Taking Science Seriously:
Straight Thinking About Spatial Sex Differences

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Sex differences in spatial functioning are frequently the source of cocktail party conversation and entertaining cartoons. These anecdotes and images feature such figures as men who forge intrepidly into the wild armed only with a compass and an innate sense of direction and ditzy women who hold maps upside down and depend on the kindness of strangers. These figures of fun, while exaggerated, have some basis in truth. Studies using standardized tests have found support for the belief that men have strengths in the spatial domain, sometimes quite marked strengths. For example, the average American man has an ability to perform mental rotation of a three-dimensional object that exceeds that of the average American woman by half a standard deviation or more (Linn & Petersen, 1985; Voyer, Voyer & Bryden, 1995). (For the statistically uninitiated, such differences are considered moderate to large, and may well be obvious to the casual observer.) There are similarly substantial sex-related differences on tests of mechanical reasoning, which involve a large spatial component (Feingold, 1995). Furthermore, and consistent with remarks made in January 2005 by Lawrence Summers, the President of Harvard, these differences are often most marked at the upper end of the distribution. That is, men outnumber women by especially large ratios at the highest levels of these abilities (Feingold, 1995; Hedges & Nowell, 1995). Lastly, in what may seem to be the final step in a devastating argument, such differences have been found to be relevant to success in science for men and women, both because mathematical ability may rest partially on spatial ability (Casey, Nuttall & Pezaris, 1997, 2001), and also because spatial visualization is directly relevant to achievement in many scientific and technical fields, including physical science, mathematics, computer science, and engineering (Shea, Lubinski & Benbow, 2001).

So, given these facts, was President Summers correct in speculating that women may be held back from success in science partly because they lack the cognitive prerequisites? I think the answer is yes, at a superficial level, because his descriptive facts were right—although I am not sure that the proportion of variance accounted for by cognitive variables is that large in comparison with issues such as family-work conflicts. But at a deeper level, I think the answer is

no, he was incorrect, because these "facts" reflexively evoke in most people two unwarranted assumptions: that any sex-related differences are biologically caused, and that they are hence immutable. (The "hence" in that last sentence is itself problematic, because many biologically-caused conditions can be easily addressed by interventions, as when we color our graying hair or treat our children's ear infections with antibiotics. But for most people there is a linkage, albeit a mistaken one, between biology and immutability.)

In this essay, I will address each of these assumptions in two parts. For biological causation, I will first present an extremely brief overview of the current state of evidence, and then I will concentrate on the evolutionary psychology framework that currently provides the primary scientific basis for taking biology very seriously, pointing out its grave inconsistencies and gaps in logic. Turning to the issue of immutability, I will discuss evidence that spatial ability levels can fairly easily be increased overall. I will then concentrate on the issue of whether sex-related differences can be eliminated and whether that matters, arguing that increasing the abilities of both women and men should be the key goal.

Current Evidence on Causation

When I first took a look at the literature on sex-related differences in spatial ability (Newcombe, 1982), it was common to see enthusiasm for the hypothesis that there was an X-linked recessive gene that accounted for greater male performance. The idea was that women would need two "doses" of the high-ability gene to show high ability, but that men would show the heightened ability even with only one "dose" because there would be no dominant gene on the Y chromosome to mask its effect. The excitement about this idea ultimately fizzled, however, in the face of disconfirming evidence (see review by Boles, 1980). Similarly, at that same time, there was an initial love affair with the idea that men excel in the spatial domain because they reach puberty later than women (Waber, 1976), but that too waned in the light of subsequent examination (Newcombe & Bandura, 1983; Newcombe & Dubas, 1986).

Another idea about sex differences back in that day, which is actually not completely dead, was that men are better at spatial tasks because they are "more lateralized"— more likely than women to use the right hemisphere for spatial tasks. However, the data on this subject are very messy indeed (for recent examples, see Johnson, McKenzie & Hamm, 2002; Rilea, Roskos-Ewoldsen & Boles, 2004) and overall, I think there is only dubious support for the hypothesis. The most plausible current biological hypothesis concerns the effects of sex hormones, although it's not quite clear which hormones are the most relevant and again the data are fairly murky (see review by Collaer & Hines, 1995). Recent reports continue to suggest that the story on hormones

and spatial ability is, at best, complex (Halari, Hines, Kumari, Mehrota, Wheeler, Ng & Sharma, 2005; Hooven, Chabris, Ellison & Kosslyn, 2004).

Before discussing sociobiology, a small digression may be in order. It is sometimes supposed that the earlier in development we observe an effect, the more likely it is to be biologically caused. This mode of reasoning is fallacious: late-emerging effects can be maturational, and early-emerging effects can be environmentally produced, perhaps even by in utero experiences. So, we should not be overly impressed by the fact that sex-related differences appear by the time children are in preschool, kindergarten or early elementary school (Levine, Huttenlocher, Taylor & Langrock, 1999; