GENDER AND THE BRAIN; CAN INTELLECTUAL ABILITIES BE DEFINED BY BIOLOGICAL DIFFERENCES?

by Jennifer Musa*

INTRODUCTION

Weighing approximately three pounds, it is a spongy, pinkish-gray mass with a consistency that has been compared to raw egg, jelly, soft butter and oatmeal. It is involved in your every thought, feeling and emotion, every action and reaction. In a sense, it defines everything you are and everything you will be. Comprised of hundreds of billions of cells, it is the human brain, the most complex system ever discovered.

It is well established that the brain is directly responsible for controlling body functions and behavior. Damage to the brain often has a profound effect on physical ability and personality. Further, activity in some defined brain regions has been linked to specific actions and cognitive tasks. When it comes to control of basic life functions like breathing, eating and sleeping, striking physical and genetic similarities exist not only among human brains but also between the brains of a host of diverse living creatures. However, brain activity that governs more subtle and complex processes is more diverse and is certainly likely to vary among individuals. When you consider the fact that your brain will have significant control over the type of person you are, how you interact with other people as a stranger, relative, friend, partner or co-worker and perhaps even what career path you choose, it is no surprise that the details of brain function can get infinitely complicated.

Adding to this complexity is the fact that humans exhibit considerable diversity not only in physical appearance but also in behavior, personality, talents and abilities. Gender specific characteristics are among some of the most obvious and recognizable differences but even these occur over a wide spectrum. The ability to identify gender is fundamentally important for most living creatures, even children under the age of three are quite adept at discriminating sex and gender role expectations.[1] In fact, this is so important to us that when we encounter another human we instantaneously look for physical and behavioral clues to assess the person's gender and make a determination of "same" or "different", perhaps without even realizing it. We have a clear set of expectations that we use to classify gender and most people would probably become quite uncomfortable if unable to determine whether an acquaintance was male or female. This was the basis of Julia Sweeney's popular androgynous and sexually ambiguous character "Pat" on Saturday Night Live. Obviously, gender is something we are used to assessing by looking at the outside of the body, but what about on the inside? Can gender be determined by looking at an individual's brain?

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To look only at a person's brain and determine gender would require sophisticated equipment and very precise testing paradigms. Perhaps even then differences would not be immediately noticeable. Although it may not be obvious to the untrained eye, researchers have identified some definite dissimilarity in both the structure and function of the male and female brain. Interestingly, these differences are not limited to the areas of the brain that control reproductive and mating behavior. Further, recently developed noninvasive techniques that can capture images of the living, functioning brain have revealed some intriguing results that support the notion that there are real differences in the way men and women actually think. One such method that has provided a great deal of information about brain function and was used in some of the studies discussed here involves a sophisticated imaging technique called functional magnetic resonance imaging (fMRI). This technique provides a way to visualize the activity of brain cells while a subject performs various tasks, like reading aloud from a book. This technique provides a way to actually look at the functioning brain and make comparisons between individuals who are performing the same task.

Based on the findings from research studies that will be discussed here, some individuals have suggested that regardless of upbringing and experience, women are biologically hard-wired to be empathetic caretakers while men have brains that are better suited for problem solving. Some have even gone so far as to say that sex differences in the brain may explain why the vast majority of scientists and engineers in the United States are men. Such speculation has been the subject of much controversy and heated discussion. Is it possible that incongruities in brain structure and function are sufficient to explain and define gender-associated behavioral disparities that contribute to differences in educational abilities and, ultimately, shape career choices? More specifically, is there such a thing as an innate aptitude for the hard sciences that is biologically linked to gender?

No discussion of brain form and function would be complete if only strictly biological, genetic or chemical influences were considered. A vast body of research has demonstrated that culture and experience have a dramatic impact on behavior and, in some cases, on the actual structure of the brain. In my opinion, it is probably impossible and ultimately pointless to attempt to completely separate the influences of nature and nurture on the human brain. However, a careful examination of the documented physical and functional variations that exist between the brains of males and females is a necessary step towards elucidation of what those differences might actually mean. A clear understanding of gender-associated variations may lead to sex-designed methods of education and treatment for mental illnesses. In addition, I believe that it is critical that we ultimately address the question as to whether any of the observed differences in intellectual aptitude and career choices between males and females may actually be created and reinforced not by innate irreversible biology, but by our own experience and expectations.

Girls, Boys, Men, Women and Science and Engineering in the United States

An examination of the performance of male and female elementary and secondary students yields some of the first insights into the existence of possible elements of gender disparity in the fields of science and math. According to the National Center for Education Statistics[2], scores on national math tests show no statistically significant differences between fourth grade (age 9) boys and girls in the United States. However, males do tend to outscore females in science in fourth grade. By 12th grade (age 17), females have historically scored lower than males on both math and science exams but the gap has closed somewhat in recent years.

Interestingly, this general trend can also be seen when comparing proficiency scores in several countries[2]. Typically, females and males had similar scores in fourth grade and eighth grade math in the U.S. and most other countries (Japan, France, Germany, Korea, Canada and Australia). In science, males performed better than females in about 40% of the countries (including the U.S.) at the fourth grade level and in about 70% of the countries (excluding the U.S.) at the eighth grade level. Although U.S. students performed similarly in science content areas, in the other countries that were studied, males outscored females in chemistry, physics and earth science while the scores for life science and environmental science were similar. In the U.S., post-secondary males and females earned similar scores in math and the gender gap in science between post-secondary males and females was among the smallest for all participating countries. However, every year for nearly four decades, men have scored more perfect scores on the math portion of the standardized college entry exam (SAT) than women.

Gender comparisons aside, several countries (particularly in Asia) continue to outperform U.S. primary and secondary students in science and math[3]. For example, students in Taiwan, Singapore and Japan outperformed fourth-graders in the U.S. in both science and math. Fourth graders in the U.S. have not improved or declined since 1995, in science or math. As a result, they have dropped in the international rankings as other countries showed an increase in test scores. This trend continues for secondary students. Nearly 44 percent of eighth-graders in Singapore scored at the most advanced level in math, as did 38 percent in Taiwan. However, only 7 percent in the U.S. did. By the end of secondary schooling, the U.S. lags behind much of the rest of the world in science and math. United States twelfth-graders performed among the lowest of 21 countries in assessment of general knowledge of mathematics and science.

In terms of post-secondary education, at this time more females than males are receiving bachelor's degrees in science fields. This is a stark contrast to 1975, when women earned only about a third of the science and engineering bachelor's degrees. In 1977, women earned less than one quarter on the science and engineering master's degrees but that percentage has now changed to nearly half of the master's awarded in science and engineering. Compared to thirty years ago when females earned only 10% of doctoral degrees in science and engineering, today they earn nearly 33% of all PhDs in science. However, despite the fact that in recent years more and more females are earning advanced degrees in science and engineering[2], men comprise the vast majority of working engineers and scientists in the United States.

Research also suggests that female scientists and engineers are less successful than males when pursuing an academic career. They are less likely to earn tenure and promotion. In some cases this may have to do with family situations. Data from the National Science Foundation report on Gender Differences in the Careers of Academic Scientists and Engineers[4] demonstrated that married women and women with children tend to be less successful than men who are married and have children. Interestingly, professional women today are much more likely to be partnered with other professionals[5]. For example, 43% of married women physicists are married to other physicists whereas only 6% of married male physicists have a physicist for a spouse. This trend holds true for female mathematicians and chemists. Therefore, married women professionals are more likely to be part of a family where there are two working professionals, making it very difficult for both partners to take advantage of opportunities for advancement that may require moving to another institution.

According to the Nelson Diversity Survey[6], males overwhelmingly dominate tenure track faculty positions at America's top universities. While women occupy nearly a third of science and engineering positions at U.S. colleges and universities, they fill less than 15% of those positions at the top fifty research universities. The picture looks even worse if you consider only minority women. In the top 50 computer science departments in America there are no Black, Hispanic or Native American tenured women faculty[6]. The study author, Donna J. Nelson, points out that the dearth of women faculty means that women being trained in these fields at top universities are unlikely to have access to a women faculty member as a mentor or role model.

Looking beyond the academic setting, the National Science Foundation report on Women, Minorities, and Persons with Disabilities in Science and Engineering[7] reports that female doctorate holders are less likely than male doctorate holders to be employed in business and industry. Women occupy 23% of the science and engineering jobs in the private sector and in government. This variation is thought to stem in part from differences in occupations, as females are less likely to be engineers and physical scientists, occupations that are more likely to result in jobs in business or industry.

Interestingly, when one considers the results of standard intelligence tests there appears to be no appreciable difference at all in general intelligence between the sexes[8]. However, statistics from several comprehensive studies looking at scores on school science tests and successful career positions in science and engineering illustrate at least some disparity between males and females. Test results aside, it is a proven fact that at this time there is relative scarcity of women in science. However, looking back over years of data, the balance seems to be shifting. Are these differences something that will eventually become only a part of academic history or is there some biological determinism that will prevent the gender gap from ever closing completely?

BEGINNING AT THE BEGINNING; BUILDING A BRAIN

A comprehensive examination of gender-associated brain differences must begin at the intrauterine stage. Differing levels of sex-associated hormones have already impacted the form and function of the brain long before a human baby ever takes his or her first breath. The beginnings of the nervous system become evident in a three-week old embryo. As a fetus develops in the womb, neurons divide, grow and make connections with other cells. Throughout development, some of these connections are strengthened while others wither away. The developing brain is influenced by internal and environmental factors and becomes stronger and more efficient, or, in the presence of adverse stimuli, can be irreversibly damaged. Research has shown that some influences acting on the brain will set it upon a particular developmental course that is shared by the majority of others with the same gender.

During the first few weeks after conception there is no visible sign to indicate that the tiny fetus is either male or female. At this time the gender is a secret that is kept in the genes. Humans have 23 pairs of chromosomes with half of each pair coming from the mother and the other half coming from the father. It is important to understand that just about every cell in the human body, whether it is a brain cell or a skin cell, contains the same genetic information. Different cell types arise when different genes are expressed. Therefore, on a more global scale, expression of different genes can give rise to different bodies. When it comes to gender, one pair of chromosomes is special and contains genes that, when activated, will determine the sex of the fetus. The mother contributes an X chromosome with her egg and the father, an X or a Y with his sperm. Normally, an XX will determine a female and an XY, a male. However, genes alone are not sufficient to determine sex. For a fetus to develop into a male, the Y chromosome must orchestrate formation of testes that will produce the male sex hormones, called androgens. At around six weeks the male fetus begins making the androgen testosterone and, subsequently, the male genitalia form. The fetus is female by default, and without the proper androgens to alter the path of development; even an XY fetus will be born looking like a normal female. At the same time that hormones are orchestrating the path of development taken by the body, they are also impacting the developing brain.

The scope of hormonal influence on gender and behavior is not completely clear. However, it makes sense to study how sex hormones influence behavior because it is clear that the brain controls behavior. Studies with animals from rats to monkeys have shown that if androgens are given to a genetic female at the right time of development, the female will exhibit behaviors that are typically associated with normal males. Conversely, blocking androgen production during brain development in a genetic male will result in an animal that behaves like a typical female[9,10]. Interestingly, behavioral changes observed in these studies are not limited to reproductive behaviors. Behavior of human babies also shows some very early gender-associated distinctions. Newborn girls show more interest in gazing at a human face than do boys, who prefer to look at a mechanical object, even as early as one day after birth[11].

Slightly older children exhibit some sex differences in their behavior as well. One area where there appears to be consistent moderate difference in behavior between males and females is in childhood play. On average, girls and boys prefer different toys. When presented with several types of toys, boys prefer toy vehicles and weapons while girls tend to choose dolls, dress-up clothes and household items[12]. These differences have been noted as early as one year of age. Research has also shown that the overwhelming majority of boys choose to play with boys and girls choose to play with girls[13]. In addition, most boys seem to engage in more aggressive rough-and-tumble play than most girls[14]. If the brain controls behavior, than we must conclude that these documented behavioral differences are in some way mediated by the brain.

There are also some differences in the way the brains of male and female mammals are influenced by prenatal stress and drug exposure. Gender has been shown to be a contributing factor to the severity of brain injury in preterm infants, with males showing greater sensitivity to insult than females[15]. Human males are also more vulnerable to perturbations in height, motor development and emotional regulation following prenatal exposure to cocaine[16]. Gender-associated differences in the vulnerability of the brain are not completely understood and at this point are only evidence that there are some differences between the early male and female brains. One popular theory suggests that the function of the female brain is a bit more plastic, where more than one region can participate in certain tasks.

Very recent research suggests that we may have to look for differences even before embryonic hormone production commences. One research study identified 54 genes that are expressed in different amounts in male and female mouse brains prior to any hormonal influence[17]. This research suggests that gender-associated differences in the brain are in place earlier than was previously imagined and are not dependent entirely on the presence of different sex hormones. The role and influence of these genes has yet to be determined and at this time there are no specific structures or functions that have been linked to any of these sex-regulated genes.

It is of interest to note that there are pretty substantial genetic differences between males and females. As was indicated earlier, women have two X chromosomes while men have one X and a tiny Y chromosome. A recent study reports that women are genetically more complex than men as they have about 200 genes that are active on their extra X chromosome[18]. This study states that the genetic difference between genders in humans is about 1%. This is pretty significant if you consider that the genetic difference between humans and chimps is about 1.5%! In fact, one of the authors of this particular study has stated that it might be better to view humans as having two collections of genetic material, or genomes, one male and one female.

PEERING INTO THE ABYSS; THE ADULT BRAIN

We have established that some gender-associated brain differences are already in place at the moment of birth. Further, we have seen that in humans, some strong evidence that there are differences between the male and female brain comes from studies showing behavioral distinctions that can be observed in very young babies and children. However, the type of studies that can be done using brain imaging and behavioral assessment are limited when it comes to prenatal or immediately postnatal human subjects. What is known about the form, function and sex-related behavior of the adult male and female brains?

Size

One of the most obvious differences is that of size. On average, the male brain is slightly larger that the female brain. In this case, does size matter? Most researchers tend to say that a larger brain is needed to control the male's larger body. After all, the brain of the elephant weighs four to five times more than the human brain. However, others suggest that when statistical techniques are used to account for differences in body size, the sex difference in brain size still remains. Other factors must be taken into account when determining the overall importance of brain size. There is evidence to suggest that women have more brain cells than men in some regions, perhaps enhancing brain functional ability[19].

Sites of Sex Hormone Action

One of the first places that scientists started looking for variations in neuroarchitecture was in brain areas that are important sites of sex hormone action and are thus closely linked to sex-related behaviors. One such brain region is a small but very important area called the hypothalamus. Research with nonhuman mammals identified a small part of the anterior hypothalamus called the preoptic area that is larger in male animals than female animals. The human counterpart of this region is thought to be an area called the interstitial nucleus of the hypothalamus (INAH-3). The INAH-3 is, on average, slightly larger in males than females[20]. Some studies have shown that homosexual men have an INAH-3 that is closer in size to heterosexual women than heterosexual men[21].

Another sex hormone-associated region that appears to differ between the male and female brain is called the bed nucleus of the stria terminalis (BNST). The BNST has many receptors for sex hormones and is thought to play a role in ovulation and sexual behavior. Research has shown that the BNST is larger in males than females[22]. The size of the BNST has also been linked to gender identity disorder, although these findings have been somewhat controversial. Interestingly, one study reported that the gender-associated size difference became significant only in adulthood, suggesting that sexual differentiation of the human brain is not limited to prenatal development and early childhood[23].

One other very small brain region in the hypothalamus called the suprachiasmatic nucleus (SCN) has a similar volume and density of cells but differs in shape with gender. Males tend to have a round SCN while women have a more oval shaped SCN[24]. The SCN is thought to regulate body functions over a twenty-four hour day, otherwise know as circadian rhythms. Overall, studies done in animals seem to hold true for humans; brain regions that have a high density of receptors for sex hormones are likely to exhibit some sexual dimorphisms.

A very recent study provides evidence that there may be some functional differences in these sexually dimorphic regions of the hypothalamus[25]. Researchers used brain imaging to study the brains of straight men, straight women and homosexual men as they experienced different odors. When the groups were exposed to an odor like lavender, there was no difference in the way the brains responded; they all showed activity in regions known to process smells. However, when the subjects were exposed to a chemical similar to the male hormone testosterone, the anterior hypothalamus of straight women and homosexual men was activated. There was no activity in the hypothalamus of the straight men when they sniffed the testosterone-like chemical. A chemical related to the female hormone estrogen stimulated the hypothalamus of straight men but not women and gay men. This study suggests that there are functional differences in the regions of the brain linked to sexual behavior and that these differences are not determined only by biological sex but may also have some association with sexual orientation.

Emotion and Memory

Sexual dimorphisms also show up in regions of the brain that control various aspects of cognition. One such brain area that has been reported to show some sex-related differences in animals and humans is a structure called the amygdala. The amygdala is an almond-shaped structure found on both sides of the brain deep within the temporal lobes. The amygdala is involved in aggression, emotion and emotional memories and has been found to be larger in males than females[26]. One study examined males and females who viewed several types of sexual and social interaction image[27]. When their brains were studied with fMRI, the researchers recorded significantly higher levels of activity of the cells in the amygdala of male subjects compared to the females, despite the fact that both males and females expressed similar subjective assessments of their levels of arousal after viewing the images. Therefore, even though the subjects found the images equally arousing, their brains differed in the way they processed visual sexual cues. Another gender difference is that the amygdala is typically activated in men, but not women, when they are exposed to stimuli that induce fear[28].

The way that men and women form memories of emotionally arousing events also appears to be different. Recall of disturbing films that provoked negative emotions was associated with activity in the left, but not the right, amygdala in women whereas for men, recall was associated with activity in the right, but not left amygdala[29]. Further studies indicated that the hemispheric differences in amygdala activity make men more likely to remember the material core of the film while women are more likely to remember specific details. A hemispheric difference between males and females has also been detected in response to emotionally unpleasant images within 300 milliseconds, again with the male brain showing enhanced activity within the right hemisphere while the female brain the left has enhanced activity[30]. This brain response is very rapid and occurs before the subject has time to consciously interpret what they have actually seen.

While the significance and meaning of these sex-related differences is not entirely clear, they do illustrate some concrete differences in the way that emotionally laden events and images are processed by the male and female brains. There is even some evidence within the brain that might help to explain why men commit the vast majority of violent crimes in the world. A region of the brain that communicates with the amygdala and is thought to play a critical role in inhibiting physical aggression is larger in the female brain than in the male brain[31].

Lateralization of Function.

Differences can also be observed when researchers take a more global look at the brain. It has been well known for quite some time that for most humans, the left side of the brain is critical for language and speech while the right is more specialized to process spatial functions. This separation of duties is called lateralization and a vast body of research (see p.32 and p.33 for review) has suggested that this interhemispheric asymmetry of function is more exaggerated and distinct in men than in women. Portions of the major connection between the two hemispheres of the brain, a structure called the corpus callosum, have been reported to be larger in women than men[34]. Although results of studies examining the corpus callosum have been varied and at times contradictory (see p.32 for review), a popular view that women have brains with better communication between the two hemispheres persists. Another line of evidence that supports the notion that women's brains are not quite so lateralized is that given a comparable brain injury, females tend to be less affected than males, theoretically because they don't rely as heavily on one specific region of the brain for some tasks. However, in some cases this may have more to do with a protective influence of progesterone [35].

Some verbal stimuli can elicit very different patterns of activity in males and females. For instance, when men and women underwent fMRI while listening to a passage being read from a popular novel, the majority of men showed activity exclusively on the left side of the brain in an area known to be involved with speech and listening while women showed activity on both sides of the brain[36]. Subsequent research has indicated that the type of auditory stimulus influences lateralization of auditory processing and that sex differences are only evident with very specific listening tasks.

Cognitive Tasks.

When it comes to certain cognitive tasks, there is some divergence between the apparent abilities of males and females. Spatial tasks that involve thinking about rotating or manipulating a three-dimensional object seem to come more naturally to males while there is a tendency for females to excel at tests related to verbal memory, like word recall. In regards to spatial abilities, like navigation, women make use of landmarks while men seem to find their way by estimating space and distance[37]. Even male rats seem to have an easier time navigating out of mazes in the absence of landmarks. This may have something to do with exposure to androgens because administering testosterone to female rats shortly after birth can substantially enhance their navigational abilities, making them similar to males[38]. Interestingly, a recent study found that like females, homosexual men tend to rely more heavily on landmarks for navigation[39]. This suggests that hormones are not entirely responsible for navigational strategies in humans.

Specific tasks that involve mental rotation of a three-dimensional object (spatial rotation) show the most consistent differences between the sexes, favoring performance of males. However, these studies may be more complicated than was originally thought. One study that examined cortical activation patterns for males and females who did not differ in overall level of performance on three mental rotation tasks found that that there are genuine between-sex differences in cerebral activation patterns during mental rotation activities[40]. Such differences suggest that the sexes use different strategies in solving mental rotation tasks. However, another study suggested that sex differences are not as obvious if you control for performance level. Men and women pre-selected to display identical performance on a task did not exhibit gender-related differences in brain activity[42]. Therefore, when subjects are matched for performance, they tend to use the same brain strategies to complete the task.

All this is very interesting but even scientists who study brain function caution that we must be very careful in how we decipher this data. According to leading psychologist and neuroendocrinologist Dr. Melissa Hines[32], findings from studies looking at functional brain differences must be interpreted with caution. “Results vary with the specific tasks used, however, the exact task characteristic that produce sex differences in lateralized function are not completely clear. In addition, several theoretical and technical issues need to be considered in interpreting data from these types of studies. One is whether increased activity signals better function, rather than simply a different neural strategy for completing the task, or even compensation for difficulty completing it. Thus, greater function can represent an advantage or a disadvantage relative to the task, or simply a different strategy for similar performance in males and females," offers Dr. Hines.

Intelligence.

A recent study reports that men and women apparently achieve similar results on intelligence tests by relying on different brain regions, suggesting that "there is no singular underlying brain structure to general intelligence and that different types of brain designs may manifest equivalent intellectual performance[42]." Part of the study involved measuring the amounts of gray matter, corresponding to cells and information processing, and white matter, representing communication networks between cells. The researchers found that when men and women are compared, men have more gray matter related to general intelligence while women have more white matter. The researchers suggest that this may support the idea that men excel at math, which requires more localized processing of information while women tend to integrate and assimilate information very well. Although the differences reported in this study are rather dramatic, it is important to point out that there is no measurable difference between males and females in their performance on intelligence tests.

Perception.

Besides structural and cognitive differences, there appear to be some differences in the way men and women actually respond to their environment. There is evidence that gender affects the brain's response to different types of sensory information. One area where differences have been reported is hunger and satiation[43]. While there are many similarities between the way men and women respond to food, neuroimaging revealed that hungry men had more activity in a region of the brain associated with emotions than hungry women did. When satiated, women had more activity in regions of the brain linked to processing of visual information while men had enhanced activity in brain regions associated with feelings of satisfaction.

Research has also uncovered differences in the way males and females respond to pain. Examination of men and women suffering from irritable bowel syndrome found that while there were some overlapping areas of the brain activated in response to pain, the female brain showed more activity in regions of the brain linked to emotions while the male brain showed greater activity in cognitive regions[44]. The researchers suggest that consideration of different brain responses might impact treatment decisions. For instance, one drug for irritable bowel syndrome that is more successful for women than men affects emotional centers in the brain. This may lead to more effective gender-specific methods for pain management.

Age and Disease.

Some researchers have reported that the male brain ages faster than the female brain[45]. There are brain associated disease states that impact males and females differently as well. Parkinson's disease is more prevalent in men than women. Research with non-human mammals has demonstrated that there are clear differences between the genders in animal models of Parkinson's disease, with female rats showing less damage and significantly more behavioral recovery than males[46]. A similar study reported that even the aged female brain has more efficient protective mechanisms against Parkinson's disease than the aged male brain[47].

THE RELATIONSHIP BETWEEN SEX HARMONES AND GENDER-RELATED BRAIN AND BEHAVIORAL DIFFERENCES

When we study the connection between the brain and behavior between genders, we must consider the extent of the role of vastly different levels of sex hormones that surge during prenatal development and again at puberty. In fact, many researchers have looked for a link between sex hormones and gender associated differences in brain structure and behavior. Sex differences in cognitive abilities, including visual/spatial and mathematical abilities do not appear to depend completely on prenatal or adult sex hormones. There is no clear evidence that higher levels of androgens stimulate enhanced ability for visual/spatial or mathematical tasks[48]. In fact, the opposite may be true. No significant relationships were found between sex hormones and cognitive performance on tasks that favor men (spatial rotation) and women (verbal task) in adults[49]. This research suggests that there are no consistent, substantial relationships between endogenous sex hormones and these particular cognitive abilities in men or women.

Considering the fact that students in Asia outperform U.S. students in science and math, we must assume that many girls in Asia are outperforming many U.S. males. Boys and girls in Asia are certainly influenced by the same sex hormones as boys and girls in the U.S. so it is unlikely that androgens are the primary driving force behind the disparity in math and science scores seen at some levels between U.S. males and females. In addition, in many countries in the developed and underdeveloped world there are notably more women in fields related to math and science than here in the U.S.

However, sex hormones have been shown to play a role in sex-associated play choices. Girls exposed to unusually high levels of prenatal androgens show increased preferences for toys (cars instead of dolls) and activities usually preferred by boys, and for male playmates as well as a decreased preference for toys and activities usually preferred by girls[12,48.] Studies of human twins have shown that even small changes in prenatal androgen exposure can influence brain processing. The female of a mixed sex set of twins is exposed to more prenatal testosterone than are two female twins. Researchers have shown that females from an opposite sex set of twins have a pattern of brain activity in response to a specific listening task that is more masculine than that of same sex twin girls[50]. However, it may be that being reared with a brother rather than a sister can influence development.

Studies with animals and humans tend to support the idea that testosterone during early development influences childhood play behavior, at least in part, by altering brain development. It appears as if female anatomy and some female behaviors are the default condition that emerges in the absence of androgens. Although prenatal hormones contribute to some behavioral differences, researchers agree that they do not act alone and do not drive all sex differences. In the cases described above, the differences between girls exposed to elevated androgen and those that were not were less than differences observed between girls and boys. It is likely that a combination of genetic and hormonal events beginning at very early development and continuing throughout the lifespan of an individual can have a varied influence on the brain and behavior.

WHAT DO THESE DIFFERENCES MEAN AND HOW DO SOCIAL FACTORS FIT IN?

We have considered many aspects of brain structure and function that have in some way or another been identified as showing some variability between the sexes. Overall, the vast majority of scientific studies indicate that male and female brains are much more alike than they are different. Documented variations between males and females are only observed with very specific testing conditions and are often smaller than deviations within each sex. However, it is undeniable that some subtle biological variations exist between the sexes. Exegesis of research on the architecture and function of male and female brains leads some individuals to conclude, as Sigmund Freud once said, “anatomy is destiny”. Leading psychologist Simon Baron-Cohen[33] hypothesizes that, “The female brain is predominantly hard wired for empathy. The male brain is predominantly hard wired for building systems.” Dr. Baron-Cohen stresses that one type of brain is not better than the other; they are just inherently different and the extent of how “female” or “male” an individual’s brain is may influence career pursuits. Alternatively, there are those who view the same data and determine that sex segregation in occupations has much more to do with social, political and economic forces than with biology. Of course, such differences in interpretation of the same research findings are really no great surprise. After all, even within a particular gender, no two people (and therefore no two brains) are exactly alike. The ability of each individual to have a unique perspective is inherently human.

Perhaps the differences discussed here signify only that male and female brains process information slightly differently but work at a similar capacity. It is conceivable that a better understanding of these variations may lead to creation and implementation of educational methods tailored for a certain brain type. “A reform in the method of education can compensate for comparative differences to some extent. It may even give us more woman architects or male social workers,” say Anne Moir and David Jessel[51] in their book examining the inherent differences between men and women. Mohr and Jessel go on to caution that even if we were able to somehow completely eliminate sexism from our society, no amount of social, educational and political change can reorganize the initial wiring of the brain, as this is the result of hormones acting prior to birth. In the words of the authors, “We will not change the essential boyness of boys or girlness of girls.”

