, 2003; Shin et al., 2005) and may be the reason that women demonstrate advantages over men in certain cognitive processing tasks (Shaywitz et al., 1995; Gur, Alsop, et al., 2000).

Myth 1 conclusion: Part false and part true

Half of this myth is true. Modern science confirms that the average male brain is slightly larger than the average female brain, but the notion that the average man is smarter than the average woman is not supported. Individuals with large brains are not smarter than individuals with average- or below-averagesized brains; in fact, no relationship between overall human brain size and mental ability has ever been established (see Wanjek, 2002, for review). The average female brain may be slightly smaller because it is more efficient at transferring neural signals than is the average male brain. In neuroscience, the size of a structure (anatomy) and its function (physiology) have little relationship.

Educational applications

Exploring the history behind this myth will provide students and educators with a perspective on how scientific fact differs from theory. Educators should use this exercise to highlight to students the need to be cautious when speculating upon the implications of scientific findings.

Other educational applications could be based on the idea that variation in gender head size could account for some minor sensory differences between boys and girls. By age 4, the average boy's head is 1.5 cm larger than the average girl's head. This may explain why the female hearing threshold is about 3 decibels lower (more sensitive) then the male threshold, but males are better at locating sounds in their environment (Eliot, 2009). Hearing differences between boys and girls might be considered for classroom seating arrangements, and changing the distance to the speaker's voice may be an effective strategy (Sax, 2005).

Examining this myth should underscore the similarities between the genders and demonstrate that the minor difference in head and brain size between boys and girls does not significantly affect learning or behavior.

Myth 2: Men and women think differently.

It is exceedingly challenging to quantify a question as complex as whether men and women think differently. With the release of the book *Men Are from Mars and Women Are from Venus* (Gray, 1992), an intense interest in cognitive gender differences developed in the United States. This prompted many nonscientists to address the topic, and, in turn, popular culture became flooded with misinformation. Scientists investigate the subject by assessing how similar cognitive tasks are processed in the male and female brain. Countless studies have explored the relationship between gender and mental ability, and differences are most often encountered when examining behaviors involving language and spatial navigation.

Research consistently finds that, on average, women outperform men in a variety of verbal reasoning tasks, such as analogies, language fluency, word recognition, phonology (sense of sound), syntax, semantics, and vocabulary (Weiss, Kemmler, Deisenhammer, Fleischhacker, & Delazer, 2003; Gur, Alsop, et al., 2000; Shaywitz et al., 1995). Sociolinguists suggest that the female language advantage may be due to cultural and social differences (Tannen, 1996, 2001; Coates, 2004), while neuroscientists propose possible gender differences in two brain structures, Wernicke's and Broca's areas (Harasty, Double, Holliday, Kril, & McRitchie, 1997; Kansaku, Yamaura, & Kitazawa, 2000). In the 1870s a German scientist named Karl Wernicke discovered that patients with damage to a specific region of the left cerebral cortex produced meaningless speech and were not able to understand the words of others. It has since been established that Wenicke's area is the region of the brain where the *meaning* of auditory information is processed. A contemporary of Wernicke, a French physician named Paul Broca, identified a region of the left frontal cortex, now appropriately known as Broca's area, that when damaged impairs an individual's ability to *produce* speech without affecting the ability to understand language.

In 1997 a group at the University of Sydney in Australia compared the volumes of both Wernicke's and Broca's areas in brains removed from male and female cadavers and observed that Wernicke's and

Broca's areas were, on average, 17.8% and 20.4% larger in female brains than in male brains (Harasty et al., 1997). These anatomical differences might be responsible for the superior language skills often exhibited by females or may be the result of females being encouraged to be more verbally active than their male counterparts. Additionally, numerous MRI studies demonstrated that significantly greater activity levels are measured in the language areas of the female brain when compared to the male brain during a wide range of verbal tasks (Rossell, Bullmore, Williams, & David, 2002; Ruytjens, Albers, van Dijk, Wit, & Willemsen, 2007; Gauthier, Duyme, Zanca, & Capron, 2009; Plante, Schmithorst, Holland, & Byars, 2006; Grabowski, Damasio, Eichhorn, & Tranel, 2003).

While woman outperform men in certain language-related activities, it appears that, on average, men exhibit some advantages over women in behaviors related to spatial navigation. When guided through a maze, men move more accurately (Astur, Ortiz, & Sutherland, 1998) and quickly (Ross, Skelton, & Mueller, 2006) than women do. Additionally, men fare better than women when required to navigate familiar and unfamiliar environments (Astur et al., 1998; Moffat, Hampson, & Hatzipantelis, 1998). Some researchers hypothesize that gender differences in navigational behaviors could be linked to anatomical differences in the hippocampus, a neurological structure primarily involved in visuospatial integration. The hippocampus is part of the limbic system, which supports a variety a functions, including learning and memory. It has been known for some time that the hippocampus plays a crucial role in forming and storing memories (Bekhterev, 1900), but recent studies have found this structure to also be responsible for maintaining cognitive maps during spatial navigation (Bohbot, Iaria, & Petrides, 2004; Iaria, Chen, Guariglia, Ptito, & Petrides, 2007). Human MRI studies reveal that during goal-directed movement, the average male hippocampus is more active than the average female hippocampus (Iaria et al., 2007), and numerous animal studies find the male hippocampus to be larger than the female hippocampus and contain a more densely packed distribution of brain cells than the female hippocampus does (Juraska, 1991; Parcudz & Garcia-Segura, 1993; Madeira & Paula-Barbosa, 1993).

Myth 2 conclusion: False

Can we confirm the myth that men and women think differently? While it is true that for a few very specific behaviors women and men perform slightly differently, it is not scientifically valid to draw the conclusion that the genders "think" or "behave" differently. The male brain and female brain are anatomically organized identically, and with slight exceptions in the corpus collosum and hippocampus, brain structures are proportionately the same size in both genders. The minor behavioral differences that may exist between genders are slight, and far greater similarities than differences exist in male and female cognitive and behavioral processes.

Educational application

There are many concrete ways to promote boys' language and literacy skills. Providing reading material with male themes, such as nonfiction books about sports and technology or action and adventure novels, can be an effective technique to stimulate a boys' interest in reading. Another suggestion is to introduce typing earlier than it currently is offered, which is around the fifth grade (Eliot, 2009). Computer typing games are common and allow boys to develop writing skills using a medium that they associate with fun. Getting boys comfortable with writing early in their lives is also important. Many girls keep diaries or write letters to their friends, and activities such as these would help boys develop their language skills. Other useful tips for increasing boys' literacy levels can be found at the Ontario Ministry of Education website (http://www.edu.gov.on.ca/eng).

Spatial skills can be easily taught in classroom environments using computer-based technologies, and girls should have access to them as early as possible. ST Math (meaning spatiotemporal math), software developed by the MIND Research Institute in Santa Ana, California, uses stimulating visual exercises to teach fractions, proportionality, and symmetry. Encouraging girls to use programs such as this not only assists visuospatial development but also promotes technological fluency. Girls also can refine their visual and spatial behaviors by playing chess; participating in sports that involve throwing, passing, and catching; and using Legos or similar toys to build and construct three-dimensional models.

Myth 3: Men have masculine brains; women have feminine brains.

Stereotypical gendered behavior is often justified by the idea that testosterone drives “masculine” characteristics of males and estrogen is responsible for the “feminine” traits of females. This statement is a misleading oversimplification, as many of the hormones that play a significant role in the development and maintenance of the male and female nervous system do not fit into gender-specific categorizations.

Sex hormones are categorized into three groups: progestagens, androgens, and estrogens, and all three are chemically very similar. Progestagens are traditionally considered a class of “female” hormones, because most are produced by the ovaries and are involved in maintaining pregnancy and regulating the female menstrual cycle; however, one very important progestagen, progesterone, plays a crucial role in both the female and male brain. Progesterone is synthesized in the brain and has the exceptionally vital responsibility of promoting myelination of brain cells (Schumacher, Guennoun, Robert, et al., 2004; Schumacher, Guennoun, Mercier, et al., 2001). Brain cells, known as neurons, communicate by rapidly transmitting electrical signals from cell to cell, and myelin is a biological insulator that allows communication to occur quickly (Martini, Magnaghi, & Melcangi, 2003). The nervous system would be dysfunctional and sluggish without myelin, for it enables electrical messages to travel at about 500 feet per second, 50 times the speed at which unmyelinated cells would be able to communicate (Purves et al., 1997). Motor degenerative diseases, such as Parkinson’s and Huntington’s, cause the nervous system to become depleted of myelin, which impairs normal movements by reducing the speed at which signals move through the brain and spinal cord. The notion that progesterone is a female hormone is wrong, considering how crucial myelin is to both men and women.

Androgens are a group of hormones typically considered “male” because they play a significant role in the growth and development of male sex organs, but they also have more than 200 functions in women (Miller, 2001). Testosterone is the primary androgen and does exist in greater quantities in men than women, although women possess higher sensitivity levels to the hormone than men do (Buster et al., 2005). The presence of testosterone is critical to women because it converts progesterone into estrogen. Lack of testosterone in women leads to deficits in estrogen and is blamed for accelerated bone loss, fatigue, depression, high cholesterol, and low blood pressure (Davis, McCloud, Strauss, & Burger, 2008; Maia, Casoy, & Valente, 2009; Hays et al., 2003).

Androgens also play an important neuroprotective role in the brain of both men and women as they age. Specifically, the androgen dehydroepiandrosterone (DHEA), which is produced by the adrenal glands and synthesized in the brain, possesses potent protective and antioxidant properties (Bastianetto, Ramassamy, Poirier, & Quirion, 1999; Stadtman, 1992). A process called oxidation damages essential brain proteins and enzymes needed for normal cognitive functioning and is the cause of age-related impaired mental ability and reductions in cell density in memory areas, as well as a potential cause of Alzheimer’s. While younger men possess higher DHEA levels than younger women do, this hormone depletes more rapidly in aging men, and after men reach age 50, it is present in higher concentrations in the female brain (Laughlin & Barrett-Connor, 2000). Androgens are equally important in women and men.

Estrogens, another class of hormones usually characterized as female, earned their name from their significant role in regulating the female estrous (reproductive) cycle, yet estrogens are essential to the male brain and body as well. Estrogen is actually a general term for three hormones: estrone, estradiol, and estriol. Outside of the female brain, estrone is primarily responsible for inducing and regulating menopause, estriol is the major hormone of pregnancy, and estradiol is the most prevalent in regulating the menstrual cycle. Interestingly, estrogen receptors are as widespread in the male brain as in the female brain (McEwen, 1999; Osterlund, Keller, & Hurd, 2000). Estrogens stimulate the production of nerve growth factors that are responsible for promoting the health and branching of brain cells, as well as repairing damaged neurons in the brains of both genders (Birge, 2000; McKuen & Alves, 1999). Additionally, estrogens improve blood flow and enhance cardiovascular function equally in men and women (Nourhashemi, Gillette-Guyonnet, & Andreu, 2000; Sarrel, 1990). Efficient regulation of estrogens is fundamental to a healthy and properly functioning nervous system for both genders.

Myth 3 conclusion: False

Overwhelming evidence exists to refute this myth, and it is obvious that men do not have specifically “masculine” brains and women specifically “feminine” ones. While it is true that certain hormones play different roles in the development of male and female sex characteristics, the brain and body of both genders require all classes of sex hormones to function properly.

Educational application

It has been proposed that the verbal advantage women have over men may be due to gender-based variations in hormone levels. Hampson (1990) found that women were faster at reading aloud while near their peak monthly estrogen and progesterone levels, but duplicating this result has proven difficult. More recently, Friederici, Pannekamp, and Partsch (2008) discovered that boys with lower testosterone levels at one month of age are better at processing speech later in childhood than are boys with higher testosterone levels at one month of age. Researchers still do not know exactly what role hormones play in language skills and other learning-related behaviors.

Exploring this myth reveals that boys and girls are hormonally quite similar, so it is not surprising that many of the same educational activities benefit both genders. Musical training, specifically on a piano or electric keyboard, significantly improves spatiotemporal abilities in boys and girls (Rauscher, Shaw, & Levine, 1997). Complex full body movements, such as swinging, leaping, and cartwheeling, stimulate the brain’s vestibular system (the inner ear sense that contributes to balance and spatial orientation) and enhance important reflexes and motor development in girls and boys (Eliot, 2000). Additionally, fine motor skills are responsible for mapping physical connections across the cerebral cortex and many other parts of the brain, so activities like painting, drawing, typing, or cutting refine coordination and are important throughout all ages of development.

General Conclusion and Future Research

Exploring these few common myths surrounding gender reveal that boys and girls are far more similar than many in society are aware. While slight differences in physical and cognitive characteristics exist between the sexes, the impact of these differences upon learning and achievement is negligible. This review demonstrates the importance of approaching scientific and technical information with skepticism, highlights the significance of providing students the opportunity to develop their critical thinking skills, and identifies a variety of educational tools and relevant literature on topics valuable to educators at every level.

Research in neurobiology and gender continues to examine how varying levels of hormones and neurochemicals affect the developing male and female nervous systems. Dr. Louann Brizendine, best-selling author of *The Female Brain* (2006) and *The Male Brain* (2010), has discovered that even though boys have significantly greater levels of testosterone at all points in development, that is no indicator of the skills at which an individual excels. Gender disparity is also being explored in behavioral disorders, such as autism and post-traumatic stress disorder. Researchers are attempting to uncover why men are four times more likely than women to develop autism and why women are twice as likely as men to exhibit symptoms of PTSD after a traumatic event. Additionally, a great deal of emphasis is being paid to attention deficit hyperactivity disorder research, specifically why it is diagnosed three times more often in boys than girls although adult ADHD is more prevalent in women than men.

Summary of Educational Applications

Myth 1: Men have larger brains than women have and are therefore more intelligent.

- Use caution when speculating on the implications of scientific findings, even if credible scientific sources promote a certain interpretation.
- Examining this myth should underscore the similarities between the genders and demonstrate that difference in head and brain size does not significantly affect learning or behavior (Wanjek, 2002).

Myth 2: Men and women think differently.

- Computer programs that teach geometry and spatial skills should be introduced to students as early as possible in their academic careers (Elliot, 2009).
- Visual and spatial skills can be developed by playing checkers or chess, and students should interact with 3-D toys, such as Legos or building blocks (Elliot, 2009).
- A pen-pal program that requires students to write letters to other children can encourage writing at a young age and provide students an opportunity to learn about other cultures (Elliot, 2009).
- Keeping a journal or diary allows students to get comfortable writing and developing language skills (Elliot, 2009)

Myth 3: Men have masculine brains; women have feminine brains.

- Training on musical instruments, such as the piano, keyboard, xylophone, or violin, can improve a child's timing, spatial abilities, and fine motor skills (Rauscher et al., 1997).
- Physical activities that include full-body movements, such as swinging, leaping, and crawling, stimulate the vestibular system, which contributes to refining balance and spatial orientation (Elliot, 2000).
- Activities that require precise coordination, such as painting, drawing, typing, or similar arts and crafts, aid the brain in forming new motor connections and strengthening those that already exist (Elliot, 2009).

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