Sex Roles (2013) 69:363–381
DOI 10.1007/s11199-011-0037-y

ORIGINAL ARTICLE

Single-Sex Education and the Brain

Lise Eliot

Published online: 18 August 2011

Abstract Of the various rationales for sex-segregated education, the claim that boys and girls should be taught in separate classrooms because their brains differ is arguably the weakest. Existing neuroscience research has identified few reliable differences between boys' and girls' brains relevant to learning or education. And yet, prominent single-sex school advocates have convinced many parents and teachers that there exist profound differences between the "male brain" and "female brain" which support the ubiquitous, but equally unfounded belief that "boys and girls learn differently" (Gurian et al. 2001; Sax 2005b; James 2007, 2009; Kaufmann 2007). Educators who cite brain or hormonal research as evidence for boys' and girls' different pedagogical needs are often misusing or misconstruing a small number of studies, when the complete data are far more equivocal and of doubtful relevance to classroom instruction. Gender differences in hearing, vision, and autonomic nervous function are modest, with large overlap between boys' and girls' measures. Similarly, studies of the neural basis of learning do not support the premise that boys and girls master reading, calculation, or other academic skills differently. Boys and girls have differing interests, but their basic cognitive, emotional and self-regulatory abilities vary far more within each gender than between the average boy and girl. Beyond the issue of scientific misrepresentation, the very logic of segregating children based on inherent anatomical or physiological traits runs counter to the purpose and principles of education.

Keywords Sex difference · Schooling · Learning · Sensory · Hormone · Stress

Introduction

As neuroscience research progresses at a rapid pace, it is clear that males and females show certain statistically-significant group differences in brain structure and function (Cahill 2006; Cosgrove et al. 2007; Lenroot et al. 2007). Nonetheless, many highly-publicized claims about brain gender differences have failed to hold up to replication (Fine 2010; Jordan-Young 2010), and research has yet to identify a definitive neural basis for any of the well-described psychological differences between men and women (McCarthy and Arnold 2011), much less the differences between boys and girls (Eliot 2009). This is not the message, however, that parents and teachers are hearing from many single-sex school advocates. Just as erroneous claims about "brain-based learning" have influenced countless teachers (Goswami 2006), false claims about gender differences in the brain and hormone effects on cognition appear to hold great sway among educators and are frequently used to justify gender-specific teaching methods and gender segregation in schools. In this paper, I evaluate several such claims, demonstrate the fallacious reasoning behind them, and conclude that current scientific understanding of male-female brain differences has little relevance to classroom learning.

The Popular Science Versus Real Science of Gender Differences in Children's Brains

> "We can teach boys and girls based on what we now know because of medical technology."

This remark, spoken by South Carolina Department of Education's Coordinator for Single-Gender Initiatives, David

L. Eliot (✉)
Department of Neuroscience, The Chicago Medical School,
Rosalind Franklin University of Medicine & Science,
3333 Green Bay Rd.,
North Chicago, IL 60064, USA
e-mail: lise.eliot@rosalindfranklin.edu

Chadwell, and quoted in *Reader'sDigest.com* (Kaufmann 2007, p. 1), sounds enormously powerful. Just imagine running a child through an MRI scanner and being able to diagnose the best way to teach her math or history. The fact that such notions are proffered by paid government officials is arresting and shows just how deep our neuro-infatuation runs. Around the U.S., over 500 public schools have instituted single-sex classrooms or entirely segregated campuses (NASSPE 2011) based in large measure on claims about brain differences between boys and girls that are debatable, at best, and most often, plain wrong.

Gender differences are a hot topic in neuroscience, just as they are in the popular press. What is often lost in the translation of basic science to the popular sphere, however, is any discussion of statistics and effect sizes. For decades, psychologists have studied gender differences in all manner of abilities and traits—from verbal and math skills to self-esteem, leadership style, and sexual preference. And, with the exception of the latter and a handful of other behaviors (like throwing accuracy), most gender differences are smaller than popularly perceived. Janet Hyde (2005) reviewed all the existing meta-analyses of male-female differences in a paper titled "The Gender Similarity Hypothesis" and found that 96 of the 124 analyses resulted in effect sizes (*d* values) smaller than .35, or, in the statistically "small" range according to Cohen's criteria.

The relatively small magnitude of most behavioral gender differences is likely one reason why it has been difficult to find reliable gender differences in the brain. Males' brains are unquestionably larger than females' brains, by some 8 to 14% (Paus 2010), which is comparable to the gender difference in height, weight, and mass of other organs like the heart (Sarikouch et al. 2010) and kidney (Schmidt et al. 2001). However, few other neural gender differences are as sizeable or consistent, and none have at this point been proven to underlie any of the well-known behavioral gender differences. Even the best-described gender difference in a mammalian brain—a small zone within the medial preoptic hypothalamus known as the SDN-POA (sexually dimorphic nucleus of the preoptic area) has been difficult to pin down with a function. Though 5 times larger in male rats, compared to females (Gorski et al. 1978), lesions to the SDN-POA have little effect on adult male rats' sexual behavior (De Vries 2004), whereas the comparable structure in humans, a tiny, .1 mm structure known as INAH-3 (third interstitial nucleus of the anterior hypothalamus) is only two times larger in men than women (Garcia-Falgueras and Swaab 2008; LeVay 1991) and not clearly related to sexual preference (Byne et al. 2001).

Few other differences between male and female brains come anywhere close to this two-fold effect, and even for the more modest differences that are looking reliable—such as males' higher proportion of white matter, females' higher proportion of gray matter (Cosgrove et al. 2007), males' larger amygdalae (Brierley et al. 2002) and females' larger ventrofrontal cortex (Wood et al. 2008)—their functional relevance is far from clear. The amygdala, for instance, is known to participate in face recognition (Gobbini and Haxby 2007), social perception (Adolphs and Spezio 2006), emotional memory (Buchanan 2007), fear (Ohman 2005), decision-making (Gupta et al. 2010) and aggression (Blair 2010). But when self-described "brain-based" consultant Michael Gurian mentions the structure in his book *Boys and Girls Learn Differently!*, he relates only this to males' larger amygdalae: "Helps make males more aggressive" (Gurian et al. 2001, p. 20).

Another problem is that single-sex school advocates often claim differences between boys' and girls' brains based on studies carried out with adult men and women. This is fallacious for several reasons. First, in most cases, the same effect has never actually been found in children. For example, in his book *Why Gender Matters,* physician Leonard Sax tells parents that in doing math problems "girls are using the cerebral cortex while boys are using the hippocampus"(Sax 2005b, p.105). But this claim is not based on children, or even on a study of math problem-solving. Instead, Sax cites a functional MRI study of spatial navigation in adult men and women (Gron et al. 2000), without mentioning that similar experiments have never been conducted in children or that navigation and mathematical problem-solving are very different cognitive processes. In fact, one of the few brain imaging studies of mathematical processing in children found no difference between boys and girls, but an entirely different pattern of brain activation overall compared to adults (Kucian et al. 2008), illustrating that one can never assume that gender differences in adult brains automatically translate to younger subjects.

The reality is that children's brains do not operate like adults: they are works-in-progress, and much of what influences adult neural circuitry is an individual's social-educational experience from birth until adulthood. Children's brains are unlikely to be as sexually dimorphic as adults', just as their bodies have yet to fully diverge into mature male and female forms. This is the pattern for most behaviors that differ consistently by gender, including spatial skills (Voyer et al. 1995), math performance (Hyde et al. 1990), writing ability (Coley 2001), emotional expressiveness (Van Tilburg et al. 2002), self-esteem (Kling et al. 1999), and physical aggressiveness (Archer 2004). For each of these traits, male-female differences are small in infancy and childhood, but grow larger and peak during adolescence or early adulthood.

Similarly, the brain is not fixed with particular neural circuits at birth (beyond those for the most basic reflexes) but selects its synaptic connections according to the social, physical and sensory environment at hand. Biologists call this process "neural plasticity," which is known to be most potent in childhood (Greenough et al. 1987). In addition to changes in synaptic connectivity and dendritic branching, neural plasticity encompasses experience-dependent changes in gene expression (McGowan et al. 2009), and gray matter (Benetti et al. 2010), and white matter volumes (Fields 2008). Considering the strength of this plasticity, especially in early life, and the often-dramatic differences in life experience between boys and girls, the assumption that male-female differences in adult brains would map identically into children's heads is highly erroneous.

Nonetheless, there is a widespread misconception that, because gender differences in the brain are biological, they are necessarily fixed, or "hardwired." This belief is demonstrated by David Chadwell when he writes in his recent guidebook for teachers, *A Gendered Choice* (2010b, p. 8) that sex-segregated education is supported by "biological brain differences, otherwise referred to as hard wiring." Although it is perhaps understandable when lay people make this mistake, educational experts should be better versed in modern neuroscience. But this misunderstanding serves their purpose well, since equating "biology" with "hardwiring" promotes the view that boys and girls differ in fixed, categorical ways that can only be managed through separate educational methods.

Picking the Wrong Cherries: Claims of Gender Differences in the Corpus Callosum and Hemispheric Lateralization

Beyond propagating the biological fallacy that "brain-based" = "innate," certain single-sex school proponents mislead through their biased selection of studies used to prove male-female differences. Two early claims about male-female brain differences are widely cited by such proponents, even though neuroscientists no longer accept them. Here is one, as it appears in an article about "wired" learning differences between boys and girls on the popular greatschools.org (n.d.) website:

> In girls, the *corpus callosum*, which connects the two hemispheres (or halves) of the brain, is generally larger than in boys. This enables more "cross talk" between the hemispheres of the brain. Boys' brains, on the other hand, are structured to compartmentalize learning. As a result, girls are usually better than boys at multitasking and can make quick transitions between lessons and tasks… On the other hand, a boy's ability to compartmentalize learning might result in better clarity and focus in certain situations.

This posting closely parrots a similar claim about females' allegedly larger corpus callosum by Michael Gurian and colleagues in *Boys and Girls Learn Differently!* (2001, p. 27), which he himself repeats in a widely-cited article in the journal *Educational Leadership,* "A girl's corpus callosum (the connecting bundle of tissues between hemispheres) is, on average, larger than a boy's—up to 25% larger by adolescence. This enables more 'cross talk' between hemispheres in the female brain" (Gurian and Stevens 2004, p. 22).

In fact, most research finds that females' corpus callosum is not larger than males', neither in adulthood nor childhood (Bell and Variend 1985; Clarke et al. 1989; Giedd et al. 1999; Koshi et al. 1997; Ng et al. 2005). Gurian's claim, though unreferenced, may be based on one small but widely-publicized early study (DeLacoste-Utamsing and Holloway 1982) that reported a marginal gender difference, not in the corpus callosum as a whole, but in the posterior one-fifth of the structure, known as the splenium. However, that tiny study was followed by dozens of others, and by 1997, enough measurements of the human corpus callosum had been published that Katherine Bishop and Douglas Wahlsten (1997) were able to conduct a meta-analysis of the gender difference. Based on their statistical compilation of 49 studies, these authors found no significant difference between males and females in either the splenium or the corpus callosum as a whole. Research is still ongoing, but the latest consensus is that any difference between males' and females' corpus callosum reflects overall brain size (larger brains having a proportionally smaller corpus callosum) rather than gender (Leonard et al. 2008; Luders and Toga 2010). Nor does animal research support Gurian's case. In rats, a more reliable difference has been identified in the corpus callosum, but it is actually larger in *males* (Nunez and Juraska 1998). Whether there is a gender difference in multitasking among rats, or even humans, has never actually been tested.

The second frequently-claimed male-female brain difference is related to this corpus callosum myth. It is the notion that females use both cerebral hemispheres for specific mental tasks, whereas males' neural function is more localized or, lateralized, to either the left or right side of the brain. If, in fact, females had a significantly larger corpus callosum than males, it could theoretically permit better integration between the hemispheres. Still, there is little support for this widespread assertion, which is expressed in typical form at a website promoting all-girls' boarding schools (Girlslearndifferently.com, n.d.): "Men tend to use only one brain hemisphere at a time, but women employ 'whole brain' thinking." Similarly, Michael Gurian et al. (2001, p. 24) assert that: "Boys use right side of brain to work on abstract problems; girls use both sides."

The main source of this belief appears to be one high-profile fMRI study that found—for only one of the three different language tasks assessed—that a majority of the 19 adult female subjects activated both left and right inferior frontal lobes, whereas all 19 adult males in the study showed significant activation of only the left inferior frontal areas. This study, conducted by Sally and Bennett Shaywitz and colleagues (1995), received enormous public attention. The *New York Times* heralded it with the headline, “Men and women use brain differently, study discovers”(Kolata 1995), with other news outlets, including *Newsweek* (Begley 1995) promptly following. So it is not surprising that single-sex school advocates began citing it.

Once again, however, the single study is not representative of the field as a whole. Since 1995, over two dozen studies have compared males’ and females’ brain activation during various language tasks. And the overall result is no difference in lateralization. Although a few studies partially confirmed the Shaywitz’ finding (Kansaku et al. 2000), others found the opposite result (more bilateral response in males; Kaiser et al. 2007), and yet others found little-to-no difference (Frost et al. 1999). According to a 2008 meta-analysis of 26 studies, involving 1536 different subjects, there is no significant difference between men and women, or boys and girls, in lateralized fMRI activation during language processing (Sommer et al. 2008).

As with the corpus callosum, research on this topic is likely to continue. As fMRI databases grow and neuroscientists are able to extract brain measures from ever larger numbers of subjects, small gender differences may indeed become detectable. One such large study, focusing on resting brain activity, did indeed find that men were somewhat more lateralized than women, although both genders were strongly left-hemisphere dominant (Liu et al. 2009). When it comes to language specifically, detecting a reliable neural difference is going to be tricky considering the very small effect size of verbal gender differences at the behavioral level (Hyde and Linn 1988).

Brain Maturation Rate and Sequence in Boys and Girls

The same issue of effect size applies to the verbal gap in children. Although the gender difference is quite real, girls are not “a year earlier than boys” in acquiring language skills as Michael Gurian et al. (2001, p. 26) state. The difference is more like a month, at least in the second year of life, when the average girl’s expressive vocabulary is roughly equal in size to the average boy a month older (Fenson et al. 1994). The verbal gap grows through the preschool years, but then declines to nil by age seven (Bornstein et al. 2004). Girls do outperform boys in reading (Freeman 2004) and writing (Salahu-Din et al. 2008), gaps that increase through elementary and high school. Comparable gender differences are found in other nations, where one large international study finds that the gender gap in reading ability is associated with an important form of experience, namely, amount of pleasure reading engaged in by boys and girls (OECD 2009).

Nonetheless, a dominant view among single-sex school advocates is that gender differences in reading ability are a fixed matter of brain maturation, such that language circuits are said to develop earlier in girls, whereas circuits related to mathematics are claimed to develop earlier in boys. According to the website of the National Association for Single-Sex Public Education (NASSPE 2006–11), which is headed by Leonard Sax, the “key insight from the past 5 years of neuroscience research” is that “The different regions of the brain develop in a different SEQUENCE in girls compared with boys” (emphasis in the original). The post continues with the description of a study of EEG development by Robert Thatcher and colleagues that is taken verbatim from *Why Gender Matters* (Sax 2005b, p. 93): “Researchers at Virginia Tech examined brain activity in 508 normal children…These researchers found that while the areas of the brain involved in language and fine motor skills mature about 6 years earlier in girls than in boys, the areas of the brain involved in targeting and spatial memory mature about 4 years earlier in boys than in girls.”

This is a dramatic claim, which, if taken literally, would suggest that educators cannot expect first-grade girls to learn their shapes or boys to begin reading and writing. Indeed, Sax goes further in an *Education Week* piece, where he again repeats verbatim his interpretation of the Virginia Tech study, and then adds: “When it comes to learning geometry, the brain of a 12-year-old girl resembles the brain of an 8-year-old boy” (Sax 2005a, p. 34).

In fact, this interpretation is an extreme extrapolation from the real findings of the Virginia Tech study. This research (Hanlon et al. 1999) compared resting EEG power spectra in a large sample of boys and girls between 2 and 16 years of age. It did not assess brain activation during language, or math, or any other specific mental activity. The study did report a gender difference in the brain, but not in global maturity. Instead, it described a cyclic pattern of maturation, with spurts of development that appeared to spiral through different brain areas. The phase of the spiral differed significantly between the average boy and girl, but the same brain areas were revisited in both genders throughout this age range and there was considerable variability in phase within each separate population of boys and girls. So the study does not demonstrate anything like a 4- or 6-year gap in maturation between the genders, or even a different sequence of maturation (Robert Thatcher, personal communication, December 25, 2009). Sax’s interpretation is clearly incorrect, but has nonetheless been widely propagated in popular media and among other single-gender school advocates (Boardingschoolsforgirls.com, n.d.; Chadwell 2010a).

Here, for example, is *Time* magazine repeating the same misinterpretation in an article about women's math ability (Ripley 2005 "Lesson 1"):

> …in a 1999 study of 508 boys and girls, Virginia Tech researcher Harriet Hanlon found that some areas mature faster in boys. Specifically, some of the regions involved in mechanical reasoning, visual targeting and spatial reasoning appeared to mature 4 to 8 years earlier in boys. The parts that handle verbal fluency, handwriting and recognizing familiar faces matured several years earlier in girls.

Though Sax is not quoted in this paragraph, he is elsewhere in the piece (Ripley 2005), so his book or website is the likely source. Although journalists cannot be expected to verify every fact using independent sources, a quick PubMed search for gender differences in EEG maturation in children reveals not only the study by Hanlon et al., but also several papers by Robert Barry, Adam Clarke and colleagues in Australia. Surprisingly, this group has found earlier maturation of EEG waveforms only in *boys* (Clarke et al. 2001), in spite of their slower average development of self-regulatory skills. Like Thatcher, Adam Clarke (personal communication, December 22, 2009) sees no relevance of this finding to educational practices.

Gender Differences in Hearing

In the same *Time Magazine* piece about gender differences in math ability, reporter Amanda Ripley (2005, "Introduction") tells millions of readers: "Some of the most dramatic differences are not just in our brains but also in our eyes, noses and ears—which feed information to our brains." The notion that there are fundamental sensory and perceptual differences between boys and girls is also frequently used to rationalize single-sex education. The truth, however, is that such perceptual differences are small, often unproven in childhood, and of no relevance in a classroom.

Once again, Leonard Sax is the main source of many claims about gender differences in perception. He is particularly emphatic about male-female hearing differences. Exploiting the fact that the decibel scale is logarithmic, Sax (2005b, pp. 4–5, 18) argues that a teenage girl hears her father's yelling voice "as being about ten times louder than what the man is hearing" and further, that a second grade boy is unable to pay attention to the teacher as well as the girl next to him, simply because he cannot hear her soft-spoken voice. (The solution: move him to the front of the class, or better yet, to an all-boys' class where the teacher can raise his or her voice without disturbing any female students.) Gender differences in hearing are also cited by David Chadwell (2010b, p.21) and Abigail James (2009, p. 16) as reasons for separating and teaching differently to boys and girls.

However, the real gender difference in hearing ability is far more modest. Though Sax selects some numbers from a 50-year-old study of adults (Corso 1959) to come up with his 10-fold claim, the true difference in adult hearing sensitivity is about three decibels. Although this represents a doubling of sound pressure level, it is nonetheless a trivial difference in an auditory system sensitive over a 130 dB range—that is, ten trillion times the sound pressure level at the ceiling of auditory perception compared to threshold (McFadden 1998). Moreover, the overlap in auditory sensitivity between populations of men and women is far greater than their average threshold difference (Liberman 2006), meaning that if you were to separate males and females for the purpose of volume adjustment, there would be both males and females in each group who experience the speaker as subjectively too loud or too quiet for their comfort.

Note that all of these studies are based on adult auditory perception. To my knowledge, no one has done a study comparing boys' and girls' auditory perception in a natural environment, such as the classroom. There are, however, a number of studies that have documented male-female differences in cochlear function in newborns (Berninger 2007; Morlet et al. 1995; Strickland et al. 1985; Thornton et al. 2003). It is not a measure of hearing per se, but babies' otoacoustic emissions—tiny echo-like sounds that cochlear hair cells actually generate themselves—that are reliably larger in girls. The difference is some .15 of a standard deviation (Liberman 2008a)—again, trivial compared to the much greater inter-individual variation in otoacoustic emissions within populations of either boys or girls. Moreover, this difference is functionally meaningless, since much of the difference in otoacoustic emission amplitude can be accounted for by boys' slightly larger cochleas. It is also clinically insignificant. Because the difference is so small compared to the large overlap between populations of boys and girls, audiologists do not take gender into account when using otoacoustic emissions to screen for hearing deficits in newborns (Berninger 2007). Nonetheless, the early appearance of this difference suggests it is indeed innate, and considerable evidence suggests that prenatal testosterone contributes to this small difference in cochlear structure and function (McFadden 2008).

Here, then, is a tiny difference that audiologists do not heed, but which teachers are supposed to reconfigure their classrooms to accommodate. Leonard Sax also tries to link gender differences in hearing to EEG measures of auditory processing, but here runs into trouble, actually citing one study that found a lower threshold for (that is, more sensitive) auditory brainstem responses in *boys* (Sininger et al. 1998). However, he does not phrase it this way to readers, stating only that the study demonstrates a newborn hearing "difference" without specifying the direction of the difference. This is ironic, since he could have chosen a number of other studies that report faster processing in one component of the auditory brainstem EEG signal, known as wave V, in newborn females compared to males (Eldredge and Salamy 1996; Ribeiro and Carvallo 2008; Stuart and Yang 2001). Then again, this gender difference in wave V latency, which is seen throughout the lifespan, is largely attributable to women's smaller head diameter (Trune et al. 1988) and so unlikely to be perceptually meaningful.

Compared to otoacoustic emissions or auditory brainstem potentials, a more relevant assessment of auditory attention is simply to test children's behavior in response to sound stimuli. Here there exists considerable data, reviewed back in 1974 by Eleanor Maccoby and Carol Jacklin, but notably overlooked by Leonard Sax, Abigail James, and David Chadwell. Out of 15 studies of infants (six studies on newborns alone), only three found greater auditory responsiveness in girls; one found higher auditory responsiveness in boys, and the remaining 11 experiments revealed no gender difference. Stimuli in these studies ranged from pure tones to music, voice, heartbeat, and other babies' cries. As Maccoby and Jacklin (1974, p. 26) concluded: "The bulk of the evidence over the period from birth to 13 months shows that the sexes are highly similar in their attentiveness to auditory stimulation." Thus, there is no basis for Sax's conclusion (2005b, p. 17) that "built-in gender differences in hearing have real consequences" for how children learn.

Gender Differences in Vision

Along with alleged hearing differences, gender differences in vision are another popular rationale for single-sex schooling. According to *Reader'sDigest.com*, David Chadwell explained it this way to a group of highly interested parents (Kaufmann 2007, p. 1):

> "They see differently. Literally," he begins. Male and female eyes are not organized in the same way, he explains. The composition of the male eye makes it attuned to motion and direction. "Boys interpret the world as objects moving through space," he says. "The teacher should move around the room constantly and be that object." The male eye is also drawn to cooler colors like silver, blue, black, grey, and brown. It's no accident boys tend to create pictures of moving objects like spaceships, cars, and trucks in dark colors instead of drawing the happy colorful family, like girls in their class. The female eye, on the other hand, is drawn to textures and colors. It's also oriented toward warmer colors—reds, yellow, oranges—and visuals with more details, like faces. To engage girls, Chadwell says, the teacher doesn't need to move as much, if at all. Girls work well in circles, facing each other.

What is the evidence for this? Are there gender differences in visual perception and if so, are they large enough to affect learning and the way children should be seated in classrooms?

Of course, girls and boys like different colors, but a quick trip to a toy store explains why girls choose baby-doll pinks and Barbie purples and boys, Lego-gray, Nintendo-black, and Hot-Wheels blue for their classroom creations. Although various evolutionary explanations have been put forth to account for girls' "innate" attraction to pink, it turns out that our current convention of gender color-coding dates back only as far as World War II. Before then, infant colors were actually reversed, blue for girls (which was widely used in paintings of the Virgin Mary) and pink for boys (which was considered a watered-down version of a warrior red; Frassanito and Pettorini 2008).

Still, we have educators believing that color preference is somehow hardwired into boys and girls. As Abigail James writes (2007, p.32) in her book *Teaching the Male Brain:* "The pathways more active in girls respond to warmer colors such as pink and red and respond to the shape and form of objects. The pathways more active in boys respond to cooler colors such as blue and green and respond to motion." There is not, to my knowledge, any EEG, fMRI, or other measure of neural activity that demonstrates a difference in the way girls' and boys' brains process color stimuli. It is true that boys and men are more likely to be color blind than girls and women: the prevalence is about 8% for males versus .5% for females because several of the genes coding for cone photoreceptors reside on the X chromosome. But when such subjects are excluded, there is no meaningful difference in color perception, and a large recent study actually found better color discrimination in adult men, compared to women (Rodriguez-Carmona et al. 2008).

What about motion perception? Is the male eye designed to better detect motion and direction than the female eye, as David Chadwell explains? Once again, this notion can be traced to Leonard Sax. In *Why Gender Matters,* Sax (2005b, p. 20) devotes several pages to the topic of visual perception, claiming in his own italics that *"Every step in each pathway, from the retina to the cerebral cortex, is different in females and males."* However, this strong statement is backed up by precisely two citations—studies not of children, but of rats. In the first of these, Tamas Horvath and Kenneth Wikler (1999) stained rat brains for the enzyme aromatase, which is responsible for converting testosterone into estradiol (the principal active form of estrogen). They found staining throughout every sensory system of the brain, and in both males and females, though they made no effort to compare staining between the sexes.

It is true that aromatase conversion is an important route by which testosterone masculinizes rat brain structures like the SDN-POA. With respect to the *human* brain, however, masculinization is mediated more by the direct action of testosterone on cells, without aromatase conversion to estrogen (Grumbach and Auchus 1999). Furthermore, nothing in the study by Horvath and Wikler demonstrates structural, much less functional differences between males and females' visual systems, and aromatase staining is especially far removed from the claim of motion-detection differences between boys and girls. Nonetheless, Sax (2005b, p. 19) pushes on, picking one more rat paper to support his belief that boys are "prewired to be more interested in moving objects." This time, it is a study of the rat retina (Salyer et al. 2001)— though Sax never mentions the species at all. Instead, he explains how the retina contains two types of output cells, M (for large or magnocellular) and P (for small or parvocellular), which are specialized, respectively, for motion and color detection. Then comes the sleight of hand, where the finding of this study—namely 20% thicker retina in male rats compared to females—is said to explain boys' and girls' different color and motion preferences. Even though the researchers made no attempt to identify individual cell types, Sax himself decides that the sex difference in rat retinal thickness is "because the male retina has mostly the larger, thicker M cells while the female retina has predominantly the smaller, thinner P ganglion cells" (Sax 2005b, p.21). On the contrary, there are many other potential reasons why one retina might be thicker than another—difference in total number of neurons or glia, in neuropil density, or in volume of individual cells—but since his readers would not be aware of these, Sax confidently asserts that it is due to a gender difference in the M/P ratio.

In fact, studies of the human retina—obviously the more pertinent data—reveal a much smaller gender difference. According to Mark Liberman, who has fact-checked many of the claims by Leonard Sax and others about gender differences, the largest and most relevant is a study of Australian school children (Huynh et al. 2006). Based on measurements from 1,543 six-year-olds, Huynh et al. reported that boys' fovea (the central and most sensitive part of the retina) is only 2.6% thicker than girls'—hardly the dramatic difference Sax portrays and, still, of no known relevance to visual perception. Liberman, who is Trustee Professor of Phonetics at the University of Pennsylvania, cleverly titles this blog posting "Retinal sex and sexual rhetoric"(Liberman 2008b), epitomizing the way Sax and others extrapolate tiny bits of biology into sweeping claims about boy-girl differences and the need for gender segregation in school.

To compare visual ability between boys and girls it is not actually necessary to analyze the retina, or the visual cortex, or anything at all inside the head. For decades, psychologists have studied visual development in children from birth onward. And though the occasional study does find a small or temporary difference between boys and girls in certain measures, the overall pattern is of profound similarity. Eleanor Maccoby and Carol Jacklin (1974) reviewed 66 existing studies of children's visual abilities from birth to adolescence, involving some 88 separate experiments. Differences were detected in only 22 of the 88 experiments, 11 favoring girls and 11 favoring boys. The other 66 studies found no significant gender differences in vision. Moreover, nine of the experiments were conducted on newborns, and none of these revealed an innate gender difference in visual fixation to various stimuli.

More recent studies, often using much more sophisticated stimuli, have not substantially altered this conclusion. If anything, the newer data reveal a slight visual advantage for infant *girls,* though the differences are short-lived and thought to reflect girls' faster maturation in the first few months of life (Gwiazda et al. 1989; Malcolm et al. 2002; Peterzell et al. 1995). However, by school age these differences are gone; in one large Swiss study, no gender difference was found beyond age 5 in children's static visual acuity or stereopsis (which is involved in depth perception; Schmid and Largo 1986). Similarly, a large German study of youths between 4 and 24 years of age found earlier maturation in girls, but no gender difference beyond 7 years of age in dynamic visual acuity (Schrauf et al. 1999)—precisely the kind of visual motion perception that Leonard Sax, David Chadwell and Abigail James claim is better in boys. Nor does an electrophysiological (EEG) study of normally-developing children indicate any difference between boys' and girls' neural activity as they consciously process visual (or auditory) stimuli (Sangal and Sangal 1996).

In other words, the idea that boys and girls see differently in the classroom is unsupported by actual studies of children's vision. Instead, it appears that real source of claims by Sax (2005b), Chadwell (2010a), and James (2007) is an article by Gerianne Alexander (2003) speculating about the evolutionary origin of the gender difference in toy choice. Unlike visual perception, there is no doubt that boys and girls differ significantly in their preference for gender-traditional playthings; this is one of the largest of all behavioral gender differences, which emerges toward the end of the first year and grows to be quite dramatic between 3 and 5 years of age (Golombok and Rust 1993; Servin et al. 1999). Alexander conjectures that the difference could originate from a gender difference in vision, citing the same two rat studies that Sax later references, and proposing that early androgen exposure may somehow differentially shape the M- and P- pathways that originate in the retina and extend, respectively, to dorsal and ventral visual streams in the cerebral cortex. But Alexander never claims such differences are proven; her argument is simply a call for further research. To date, no such findings been published, leaving the proposed gender difference in visual circuitry purely hypothetical, and in contrast to perceptual studies that have found no consistent gender differences in children's vision.

In spite of its lack of evidence, the idea that visual abilities differ critically between boys and girls resonates strongly with many educators, as we hear from a Kentucky high school English teacher (Kuhens 2009, p. 1) who divided her classes down the middle, boys near the windows "because Gurian's research shows boys' occipital lobes are more developed, allowing them to see better in brighter light," whereas she put girls, whose "brains have a greater ability to multitask," near the door and phone so that "when visitors or callers interrupted, girls could answer either, take care of business and return to work."

Gender Differences in the Autonomic Nervous System

The nervous system is inarguably the most complex organ in the human body, offering endless avenues for finding gender differences of supposed relevance in the classroom. Part of its complexity lies in its organization as essentially two nervous systems operating in parallel: the more familiar sensory-motor-cognitive structures, alongside the autonomic nervous system (ANS), divided into its yin-yang, sympathetic and parasympathetic limbs. Heading up the ANS is the master regulator of bodily states, the hypothalamus. Through its extensive neural and hormonal connections, this remarkably small structure—really a collection of a dozen or more tiny nuclei—governs our growth, metabolism, reproductive physiology, appetite, thirst, temperature, wakefulness, and response to stress. But beyond the long-sought gender dimorphism in INAH-3 described above, and some differences in the levels of neurochemical and hormonal receptor expression (e.g., Hrabovszky et al. 2010), few other significant gender differences have been identified thus far in the human hypothalamus, and none of the known gender differences in the hypothalamus has been proven to relate to behavioral differences between boys and girls, or even adult men and women.

Nonetheless, in an article for teachers, Leonard Sax (2006, p. 191) claims that a recent "avalanche of studies" demonstrates "fundamental sex differences in the organization of the autonomic nervous system." This research, according to Sax, shows that females are governed more by the parasympathetic (rest and digest) limb of the ANS, whereas males are more influenced by the sympathetic (fight or flight) limb. His evidence for this claim lies entirely in studies of adults' cardiac responses to a simple physical stressor, such as dunking one's hand in ice-cold water (Shoemaker et al. 2001). These studies, which looked at measures like blood pressure, heart rate variability, constriction of peripheral blood vessels, and sympathetic nerve firing rate, did indeed find statistically significant differences between men and women in some measures that may be relevant to men's greater risk for heart attacks—the primary motivation of the research. However, none of the studies looked at children, nor do they automatically translate to mental stressors, which other research finds to provoke similar responsiveness in men and women (Filaire et al. 2010). Nonetheless, Sax (2006, p. 192) easily makes the leap from adult cardiovascular research to children in a classroom, stating that it shows:

> When most young boys are exposed to threat and confrontation, their senses sharpen, and they feel a thrill. When most young girls are exposed to such stimuli, however, they feel dizzy and "yucky." They may have unaccustomed trouble expressing themselves with just the right words.

On the same page, Sax goes so far as to chart this in a dichotomous table, with separate columns for girls and boys, who allegedly activate different limbs of the ANS, release different neurotransmitters, and respond in diametrically opposite ways: freezing and mental slowing for girls ("I felt paralyzed," as Sax interprets girls' reaction) versus arousal and sharpened senses ("I've never felt so alive!") for boys.

According to this line of reasoning, the only solution for girls' purported intimidation is to segregate the genders into different classrooms where Sax (2006, pp. 192–193) informs us that "best practice" for teachers of boys is to: "speak loudly and in short, direct sentences with clear instructions: 'Put down your papers. Open your books. Let's get to work! Mr. Jefferson, that includes you.'" In contrast, teachers of girls are advised to "speak much more softly, using more first names with more terms of endearment and fewer direct commands: 'Lisa, sweetie, it's time to open your book. Emily, darling, would you please sit down for me and join us for this exercise?'"(Sax 2006, p. 195).

Considering the dramatic advances girls have made in recent decades in athletic and academic competitions, such recommendations sound archaic. Nor do they mesh with actual measures of stress responses in boys and girls. According to a review by Jessop and Turner-Cobb (2008), most studies have found no significant gender difference in children's levels of the stress hormone, cortisol, at least before puberty. Other evidence for gender similarity in children's stress response comes from a recent study of α-amylase secretion in 6–10 year old children; this salivary enzyme, whose release is triggered by the central sympathetic nervous system, was comparably elevated in boys and girls during a standard test of social stress (Strahler et al. 2010). Similarly, the balance of sympathetic and parasympathetic control of heart rate variability did not differ between boys and girls at 8 to 14 years of age, in contrast to the findings in adults, according to a recent Japanese study (Fukuba et al. 2009).

In fact, a more reliable gender difference in children's ANS activity is found in newborn babies, where lower stress tolerance is more commonly exhibited in *boys.* Premature and young full-term male infants are fussier and more irritable than female infants, on average (Boatella-Costa et al. 2007; Haviland and Malatesta 1981), a difference that is thought to reflect their greater immaturity and is associated with higher levels of stress-induced cortisol release in boys during the newborn period (Davis and Emory 1995).

So although adult men and women may exhibit a somewhat different balance of sympathetic and parasympathetic activity in response to physical stressors, there is no evidence that this difference exists between prepubertal boys and girls and, if anything, it appears that infant boys are less tolerant of stress than infant girls.

Nonetheless, Leonard Sax perseveres, extrapolating from another line of research—this time on rats—to further his argument that boys and girls respond differently to classroom stress. In *Why Gender Matters,* Sax (2005b, p. 89) explains how one middle-school student, Sam, suddenly stepped up his academic game thanks to his frustrated teacher finally yelling at him in class in front of other students. However, Sax continues, "that kind of confrontational, in-your-face approach would be precisely the *wrong* approach to use with most girls." As evidence for the notion that boys learn better under stress, whereas girls learn more poorly, he cites research by Rutgers University psychologists Gwendolyn Wood and Tracey Shors (1998), which he described this way on an earlier version of his website (NASSPE 2004): "Professor Shors has demonstrated that violent stress—such as delivering electrical shocks to an animal—improves the learning curve of a male animal, while it impairs the learning of a female animal."

Shors' research focuses on classical conditioning of the eyeblink reflex, a standard motor learning procedure involving several hundred pairings of a brief auditory tone followed by a shock to the eyelid that triggers a blink. With repeated pairings, animals begin blinking to the tone alone (even before the lid shock), demonstrating associative learning. This research shows that male and female rats do indeed respond differently to stress, which in these experiments involved being isolated and restrained in a plexiglass tube and receiving 30 shocks to the tail over the course of 30 min. Surprisingly, this experience enhances eyeblink conditioning 24 hr later in males, but suppresses it in females (Wood and Shors 1998). Shors and colleagues have further explored this difference at the level of dendritic spines (Shors et al. 2001), providing a fascinating cellular model of sex differences in motor learning in a non-human species.

However, this research also reveals enormous complexity in the interaction between stress and learning at different life stages (Shors 2006). For one thing, the contrasting effect of stress on males and females is not found in young and adolescent rats. According to Georgia Hodes and Shors (2005), the same stressful experience had no effect on classical conditioning in either male or female rats during the prepubescent and pubescent period, leading them to conclude that this sex difference emerges only in adulthood. In other words, forget the loud confrontational teacher in middle and high school; he or she will have to wait until college to scare the men into learning. Other research by Shors' group found that the sex difference is absent in aged male and female rats, and that postpartum rat mothers are immune to the effect of stress on learning.

To be fair, one study in human adults has found something similar to the effect Wood and Shors (1998) described in rats. In this study (Jackson et al. 2006), men and women were put through a stressful experience (public speaking) and then an hour later underwent fear conditioning, in which the picture of a face was repeatedly paired with a piercing female scream. Like male rats, the men exhibited greater conditioning of their fear response (measured using skin conductance), whereas women actually exhibited less conditioned fear following the stressful public speaking. But think about what this actually means (if it even applied to children): the loud, confrontational teacher may indeed have a bigger effect on boys than girls, namely, training them to be more fearful in the classroom!

Indeed, other forms of learning change in exactly the opposite way in stressed male and female rats. According to research by Victoria Luine and colleagues, 21 days of chronic stress (being restrained, but not shocked, for 6 hr per day) impaired learning on several spatial tasks (like navigating a familiar maze) in *males*; however, the same restraint stress improved spatial learning in female rats (Luine et al. 2007).

Of the two forms of learning, eyeblink conditioning versus spatial navigation, it seems a stretch to claim that the former is more relevant to children's academic learning. The point is, one simply cannot extrapolate from rat learning to humans in this context. Particularly with regard to sex differences, rats are in many ways the reverse of our species. Notably, females are the more active, less anxious sex in rats (Fernandes et al. 1999), which is the opposite of humans. So the idea that we can use research on rat stress to explore gender differences in children's learning is not supportable.

The last piece of Leonard Sax's ANS theory relates to the catchy title of the article he proposes it in (Sax 2006): "Six degrees of separation." The title does not refer to social connectedness, but to a literal gender difference in temperature sensitivity, another function of the autonomic nervous system. In a challenge to Michael Gurian et al. (2001), who had initially argued that teachers could accommodate boy-girl differences in coed classrooms, Sax (2006, p. 194) writes that Gurian is "simply not aware of new research showing, for example, that the ambient room temperature for learning differs for girls and boys."

The single paper Sax cites to support this claim is, again, a study of adults, and far from new, it is some 30 years old. In this study, Mohamed Beshir and Jerry Ramsey (1981) asked 31 men (aged 18 to 40 years old) and 15 women (aged 18 to 24 years old) to rate their subjective level of attention and comfort at various indoor temperatures. Both males and females responded with an inverted U-shaped function—more subjective discomfort at very cool or warm temperatures, with women reporting both greater "boredom" and "drowsiness" at all temperatures ranging from 74°F to 110°F. Nonetheless, Sax picks out a single number, 5.5°F, extrapolated from two nearly identical curves of subjective thermal sensation, as the key difference between men and women in temperature preference. He makes no mention of the three other studies Beshir and Ramsey (1981) compared their results to—two finding smaller preferred temperature differences between men and women, and one study finding that females actually preferred the cooler room. Instead, Sax (2006, p. 194) takes this single, indirect measure, rounds it up to the magic 6°, and then extrapolates it to children to confidently assert that "the ambient room temperature for learning differs for girls and boys." This difference is the real deal-breaker, as Sax sees it, when considering whether girls and boys can be educated together. As he continues in the same passage: "There is no way to implement that finding in a coed classroom. A classroom can either be 69°F or 75°F, but not both simultaneously."

Not only does this conclusion rest on a single number, picked out of a single study that is not representative of all adult studies, it ignores actual research on children. For instance, one recent German study (Blankenburg et al. 2010) tested 176 boys and girls from 6 to 16 years of age and found reliable differences between girls and boys in each of the following measures: cold detection threshold, warmth detection threshold, cold pain threshold, hot pain threshold, and thermal sensory limen (the minimal temperature change a subject can detect). For each of these measures, girls exhibited greater thermal sensitivity, but the difference at most ages is less than 1°C, or less than 2°F.

Of course, the greater extrapolation is assuming that such tests of thermal sensitivity have anything to do with learning. Considering the large number of schools that may be implementing Sax's recommendations verbatim—heating up the girls' classrooms, and cooling down the boys', you might think that such learning differences were well-proven. To my knowledge, however, there are no scientific data addressing children's classroom performance at different ambient temperatures. Moreover, men and women manage to work in the same offices, even though their temperature sensitivity—at least according to Sax's analysis—appears to be even more disparate than boys' and girls'. Finally, it should be noted that the bigger influence over thermal comfort is body mass index, which varies enormously within gender. If schools actually adhered to Sax's recommendations, the heavier girls would swelter, the skinnier boys would freeze, and it seems unlikely that any child would learn better than at a typical, energy-efficient indoor temperature for that climate. Or, for a more humorous take on Sax's temperature prescriptions, one New Orleans mother (Radfem 2008) blogged: "Are you trying to teach girls home ec[onomics] by cooking them?"

Gonadal Hormones and Learning

Do gonadal hormones affect the way boys and girls think? To many single-sex school proponents, such as JoAnn Deak, the issue is already resolved. As she writes with co-author Teresa Barker (2002, p. 83): "the fact is fairly well established that estrogen has an enhancing effect on some areas of the left hemisphere of the brain, and testosterone has an enhancing effect on some areas of the right hemisphere of the brain." Other single-sex school advocates similarly assume without question that any behavioral differences between the genders are hormonal in origin. For example, David Chadwell (2010b, p. 24) simply asks teachers to rate their agreement with the sentence, "I think hormones play an important role in how boys and girls behave," when evaluating the need for single-sex instruction. So it is not a matter of scientific evidence, but personal opinion that establishes hormonal differences as a rationale for single-sex schooling.

Yet another hormone believer is Michael Gurian, who makes no attempt to look up real data when he and colleagues assert in *Boys and Girls Learn Differently!* (2001, p. 294):

> Girls have great difficulty in learning certain aspects of math, perhaps because they are not called on as much by teachers but also for some biological

> reasons. One involves testosterone: surges of the hormone, which males receive during adolescence between five and seven times a day, can increase spatial skills. Heightened presence of estrogen during the menstrual cycle increases female performance on all skills, including spatials [sic], but the female cycle is not as diurnal as the male. Thus the adolescent girl may have a few days a month when she performs very well on any sort of test, including math, but the male may have certain times *every day* when he might perform better at spatials [sic], such as higher math.

Note the lack of footnotes accompanying any of these strong claims. That is because none of these hormonal "facts" are backed up by actual science. Even the statement that testosterone is released in multiple surges in adolescent boys is inaccurate: rather, it is a pituitary substance, luteinizing hormone (LH), that is released in pulsatile fashion (in both genders), beginning at the onset of puberty. Although LH triggers the release of testosterone, its pulses get smoothed out so that there are just two broad peaks of testosterone release during the day–morning and night—in postpubertal men (Haynes and Pitteloud 2004). More importantly, the evidence linking testosterone to math, spatial skills, or any other cognitive ability is very weak. Nor are girls limited to a few days per month for optimal test-taking.

Here is what is known about the cognitive effects of gonadal hormones, which are released at two distinct phases of life. The first surge happens in the fetus, between 7 and 24 weeks past conception (Nagamani et al. 1979; Reyes et al. 1974), when males' testes secrete testosterone and other hormones. (The fetal ovary in females similarly secretes estrogens and progesterone, but these appear to play little role in brain sexual differentiation.) The second phase happens at puberty, when boys' and girls' gonads reawaken and start producing adult reproductive hormones in their daily (for males) or monthly (for females) cycles. There is also another brief phase of hormone production by both the testes and ovaries in newborn babies, but this neonatal surge settles down within a few months after birth. Consequently, there is no significant difference in levels of testosterone, estradiol, or progesterone between boys and girls for some 10 years, a period known as the juvenile pause, which ends at the onset of puberty (Grumbach 2002).

In other words, one cannot blame behavioral differences on circulating hormones in grade school-aged children, because there are no hormonal differences. Circulating levels of testosterone and estrogens are extremely low before puberty, often below the limit of chemical detection, and not significantly different between boys and girls (Elmlinger et al. 2002, 2005). The prenatal testosterone surge in boys is another matter. Here the evidence is clear that hormonal exposure biases certain later behaviors and interests (such as boys' higher level of physical activity, preference for rough-and-tumble play, and later sexual attraction to females). However, researchers have found scant evidence that prenatal testosterone influences cognitive skills, such as speaking, math, or learning in general, in spite of many attempts to identify such relationships (Hines 2007).

This stands to reason, since the purpose of gonadal hormones is reproduction, not academic learning. Accordingly, the receptors for estrogen and testosterone are expressed far more heavily in the limbic areas of the brain that subserve emotional and sexual behaviors, than in the cognitive areas that control perception and thinking skills (Pfaff and Keiner 1973).

Nonetheless, single-sex education proponents like Michael Gurian, JoAnn Deak and David Chadwell inform teachers that girls and boys are essentially handicapped by their hourly or monthly surges of gonadal hormones, necessitating different classrooms and forms of instruction. Such claims overlook substantial data showing that, even after puberty, gonadal hormone effects on verbal, spatial, and even mood differences between the genders are extremely weak. Several lines of research have set out to explore such influences, and taken together, they prove only the most modest influence, if any, of estrogen or testosterone on cognitive function.

First, we can dispense with the idea that women's cognition fluctuates meaningfully over the menstrual cycle. Although some studies (Hampson 1990; Hausmann et al. 2000; Maki et al. 2002) have reported differences in spatial ability or verbal fluency at low estrogen (menstruation) compared to high estrogen (ovulation or midluteal) phases of the cycle, other studies (Gordon and Lee 1993; Mordecai et al. 2008) have failed to replicate such effects—especially in young women (Epting and Overman 1998)—and the consensus is that any influence of ovarian hormones on women's cognition probably would not be detectable outside the laboratory (Halpern et al. 2004).

Then there are studies of postmenopausal women, whom hormone advocates (and pharmaceutical companies) had hoped would show cognitive benefits of estrogen/progesterone replacement therapy. Again, some studies looked very promising (reviewed in Sherwin 2003), but subsequent research, including the very large, NIH-sponsored Women's Health Initiative Memory Study (WHIMS), found either no benefit or, in the case of WHIMS, actually increased risk of dementia and cognitive decline with hormone replacement (Rapp et al. 2003; Shumaker et al. 2004).

Yet another line of research has measured cognitive function in transsexual individuals as they undergo hormonal manipulations for gender reassignment. In 1995, Dutch researchers (Van Goozen et al. 1995) reported that females who were changing into men did indeed improve at mental rotation (a spatial task) and declined in verbal fluency when they took an androgen blocker combined with estrogen therapy. However, a subsequent follow-up study by the same group (Slabbekoorn et al. 1999) failed to replicate the finding for verbal fluency, and two further studies failed to find any change in cognitive function following cross-sex hormone treatment in either male-to-female or female-to-male transsexuals (Miles et al. 2006; van Goozen et al. 2002).

Finally, the most relevant research in this context is a well-controlled study of adolescents by Lynn Liben et al. (2002). Boys and girls who were delayed in their onset of puberty were enrolled in a double-blind, placebo controlled trial of testosterone (for boys) or estrogen (for girls) treatment, during which a large number of psychological tests were conducted. Although this research did uncover a modest increase in sex drive in both boys and girls following hormone treatment (Finkelstein et al. 1998), there was no effect on cognitive skills such as mental rotation or verbal fluency, in either girls or boys.

Taken together, all of this evidence tells us that circulating gonadal hormones have little, if any, effect on human cognition. But such proof is unlikely to sway single-sex school advocates, who continue to use tidbits of hormonal research to justify gender segregation practices. The problem is that such hormonal misconceptions also reinforce teacher expectations and can create a self-fulfilling prophecy. Just such an effect of hormonal ideology was revealed in one recent study (Eisenegger et al. 2010) which found that women bargained less fairly when they were given a pill they believed was testosterone, but more fairly when they believed they were given a placebo—even though the real testosterone resulted in *fairer* bargaining compared to the placebo. In other words, our beliefs about hormones also hold sway over behavior—perhaps more powerful than the hormones themselves—an important finding for teachers to take note of.

Do Boys and Girls Learn Differently?

Ultimately, claims about hormones and brain structure are meant to support the singular tenet that "boys and girls learn differently" (Gurian et al. 2001; Sax 2005b; James 2007, 2009; Kaufmann 2007). Once you adopt this view—now apparently an article of faith among many educators—then the inescapable conclusion is that boys and girls should also be educated differently. Current law does not permit the curricula or resources to differ between all-boys and all-girls' classes in public schools, but the idea that each gender needs different incentives, physical environments, and pedagogical methods has become quite popular with many parents and teachers, so it is worth examining the evidence for gender differences in children's learning styles.

Learning is defined as the process of acquiring information about the world. There is no doubt that boys and girls differ in certain of their interests, which will shape how they resonate with different academic subjects. But education is not about what children already know and enjoy; it is about introducing them to new areas of knowledge and thinking skills. The challenge is to motivate *all* children to study and learn about topics like military history or Renaissance art, whether or not they like to play shooting games or paint pictures after school.

The good news is that there already exist many studies comparing boys' and girls' learning ability. In their exhaustive review of the literature, Maccoby and Jacklin (1974) found no difference between boys and girls in various laboratory tests of learning, including paired associates learning, discrimination learning, complex problem solving, and strategies for memorizing. Granted, their review is now some 37 years old, but the data do include many dozens of studies of subjects ranging in age from infancy through the end of adolescence—a feat of scholarship that has not thus far been repeated. Moreover, recent research, particularly on infants, supports the notion that boys and girls learn and process information in very similar ways from birth (Spelke 2005; Carolyn Rovee-Collier, personal communication, January 29, 2008).

When it comes to the brain, studies of human academic learning are still rare, but one skill has been explored by neuroscientists more than others: the development of reading. There is very little difference between the neural circuits men and women use to decode and interpret written text, with gender accounting for a mere 2% of the variation in cerebral asymmetry associated with reading (Chiarello et al. 2009). Similarly in children, some fMRI studies of reading find no gender differences in neural activation during reading tasks (e.g., Wood et al. 2004), and other studies that have found neural gender differences have been unable to link them to actual differences in reading ability between boys and girls (Bitan et al. 2010; Molfese et al. 2006). Where differences are found, they are generally consistent with somewhat earlier maturation of reading circuits in girls (Burman et al. 2008; Plante et al. 2006). However, as Elena Plante et al. (2006, p. 1220) concluded in their fMRI study of brain activation in children's reading: "the distributions for the two sexes in all tasks was characterized by considerable overlap, suggesting these [gender] differences may be of little practical importance."

In other words, even for the best-studied instance of learning—the acquisition of reading ability—neuroscientists have had great difficulty identifying meaningful differences between boys' and girls' neural processing. There are hints, in a handful of studies, that girls' reading circuits may mature a bit earlier, but the differences are modest and do not demonstrate any qualitative gap in the way male or female brains approach the task of recognizing, decoding and comprehending the written word.

Nonetheless, the belief in gender learning differences lives on, particularly among single-sex school advocates. If evidence cannot be found in studies of the brain, there remains a large popular literature on "learning styles" which has been readily co-opted by single-sex school proponents to argue for separate teaching to girls and boys.

In brief, the notion of learning styles proposes that individual learners come in distinct types, such as "visual," "auditory," or "kinesthetic," according to one popular scheme; other inventories characterize students as "active versus reflective," "deductive versus inductive," and "global versus detail-oriented," learners. In recent years, a massive industry has grown up, selling products from kindergarten to college to help teachers assess students' individual learning styles for the purpose of adapting their methods to students' individual needs (Paschler et al. 2009).

Although single-sex school advocates have not explicitly adopted any of the specific learning style inventories, their claims about boys' and girls' learning differences (Gurian et al. 2001) often pit the two genders at opposite ends of the various dichotomies—e.g., verbal (girls) versus visual (boys); active (boys) versus reflective (girls); abstract (boys) versus concrete (girls). Considering the widespread use of learning style inventories, it is interesting that few studies have systematically compared boys' and girls' self-described learning preferences. However, the topic has been addressed among college students, where meta-analysis finds (in contrast to common belief) almost no differences in learning styles between men and women (Severiens and Ten Dam 1994).

More important is that the very value of learning style assessment has come under serious question. Although it is clear that individuals characterize themselves differently on such surveys, it turns out that there is virtually no evidence that learning is more successful when teachers attempt to adjust their instruction to these specific styles. According to a recent review by Harold Paschler et al. (2009), empirical support for such a meshing hypothesis is largely lacking, and in some cases, actually contradicted by rigorous research. Regardless of individuals' preferences, some methods of instruction simply work better than others; what matters most is that the teaching method is optimized to the particular content (math, reading, science, etc.) being conveyed (Willingham 2005). Even within single-sex schools, so-called "gender-differentiated instruction" has little benefit (Younger and Warrington 2006). Good teaching looks the same regardless of the gender composition of the classroom (Tyre 2008, p. 224).

By all objective measures, then, the belief that "boys and girls learn differently" (Gurian et al. 2001; Sax 2005b; James 2007, 2009; Kaufmann 2007) is unfounded. The basic brain mechanisms of learning and memory do not differ between boys and girls, and controlled studies of actual learning processes have not identified any meaningful gender differences, from infancy through adulthood. Although boys and girls (or more precisely, men and women) tend towards different self-professed learning styles, there is no evidence that teaching specifically geared to such differences is actually beneficial.

In the final analysis, the only evidence that "boys and girls learn differently" (Gurian et al. 2001; Sax 2005b; James 2007, 2009; Kaufmann 2007) boils down to a tautology: they perform differently in school, therefore, they must learn differently. Girls do earn higher GPAs than boys and score consistently higher on standardized reading and writing assessments; boys outperform girls, though by a smaller margin, on standardized math tests (Corbett et al. 2008). But once again, group differences hide enormous diversity within demographic entities. The fact that girls earn an average .2 point higher on a 4.0 scale GPA also means that there are very many boys who "learn better" than the average girl (if we assume grades are a measure of learning) and vice versa.

Conclusion

Over the past decade, gender segregationists have been highly successful at distorting basic research findings to persuade parents and teachers that boys and girls are categorically different types of thinkers and learners (Chadwell 2010b; Deak and Barker 2002; Gurian et al. 2001; Sax 2005b). But the real science of gender difference does not come close to supporting such conclusions. Boys and girls do not see, hear, learn, remember, or respond to stress in meaningfully different ways. Nonetheless, the misleading presentation of isolated biological findings has fueled a growing belief in "hardwired" gender differences that can only be managed through fundamentally different, and segregated, educational methods.

Beyond their misuse in promoting single-sex education, these pseudo-biological claims about boy-girl differences are dangerous in other ways. First, such beliefs promote gender stereotyping, as we are starting to hear in the many news reports about new single-gender classrooms: girls are now being sheltered from competition and bright lights; boys learn their math facts using gimmicky stress balls and relay races; and the selection of literature is guided more by gender of the protagonist than by the quality of the writing. The more parents and teachers hear that boys and girls are innately, immutably different, the likelier they are to anticipate each gender living up to type. Boys cannot be expected to enjoy books or engage much in conversation; girls will never find physics or chemistry as interesting as "people-oriented" subjects. The natural tendency to teach to students' perceived strengths will mean further neglect of their weaker areas, inflating small academic gaps into much larger ones. Worst of all is the effect of such essentialist views on children's own self-perceptions. What happens when boys and girls hear they must be educated separately because their brains are fundamentally different? Or that they cannot learn math in the same way? Or that one gender is "hardwired" to be interested in objects, whereas the other is naturally more interested in people?

The irony is that if neuroscience has taught us anything about learning, it is that children's brains are far from "hardwired," but massively more malleable than at any later time of life. Neuroplasticity, defined as the structural and functional modification of the brain, is the basis of all learning, academic or otherwise: everyday experience generates the neural activity that selects and strengths certain synapses at the expense of others, adapting each child's brain to the academic, social and leisure tasks at hand. In one intervention, children who were taught about neuroplasticity and coached in the belief that they can get smarter through hard work, scored higher on state achievement tests than a matched control group of students (Good et al. 2003). Rather than segregating children in the name of "hardwired" abilities and learning styles, schools should be doing the opposite: instilling in children the faith in their own malleability and promoting their self-efficacy as learners, regardless of gender, race or other demographic characteristics.

Acknowledgements I am grateful to Peggy Signorella, Diane Halpern, Mark Liberman, and two anonymous reviewers for their helpful comments on the manuscript.

References

Adolphs, R., & Spezio, M. (2006). Role of the amygdala in processing visual social stimuli. *Progress in Brain Research, 156*, 363–378. doi:10.1016/S0079-6123(06)56020-0.

Alexander, G. M. (2003). An evolutionary perspective of sex-typed toy preferences: pink, blue, and the brain. *Archives of Sexual Behavior, 32*, 7–14. doi:10.1023/A:1021833110722.

Archer, J. (2004). Sex differences in aggression in real-world settings: A meta-analytic review. *Review of General Psychology, 8*, 291–322. doi:10.1037/1089-2680.8.4.291.

Begley, S. (1995). Gray matters. *Newsweek*. Retrieved from http://www.newsweek.com.

Bell, A. D., & Variend, S. (1985). Failure to demonstrate sexual dimorphism of the corpus callosum in childhood. *Journal of Anatomy, 143*, 143–147.

Benetti, S., McCrory, E., Arulanantham, S., De Sanctis, T., McGuire, P., & Mechelli, A. (2010). Attachment style, affective loss and gray matter volume: A voxel-based morphometry study. *Human Brain Mapping, 31*, 1482–1489. doi:10.1002/hbm.20954.

Berninger, E. (2007). Characteristics of normal newborn transient-evoked otoacoustic emissions: Ear asymmetries and sex effects. *International Journal of Audiology, 46*, 661–669. doi:10.1080/14992020701438797.

Beshir, M. Y., & Ramsey, J. D. (1981). Comparison between male and female subjective estimates of thermal effects and sensations. *Applied Ergonomics, 12*, 29–33. doi:10.1037/0735-7044.112.6.1304.

Bishop, K. M., & Wahlsten, D. (1997). Sex differences in the human corpus callosum: Myth or reality? *Neuroscience and Biobehavioral Reviews, 21*, 581–601. doi:10.1016/S0149-7634(96)00049-8.

Bitan, T., Lifshitz, A., Breznitz, Z., & Booth, J. R. (2010). Bidirectional connectivity between hemispheres occurs at multiple levels in language processing but depends on sex. *Journal of Neuroscience, 30*, 11576–11585. doi:10.1523/JNEUROSCI.1245-10.2010.

Blair, R. J. (2010). Neuroimaging of psychopathy and antisocial behavior: A targeted review. *Current Psychiatry Reports, 12*, 76–82. doi:10.1007/s11920-009-0086-x.

Blankenburg, M., Boekens, H., Hechler, T., Maier, C., Krumova, E., Scherens, A., … Zernikow, B. (2010). Reference values for quantitative sensory testing in children and adolescents: developmental and gender differences of somatosensory perception. *Pain, 149*, 76–88. doi:10.1016/j.pain.2010.01.011.

Boardingschoolsforgirls.com. (n.d.). Studies of male and female brains show differences in structure, function Retrieved from http://www.boardingschoolsforgirls.com/study-summary-brain-differences.html.

Boatella-Costa, E., Costas-Moragas, C., Botet-Mussons, F., Fornieles-Deu, A., & De Caceres-Zurita, M. L. (2007). Behavioral gender differences in the neonatal period according to the Brazelton scale. *Early Human Development, 83*, 91–97. doi:10.1016/j.earlhumdev.2006.05.006.

Bornstein, M. H., Hahn, C.-S., & Haynes, O. M. (2004). Specific and general language performance across early childhood: Stability and gender considerations. *First Language, 24*, 267–304. doi:10.1177/0142723704045681.

Brierley, B., Shaw, P., & David, A. S. (2002). The human amygdala: A systematic review and meta-analysis of volumetric magnetic resonance imaging. *Brain Research Reviews, 39*, 84–105. doi:10.1016/S0165-0173(02)00160-1.

Buchanan, T. W. (2007). Retrieval of emotional memories. *Psychological Bulletin, 133*, 761–779. doi:10.1037/0033-2909.133.5.761.

Burman, D. D., Bitan, T., & Booth, J. R. (2008). Sex differences in neural processing of language among children. *Neuropsychologia, 46*(5), 1349–1362. doi:10.1016/j.neuropsychologia.2007.12.021.

Byne, W., Tobet, S., Mattiace, L. A., Lasco, M. S., Kemether, E., Edgar, M. A., … Jones, L. B. (2001). The interstitial nuclei of the human anterior hypothalamus: an investigation of variation with sex, sexual orientation, and HIV status. *Hormones and Behavior, 40*, 86–92. doi:10.1006/hbeh.2001.1680.

Cahill, L. (2006). Why sex matters for neuroscience. *Nature Reviews Neuroscience, 7*, 477–484. doi:10.1038/nrn190.

Chadwell, D. W. (2010a). Gender differences in how boys and girls "process" the world. Retrieved from http://www.chadwellconsulting.com/GD%20Processing.htm.

Chadwell, D. W. (2010b). *A gendered choice: Designing and implementing single-sex programs and schools*. Thousand Oaks: Corwin.

Chiarello, C., Welcome, S. E., Halderman, L. K., Towler, S., Julagay, J., Otto, R., et al. (2009). A large-scale investigation of lateralization in cortical anatomy and word reading: Are there sex differences? *Neuropsychology, 23*, 210–222. doi:10.1037/a0014265.

Clarke, S., Kraftsik, R., Van der Loos, H., & Innocenti, G. M. (1989). Forms and measures of adult and developing human corpus callosum: Is there sexual dimorphism? *The Journal of Comparative Neurology, 280*, 213–230. doi:10.1002/cne.902800205.

Clarke, A. R., Barry, R. J., McCarthy, R., & Selikowitz, M. (2001). Age and sex effects in the EEG: Development of the normal child. *Clinical Neurophysiology, 112*, 806–814. doi:10.1016/S1388-2457(01)00488-6.

Coley, R. J. (2001). *Differences in the gender gap: Comparisons across racial/ethnic groups in education and work*. Princeton: Research Division, Policy Information Center, Educational Testing Service.

Corbett, C., Hill, C., & St. Rose, A. (2008). *Where the girls are: The facts about gender equity in education*. Washington, DC: AAUW Educational Foundation.

Corso, J. (1959). Age and sex differences in pure-tone thresholds. *Journal of the Acoustical Society of America, 31*, 498–507. doi:10.1121/1.1907742.

Cosgrove, K. P., Mazure, C. M., & Staley, J. K. (2007). Evolving knowledge of sex differences in brain structure, function, and chemistry. *Biological Psychiatry, 62*, 847–855. doi:10.1016/j.biopsych.2007.03.001.

Davis, M., & Emory, E. (1995). Sex differences in neonatal stress reactivity. *Child Development, 66*, 14–27. doi:10.1111/j.1467-8624.1995.tb00852.x.

De Vries, G. J. (2004). Minireview: Sex differences in adult and developing brains: compensation, compensation, compensation. *Endocrinology, 145*, 1063–1068. doi:10.1210/en.2003-1504.

Deak, J. M., & Barker, T. (2002). *Girls will be girls: Raising confident and courageous daughters*. New York: Hyperion.

DeLacoste-Utamsing, C., & Holloway, R. L. (1982). Sexual dimorphism in the human corpus callosum. *Science, 216*, 1431–1432. doi:10.1126/science.7089533.

Eisenegger, C., Naef, M., Snozzi, R., Heinrichs, M., & Fehr, E. (2010). Prejudice and truth about the effect of testosterone on human bargaining behaviour. *Nature, 463*, 356–359. doi:10.1038/nature08711.

Eldredge, L., & Salamy, A. (1996). Functional auditory development in preterm and full term infants. *Early Human Development, 45*, 215–228. doi:10.1016/0378-3782(96)01732-X.

Eliot, L. (2009). *Pink brain, blue brain: How small differences grow into troublesome gaps—and what we can do about it*. Boston: Houghton Mifflin Harcourt.

Elmlinger, M. W., Kuhnel, W., & Ranke, M. B. (2002). Reference ranges for serum concentrations of lutropin (LH), follitropin (FSH), estradiol (E2), prolactin, progesterone, sex hormone-binding globulin (SHBG), dehydroepiandrosterone sulfate (DHEAS), cortisol and ferritin in neonates, children and young adults. *Clinical Chemistry and Laboratory Medicine, 40*, 1151–1160. doi:10.1515/CCLM.2002.202.

Elmlinger, M. W., Kuhnel, W., Wormstall, H., & Doller, P. C. (2005). Reference intervals for testosterone, androstenedione and SHBG levels in healthy females and males from birth until old age. *Clinical Laboratory, 51*, 625–632.

Epting, L. K., & Overman, W. H. (1998). Sex-sensitive tasks in men and women: A search for performance fluctuations across the menstrual cycle. *Behavioral Neuroscience, 112*, 1304–1317. doi:10.1037/0735-7044.112.6.1304.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, Vol. 59(5, Serial No. 242).

Fernandes, C., Gonzalez, M. I., Wilson, C. A., & File, S. E. (1999). Factor analysis shows that female rat behaviour is characterized primarily by activity, male rats are driven by sex and anxiety. *Pharmacology Biochemistry and Behavior, 64*, 731–738. doi:10.1016/S0091-3057(99)00139-2.

Fields, R. D. (2008). White matter in learning, cognition and psychiatric disorders. *Trends in Neuroscience, 31*, 361–370. doi:10.1016/j.tins.2008.04.001.

Filaire, E., Portier, H., Massart, A., Ramat, L., & Teixeira, A. (2010). Effect of lecturing to 200 students on heart rate variability and alpha-amylase activity. *European Journal of Applied Physiology, 108*, 1035–1043. doi:10.1007/s00421-009-1310-4.

Fine, C. (2010). *Delusions of gender: How our minds, society, and neurosexism create difference*. New York: W.W.Norton.

Finkelstein, J. W., Susman, E. J., Chinchilli, V. M., D'Arcangelo, M. R., Kunselman, S. J., Schwab, J., … Kulin, H. E. (1998). Effects of estrogen or testosterone on self-reported sexual responses and behaviors in hypogonadal adolescents. *Journal of Clinical Endocrinology and Metabolism, 83*, 2281–2285. doi:10.1210/jc.83.7.2281.

Frassanito, P., & Pettorini, B. (2008). Pink and blue: The color of gender. *Child's Nervous System, 24*, 881–882. doi:10.1007/s00381-007-0559-3.

Freeman, C. E. (2004). *Trends in educational equity of girls & women: 2004*. Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Frost, J. A., Binder, J. R., Springer, J. A., Hammeke, T. A., Bellgowan, P. S., Rao, S. M., et al. (1999). Language processing is strongly left lateralized in both sexes. Evidence from functional MRI. *Brain, 122*, 199–208. doi:10.1093/brain/122.2.199.

Fukuba, Y., Sato, H., Sakiyama, T., Endo, M. Y., Yamada, M., Ueoka, H., … Koga, S. (2009). Autonomic nervous activities accessed by heart rate variability in pre- and post-adolescent Japanese. *Journal of Physical Anthropology, 28*, 269–273. doi:10.2114/jpa2.28.269

Garcia-Falgueras, A., & Swaab, D. F. (2008). A sex difference in the hypothalamic uncinate nucleus: Relationship to gender identity. *Brain, 131*, 3132–3146. doi:10.1093/brain/awn276.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Rajapakse, J. C., Vaituzis, A. C., Liu, H., … Castellanos, F. X. (1999). Development of the human corpus callosum during childhood and adolescence: A longitudinal MRI study. *Progress in Neuropsychopharmacology & Biological Psychiatry, 23*, 571–588. doi:10.1016/S0278-5846(99)00017-2.

Girlslearndifferently.com (n.d.) Girls' learning styles. Retrieved from www.girlslearndifferently.com.

Gobbini, M. I., & Haxby, J. V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia, 45*, 32–41. doi:10.1016/j.neuropsychologia.2006.04.015.

Golombok, S., & Rust, J. (1993). The pre-school activities inventory: A standardized assessment of gender role in children. *Psychological Assessment, 5*, 131–136. doi:10.1037/1040-3590.5.2.131.

Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology, 24*, 645–662. doi:10.1016/j.appdev.2003.09.002.

Gordon, H. W., & Lee, P. A. (1993). No difference in cognitive performance between phases of the menstrual cycle. *Psychoneuroendocrinology, 18*, 521–531. doi:10.1016/0306-4530(93)90045-M.

Gorski, R. A., Gordon, J. H., Shryne, J. E., & Southam, A. M. (1978). Evidence for a morphological sex difference within the medial preoptic area of the rat brain. *Brain Research, 148*, 333–346. doi:10.1016/0006-8993(78)90723-0.

Goswami, U. (2006). Neuroscience and education: From research to practice? *Nature Reviews Neuroscience, 7*, 406–413. doi:10.1038/nrn1907.

GreatSchools. (n.d.). Are boys and girls wired to learn differently? Retrieved from http://www.greatschools.org.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Develoment, 58*, 539–559. doi:10.1111/1467-8624.ep7264422.

Gron, G., Wunderlich, A. P., Spitzer, M., Tomczak, R., & Riepe, M. W. (2000). Brain activation during human navigation: Gender-different neural networks as substrate of performance. *Nature Neuroscience, 3*, 404–408. doi:10.1038/73980.

Grumbach, M. M. (2002). The neuroendocrinology of human puberty revisited. *Hormone Research, 57*(Suppl 2), 2–14. doi:10.1159/000058094.

Grumbach, M. M., & Auchus, R. J. (1999). Estrogen: Consequences and implications of human mutations in synthesis and action. *Journal of Clinical Endocrinology and Metabolism, 84*, 4677–4694. doi:10.1210/jc.84.12.4677.

Gupta, R., Koscik, T. R., Bechara, A., & Tranel, D. (2010). The amygdala and decision-making. *Neuropsychologia, 49*, 760–766. doi:10.1016/j.neuropsychologia.2010.09.029.

Gurian, M., & Stevens, K. (2004). With boys and girls in mind. *Educational Leadership, 62*, 21–26.

Gurian, M., Henley, P., & Trueman, T. (2001). *Boys and girls learn differently: A guide for teachers and parents*. San Francisco: Jossey-Bass.

Gwiazda, J., Bauer, J., & Held, R. (1989). Binocular function in human infants: Correlation of stereoptic and fusion-rivalry discriminations. *Journal of Pediatric Ophthalmology and Strabismus, 26*, 128–132.

Halpern, D. F., Wai, J., & Saw, A. (2004). A psychobiosocial model: Why females are sometimes greater than and sometimes less than males in male achievement. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics: An integrative psychological approach* (pp. 48–72). Cambridge: Cambridge University Press.

Hampson, E. (1990). Variations in sex-related cognitive abilities across the menstrual cycle. *Brain & Cogniton, 14*, 26–43. doi:10.1016/0278-2626(90)90058-V.

Hanlon, H. W., Thatcher, R. W., & Cline, M. J. (1999). Gender differences in the development of EEG coherence in normal children. *Developmental Neuropsychology, 16*, 479–506. doi:10.1207/S15326942DN1603_27.

Hausmann, M., Slabbekoorn, D., Van Goozen, S. H., Cohen-Kettenis, P. T., & Gunturkun, O. (2000). Sex hormones affect spatial abilities during the menstrual cycle. *Behavioral Neuroscience, 114*, 1245–1250. doi:10.1037/0735-7044.114.6.1245.

Haviland, J. J., & Malatesta, C. Z. (1981). The development of sex differences in nonverbal signals: Fallacies, fact, and fantasies. In C. Mayo & N. Henley (Eds.), *Gender and nonverbal behavior* (pp. 183–208). New York: Springer.

Haynes, F. J., & Pitteloud, N. (2004). Hypogonadotropic hypogonadism (HH) and gonadotropin therapy. In B. Carr, G. P. Chrousos, L. J. De Groot, I. Goldfine, A. Grossman, J., Hershman, R. McLauchlan, M. I. New, R. Rebar, R. Rushakoff, F. Singer, D. Trence, M. Tschoep & A. Vinik (Eds.), *Endotext.org* (chapter 5).

Hines, M. (2007). Do sex differences in cognition cause the shortage of women in science? In S. J. Ceci & W. M. Williams (Eds.), *Why aren't more women in science?* (pp. 101–112). Washington, DC: American Psychological Association.

Hodes, G. E., & Shors, T. J. (2005). Distinctive stress effects on learning during puberty. *Hormones and Behavior, 48*, 163–171. doi:10.1016/j.yhbeh.2005.02.008.

Horvath, T. L., & Wikler, K. C. (1999). Aromatase in developing sensory systems of the rat brain. *Journal of Neuroendocrinology, 11*, 77–84. doi:10.1046/j.1365-2826.1999.00285.x.

Hrabovszky, E., Ciofi, P., Vida, B., Horvath, M. C., Keller, E., Caraty, A., … Kallo, I. (2010). The kisspeptin system of the human hypothalamus: sexual dimorphism and relationship with gonadotropin-releasing hormone and neurokinin B neurons. *European Journal of Neuroscience, 31*, 1984–1998. doi:10.1111/j.1460-9568.2010.07239.x.

Huynh, S. C., Wang, X. Y., Rochtchina, E., & Mitchell, P. (2006). Distribution of macular thickness by optical coherence tomography: Findings from a population-based study of 6-year-old children. *Investigative Ophthalmology & Visual Science, 47*, 2351–2357. doi:10.1167/iovs.05-1396.

Hyde, J. S. (2005). The gender similarities hypothesis. *American Psychologist, 60*, 581–592. doi:10.1037/0003-066X.60.6.581.

Hyde, J. S., & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bulletin, 104*, 53–69. doi:10.1037/0033-2909.104.1.53.

Hyde, J. S., Fennema, E., & Lamon, S. J. (1990). Gender differences in mathematics performance: A meta-analysis. *Psychological Bulletin, 107*, 139–155. doi:10.1037/0033-2909.107.2.139.

Jackson, E. D., Payne, J. D., Nadel, L., & Jacobs, W. J. (2006). Stress differentially modulates fear conditioning in healthy men and women. *Biological Psychiatry, 59*, 516–522. doi:10.1016/j.biopsych.2005.08.002.

James, A. N. (2007). *Teaching the male brain: How boys think, feel, and learn in school*. Thousand Oaks: Corwin.

James, A. N. (2009). *Teaching the female brain: How girls learn science and math*. Thousand Oaks: Corwin.

Jessop, D. S., & Turner-Cobb, J. M. (2008). Measurement and meaning of salivary cortisol: A focus on health and disease in children. *Stress, 11*, 1–14. doi:10.1080/10253890701365527.

Jordan-Young, R. M. (2010). *Brain storm: The flaws in the science of sex differences*. Cambridge: Harvard University Press.

Kaiser, A., Kuenzli, E., Zappatore, D., & Nitsch, C. (2007). On females' lateral and males' bilateral activation during language production: A fMRI study. *International Journal of Psychophysiology, 63*, 192–198. doi:10.1016/j.ijpsycho.2006.03.008.

Kansaku, K., Yamaura, A., & Kitazawa, S. (2000). Sex differences in lateralization revealed in the posterior language areas. *Cerebral Cortex, 10*, 866–872. doi:10.1093/cercor/10.9.866.

Kaufmann, C. (2007). How boys and girls learn differently. *Reader'sDigest.com*. Retrieved from http://www.rd.com.

Kling, K. C., Hyde, J. S., Showers, C. J., & Buswell, B. N. (1999). Gender differences in self-esteem: A meta-analysis. *Psychological Bulletin, 125*, 470–500. doi:10.1037/0033-2909.125.4.470.

Kolata, G. (1995). Men and women use brain differently, study discovers. *The New York Times*. Retrieved from http://www.nytimes.com.

Koshi, R., Koshi, T., Jeyaseelan, L., & Vettivel, S. (1997). Morphology of the corpus callosum in human fetuses. *Clinical Anatomy, 10*, 22–26. doi:10.1002/(SICI)1098-2353(1997)10:1<22::AID-CA4>3.0.CO;2-V.

Kucian, K., von Aster, M., Loenneker, T., Dietrich, T., & Martin, E. (2008). Development of neural networks for exact and approximate calculation: A FMRI study. *Developmental Neuropsychology, 33*, 447–473. doi:10.1080/87565640802101474.

Kuhens, O. (2009). Measuring gender's role in learning, *Knoxville News Sentinel*. Retrieved from http://m.knoxnews.com.

Lenroot, R. K., Gogtay, N., Greenstein, D. K, Wells, E.M. Wallace, G. L., Clasen, L. S., … Giedd, J. N. (2007) Sexual dimorphism of brain developmental trajectories during childhood and adolescence. *NeuroImage, 36*, 1065–1073. doi:10.1016/j.neuroimage.2007.03.053.

Leonard, C. M., Towler, S., Welcome, S., Halderman, L. K., Otto, R., Eckert, M. A., et al. (2008). Size matters: Cerebral volume influences sex differences in neuroanatomy. *Cerebral Cortex, 18*, 2920–2931. doi:10.1093/cercor/bhn052.

LeVay, S. (1991). A difference in hypothalamic structure between heterosexual and homosexual men. *Science, 253*, 1034–1037. doi:10.1126/science.1887219.

Liben, L. S., Susman, E. J., Finkelstein, J. W., Chinchilli, V. M., Kunselman, S., Schwab, J., … Kulin, H. E. (2002). The effects of sex steroids on spatial performance: a review and an experimental clinical investigation. *Developmental Psychology, 38*(2), 236–253. doi:10.1037/0012-1649.38.2.236.

Liberman, M. (2006). Neuroscience in the service of sexual stereotypes. *Language Log*. Retrieved from http://itre.cis.upenn.edu/~myl/languagelog/archives/003419.html.

Liberman, M. (2008a). Liberman on Sax on Liberman on Sax on hearing. *Language Log*. Retrieved from http://languagelog.ldc.upenn.edu/nll/?p=171.

Liberman, M. (2008b). Retinal sex and sexual rhetoric. *Language Log* Retrieved from http://languagelog.ldc.upenn.edu/nll/?p=174.

Liu, H., Stufflebeam, S. M., Sepulcre, J., Hedden, T., & Buckner, R. L. (2009). Evidence from intrinsic activity that asymmetry of the human brain is controlled by multiple factors. *Proceedings of the National Academy of Sciences, 106*, 20499–20503. doi:10.1073/pnas.0908073106.

Luders, E., & Toga, A. W. (2010). Sex differences in brain anatomy. *Progress in Brain Research, 186*, 3–12. doi:10.1016/B978-0-444-53630-3.00001-4.

Luine, V. N., Beck, K. D., Bowman, R. E., Frankfurt, M., & Maclusky, N. J. (2007). Chronic stress and neural function: Accounting for sex and age. *Journal of Neuroendocrinology, 19*, 743–751. doi:10.1111/j.1365-2826.2007.01594.x.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences*. Stanford: Stanford University Press.

Maki, P. M., Rich, J. B., & Rosenbaum, R. S. (2002). Implicit memory varies across the menstrual cycle: Estrogen effects in young women. *Neuropsychologia, 40*, 518–529. doi:10.1016/S0028-3932(01)00126-9.

Malcolm, C. A., McCulloch, D. L., & Shepherd, A. J. (2002). Pattern-reversal visual evoked potentials in infants: Gender differences during early visual maturation. *Developmental Medicine and Child Neurology, 44*, 345–351. doi:10.1111/j.1469-8749.2002.tb00822.x.

McCarthy, M. M., & Arnold, A. P. (2011). Reframing sexual differentiation of the brain. *Nature Reviews Neuroscience, 14*, 677–683. doi:10.1038/nn.2834.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology, 14*, 261–298. doi:10.1080/87565649809540712.

McFadden, D. (2008). What do sex, twins, spotted hyenas, ADHD, and sexual orientation have in common? *Perspectives on Psychological Science, 3*, 309–323. doi:10.1111/j.1745-6924.2008.00082.x.

McGowan, P. O., Sasaki, A., D'Alessio, A. C., Dymov, S., Labonte, B., Szyf, M., … Meaney, M. J. (2009). Epigenetic regulation of the glucocorticoid receptor in human brain associates with childhood abuse. *Nature Neuroscience*, *12*, 342–348. doi:10.1038/nn.2270.

Miles, C., Green, R., & Hines, M. (2006). Estrogen treatment effects on cognition, memory and mood in male-to-female transsexuals. *Hormones and Behavior, 50*, 708–717. doi:10.1016/j.yhbeh.2006.06.008.

Molfese, D. L., Key, A. F., Kelly, S., Cunningham, N., Terrell, S., Ferguson, M., … Bonebright, T. (2006). Below-average, average, and above-average readers engage different and similar brain regions while reading. *Journal of Learning Disabilities*, *39*, 352–363. doi:10.1177/00222194060390040801.

Mordecai, K. L., Rubin, L. H., & Maki, P. M. (2008). Effects of menstrual cycle phase and oral contraceptive use on verbal memory. *Hormones and Behavior, 54*, 286–293. doi:10.1016/j.yhbeh.2008.03.006.

Morlet, T., Lapillonne, A., Ferber, C., Duclaux, R., Sann, L., Putet, G., … Collet, L. (1995). Spontaneous otoacoustic emissions in preterm neonates: prevalence and gender effects. *Hearing Research*, *90*, 44–54. doi:10.1016/0378-5955(95)00144-4.

Nagamani, M., McDonough, P. G., Ellegood, J. O., & Mahesh, V. B. (1979). Maternal and amniotic fluid steroids throughout human pregnancy. *American Journal of Obstetrics and Gynecology, 134*, 674–680.

NASSPE. (2004). Brain differences. *National Association for Single-Sex Public Education.* Retrieved from http://www.genderdifferences.org/research-brain.htm.

NASSPE. (2006–11). Gender differences in the brain. *National Association for Single-Sex Public Education.*Retrieved from http://www.singlesexschools.org/research-brain.htm.

NASSPE. (2011). Schools. *National Association for Single-Sex Public Education.* Retrieved from http://www.singlesexschools.org/schools-schools.htm#29.

Ng, W. H., Chan, Y. L., Au, K. S., Yeung, K. W., Kwan, T. F., & To, C. Y. (2005). Morphometry of the corpus callosum in Chinese children: Relationship with gender and academic performance. *Pediatric Radiology, 35*, 565–571. doi:10.1007/s00247-004-1336-z.

Nunez, J. L., & Juraska, J. M. (1998). The size of the splenium of the rat corpus callosum: Influence of hormones, sex ratio, and neonatal cryoanesthesia. *Developmental Psychobiology, 33*, 295–303. doi:10.1002/(SICI)1098-2302(199812)33:4<295::AID-DEV1>3.0.CO;2-L.

OECD. (2009). Equally prepared for life? How 15-year-old boys and girls perform in school. *Organization for Economic Cooperation and Development.* Retrieved from http://www.sourceoecd.org/education/9789264063945.

Ohman, A. (2005). The role of the amygdala in human fear: Automatic detection of threat. *Psychoneuroendocrinology, 30*, 953–958. doi:10.1016/j.psyneuen.2005.03.019.

Paschler, H., McDaniel, M., Rohrer, D., & Bjork, R. (2009). Learning styles: Concepts and evidence. *Psychological Science in the Public Interest, 9*, 105–119. doi:10.1111/j.1539-6053.2009.01038.x.

Paus, T. (2010). Sex differences in the human brain: A developmental perspective. *Progress in Brain Research, 186*, 13–28. doi:10.1016/B978-0-444-53630-3.00002-6.

Peterzell, D. H., Werner, J. S., & Kaplan, P. S. (1995). Individual differences in contrast sensitivity functions: Longitudinal study of 4-, 6- and 8-month-old human infants. *Vision Research, 35*, 961–979. doi:10.1016/0042-6989(94)00117-5.

Pfaff, D., & Keiner, M. (1973). Atlas of estradiol-concentrating cells in the central nervous system of the female rat. *The Journal of Comparative Neurology, 151*, 121–158. doi:10.1002/cne.901510204.

Plante, E., Schmithorst, V. J., Holland, S. K., & Byars, A. W. (2006). Sex differences in the activation of language cortex during childhood. *Neuropsychologia, 44*, 1210–1221. doi:10.1016/j.neuropsychologia.2005.08.016.

Radfem, N. (2008). Memo to Sax and Gurian. Retrieved from http://nolaradfem.blogspot.com/2008/03/memo-to-sax-and-gurian.html.

Rapp, S. R., Espeland, M. A., Shumaker, S. A., Henderson, V. W., Brunner, R. L., Manson, J. E., … Bowen, D. (2003). Effect of estrogen plus progestin on global cognitive function in postmenopausal women: the Women's Health Initiative Memory Study: A randomized controlled trial. *JAMA, 289*, 2663–2672. doi:10.1001/jama.289.20.2663.

Reyes, F. I., Boroditsky, R. S., Winter, J. S., & Faiman, C. (1974). Studies on human sexual development. II. Fetal and maternal serum gonadotropin and sex steroid concentrations. *Journal of Clinical Endocrinology and Metabolism, 38*, 612–617. doi:10.1210/jcem-38-4-612.

Ribeiro, F. M., & Carvallo, R. M. (2008). Tone-evoked ABR in full-term and preterm neonates with normal hearing. *International Journal of Audiology, 47*, 21–29. doi:10.1080/14992020701643800.

Ripley, A. (2005). Who says a woman can't be Einstein? *Time Magazine*. Retrieved from http://www.time.com.

Rodriguez-Carmona, M., Sharpe, L. T., Harlow, J. A., & Barbur, J. L. (2008). Sex-related differences in chromatic sensitivity. *Visual Neuroscience, 25*, 433–440. doi:10.1017/S095252380808019X.

Salahu-Din, D., Persky, H., & Miller, J. (2008) *The Nation's Report Card: Writing 2007. National Assessment of Educational Progress at Grades 8 and 12.* (NCES 2008–468.) Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Salyer, D. L., Lund, T. D., Fleming, D. E., Lephart, E. D., & Horvath, T. L. (2001). Sexual dimorphism and aromatase in the rat retina. *Developmental Brain Research, 126*, 131–136. doi:10.1016/S0165-3806(00)00147-4.

Sangal, R. B., & Sangal, J. M. (1996). Topography of auditory and visual P300 in normal children. *Clinical Electroencephalography, 27*, 46–51.

Sarikouch, S., Peters, B., Gutberlet, M., Leismann, B., Kelter-Kloepping, A., Koerperich, H., … Beerbaum, P. (2010). Sex-specific pediatric percentiles for ventricular size and mass as reference values for cardiac MRI: assessment by steady-state free-precession and phase-contrast MRI flow. *Circulation: Cardiovascular Imaging*, *3*, 65–76. doi:10.1161/CIRCIMAGING.109.859074.

Sax, L. (2005a). The promise and peril of single sex public education. *Education Week*, pp. 48, 34, 35.

Sax, L. (2005b). *Why gender matters: What parents and teachers need to know about the emerging science of sex differences*. New York: Doubleday.

Sax, L. (2006). Six degrees of separation: What teachers need to know about the emerging science of sex differences. *Educational Horizons, 84*, 190–200.

Schmid, M., & Largo, R. H. (1986). Visual acuity and stereopsis between the ages of 5 and 10 years. A cross-sectional study. *European Journal of Pediatrics, 145*, 475–479. doi:10.1007/BF02429046.

Schmidt, I. M., Molgaard, C., Main, K. M., & Michaelsen, K. F. (2001). Effect of gender and lean body mass on kidney size in healthy 10-year-old children. *Pediatric Nephrology, 16*, 366–370. doi:10.1007/s004670100568.

Schrauf, M., Wist, E. R. & Ehrenstein, W. H. (1999). Development of dynamic vision based on motion contrast. *Experimental Brain Research, 124*, 469–473. doi:10.1007/s002210050642

Servin, A., Bohlin, G., & Berlin, L. (1999). Sex differences in 1-, 3-, and 5-year-olds' toy-choice in a structured play-session. *Scandinavian Journal of Psychology, 40*, 43–48. doi:10.1111/1467-9450.00096.

Severiens, S. E., & Ten Dam, G. T. M. (1994). Gender differences in learning styles: A narrative review and quantitative meta-analysis. *Higher Education, 27*, 487–501. doi:10.1007/BF01384906.

Shaywitz, B. A., Shaywitz, S. E., Pugh, K. R., Constable, R. T., Skudlarski, P., Fulbright, R. K., … et al. (1995). Sex differences in the functional organization of the brain for language. *Nature*, *373*, 607–609. doi:10.1038/373607a0.

Sherwin, B. B. (2003). Estrogen and cognitive functioning in women. *Endocrine Reviews, 24*, 133–151. doi:10.1210/er.2001-0016.

Shoemaker, J. K., Hogeman, C. S., Khan, M., Kimmerly, D. S., & Sinoway, L. I. (2001). Gender affects sympathetic and hemodynamic response to postural stress. *American Journal of Physiology. Heart and Circulatory Physiology, 281*, H2028–H2035.

Shors, T. J. (2006). Stressful experience and learning across the lifespan. *Annual Review of Psychology, 57*, 55–85. doi:10.1146/annurev.psych.57.102904.190205.

Shors, T. J., Chua, C., & Falduto, J. (2001). Sex differences and opposite effects of stress on dendritic spine density in the male versus female hippocampus. *Journal of Neuroscience, 21*, 6292–6297.

Shumaker, S. A., Legault, C., Kuller, L., Rapp, S. R., Thal, L., Lane, D. S., … Coker, L. H. (2004). Conjugated equine estrogens and incidence of probable dementia and mild cognitive impairment in postmenopausal women: Women's Health Initiative Memory Study. *JAMA*, *291*, 2947–2958. doi:10.1001/jama.291.24.2947.

Sininger, Y. S., Cone-Wesson, B., & Abdala, C. (1998). Gender distinctions and lateral asymmetry in the low-level auditory brainstem response of the human neonate. *Hearing Research, 126*, 58–66. doi:10.1016/S0378-5955(98)00152-X.

Slabbekoorn, D., van Goozen, S. H., Megens, J., Gooren, L. J., & Cohen-Kettenis, P. T. (1999). Activating effects of cross-sex hormones on cognitive functioning: A study of short-term and long-term hormone effects in transsexuals. *Psychoneuroendocrinology, 24*, 423–447. doi:10.1016/S0306-4530(98)00091-2.

Sommer, I. E., Aleman, A., Somers, M., Boks, M. P., & Kahn, R. S. (2008). Sex differences in handedness, asymmetry of the planum temporale and functional language lateralization. *Brain Research, 1206*, 76–88. doi:10.1016/j.brainres.2008.01.003.

Spelke, E. S. (2005). Sex differences in intrinsic aptitude for mathematics and science?: A critical review. *American Psychologist, 60*, 950–958. doi:10.1037/0003-066X.60.9.950.

Strahler, J., Mueller, A., Rosenloecher, F., Kirschbaum, C., & Rohleder, N. (2010). Salivary alpha-amylase stress reactivity across different age groups. *Psychophysiology, 47*, 587–595. doi:10.1111/j.1469-8986.2009.00957.x.

Strickland, E. A., Burns, E. M., & Tubis, A. (1985). Incidence of spontaneous otoacoustic emissions in children and infants. *Journal of the Acoustical Society of America, 78*, 931–935. doi:10.1121/1.392924.

Stuart, A., & Yang, E. Y. (2001). Gender effects in auditory brainstem responses to air- and bone-conducted clicks in neonates. *Journal of Communication Disorders, 34*, 229–239. doi:10.1016/S0021-9924(01)00048-X.

Thornton, A. R., Marotta, N., & Kennedy, C. R. (2003). The order of testing effect in otoacoustic emissions and its consequences for sex and ear differences in neonates. *Hearing Research, 184*, 123–130. doi:10.1016/S0378-5955(03)00234-X.

Trune, D. R., Mitchell, C., & Phillips, D. S. (1988). The relative importance of head size, gender and age on the auditory brainstem response. *Hearing Research, 32*, 165–174. doi:10.1016/0378-5955(88)90088-3.

Tyre, P. (2008). *The trouble with boys: A surprising report card on our sons, their problems at school, and what parents and educators must do*. New York: Crown.

Van Goozen, S. H., Cohen-Kettenis, P. T., Gooren, L. J., Frijda, N. H., & Van de Poll, N. E. (1995). Gender differences in behaviour: Activating effects of cross-sex hormones. *Psychoneuroendocrinology, 20*, 343–363. doi:10.1016/0306-4530(94)00076-X.

van Goozen, S. H., Slabbekoorn, D., Gooren, L. J., Sanders, G., & Cohen-Kettenis, P. T. (2002). Organizing and activating effects of sex hormones in homosexual transsexuals. *Behavioral Neuroscience, 116*, 982–988. doi:10.1037//0735-7044.116.6.982.

Van Tilburg, M. A. L., Unterberg, M. L., & Vingerhoets, J. J. M. (2002). Crying during adolescence: The role of gender, menarche, and empathy. *British Journal of Developmental Psychology, 20*, 77–87.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*, 250–270. doi:10.1037//0033-2909.117.2.250.

Willingham, D. T. (2005). Do visual, auditory, and kinesthetic learners need visual, auditory, and kinesthetic instruction? *American Educator, 29*(2), 31–35, 44.

Wood, G. E., & Shors, T. J. (1998). Stress facilitates classical conditioning in males, but impairs classical conditioning in females through activational effects of ovarian hormones. *Proceedings of the Naional Academy of Sciences, 95*, 4066–4071. doi:10.1073/pnas.95.7.4066.

Wood, A. G., Harvey, A. S., Wellard, R. M., Abbott, D. F., Anderson, V., Kean, M., … Jackson, G. D. (2004). Language cortex activation in normal children. *Neurology*, *63*, 1035–1044. doi:10.1212/01.WNL.0000140707.61952.CA.

Wood, J. L., Heitmiller, D., Andreasen, N. C., & Nopoulos, P. (2008). Morphology of the ventral frontal cortex: Relationship to femininity and social cognition. *Cerebral Cortex, 18*, 534–540. doi:10.1093/cercor/bhm079.

Younger, M. R., & Warrington, M. (2006). Would Harry and Herminone have done better in single-sex classes? A review of single-sex teaching within coeducational secondary schools in the United Kingdom. *American Educational Research Journal, 43*, 579–620. doi:10.3102/00028312043004579.