I would argue that the story is more complicated and broader than relegating ourselves to a level of “boyness” or “girlness” or as a “system-builder” or “empathizer” that is irreversibly programmed before birth. There is a wide spread spectrum of human behavior and research has proven that hormones are certainly not the only driving force behind behavior; many other factors can have a strong influence on whether or not an individual realizes their full potential. No gender-associated biological distinction identified to date appears to convey a profound difference in brain capacity that can fully account for the under-representation of women in fields related to science and math. Even if men are marginally better at completing mental rotation of three-dimensional objects, surely this is not the only skill needed for a successful career in science and engineering. In fact, is it within the realm of possibility that the careers of science and engineering are influenced by the preponderance of men in these fields? Would “engineering” be different if it evolved in a female dominated environment?

It is also important to reinforce that the differences described here are actually quite small in magnitude. All are smaller than another well established physical difference between males and females, the difference in height. Keep in mind that, like the difference in height, sex differences in the brain and behavior are averages and there is a lot of variation and overlap within the population. For instance, in a room full of people you are sure to spot some women who are taller than some men, even though in general men are taller than women. There will also always be some women who are better at three-dimensional rotations than some men and some men who excel at verbal tasks.

Research suggests that perhaps many women who are confident in their analytical abilities may choose a career where they would have the opportunity to directly help people or other living things, like biology or medicine[52]. The scientists who completed this study suggest that because boys and girls have different beliefs and values, they make different career choices. This would support the theory that women are generally more empathetic than men. Careers in engineering and physical sciences do not deal directly with living organisms and may not be perceived as being as valuable to society and, perhaps, not as fulfilling for some women. Can the lack of women in some careers be attributed, at least in part, to a conscious choice based on whether fields are deemed as likely to benefit society?

Research has also shown that women who succeed in male-dominated careers are often seen negatively, suggesting that women may be penalized for success in these fields[53]. If women who succeed in male-dominated fields are perceived negatively by other men and women, it seems that this might discourage other women from aspiring to these positions. A recent study examining what men and women look for in a role model emphasized the importance of a role model's gender in the career development of female physician-scientists[54]. If young women do not expect to find mentors, teachers, co-workers and peers that meet their ideals in certain fields, it seems likely that they will be reluctant to pursue a career in those fields.

Regardless of how you interpret the biological findings, results from studies examining social attitudes suggest that the effects of widely held societal tenets have a powerful influence on the choices women make. Many of these beliefs are based on the experience of generations of men and women. When we assess gender in another individual, what kind of assumptions do we link with “male” or “female”? What characteristics do we automatically associate with gender? One research study demonstrated that women actually perform better in math when they are tested without men being present, although being in a classroom with men did not affect women’s overall intellectual performance[55]. The authors of this study suggest that because performance differences were limited only to situations where females were tested on math, a subject that has a significant stereotype associated with it, such stereotypes might actually impair performance.

CONCLUSIONS

As a scientist who is interested in neurobiology, I am intrigued by and see the benefits of understanding differences in the brain. However, I doubt that studying these differences from a gender perspective is an optimal approach. If we take the emphasis off gender and all of the deep rooted and perhaps unconscious beliefs that surround our concept of gender and focus instead on differences, we are more likely to produce practical results that might be useful for reforming education or developing more effective medical therapeutics. Biological inclinations or predispositions aside, for some women, beliefs and resulting expectations may present significant obstacles that foster a lack of interest and, quite possibly, the potentially damaging perception of an innate lack of ability for science, engineering and math.

As a scientist who is also a mother (or maybe a mother who is also a scientist), I will encourage my own daughters to make educational and career choices based not on perceived “appropriate” gender roles but on inherent talents and passion for a particular field or lifestyle. For both men and women, such choices may need to be reevaluated based on changing life circumstances.

I believe that more women with children will achieve success in science and math careers as more men are drawn to playing an active role in finding better ways to balance work and family. Women and men should be able to make educational, career and life decisions that are not hindered by societal expectations based on perceived gender roles. The world is sure to benefit if individuals are free to explore and follow their own unique path and are not constrained by limitations that are based, not on innate irreversible biology, but only in stereotype. In the words of Dr. Seuss, "You have a brain in your head. You have feet in your shoes. You can steer yourself in any direction you choose."

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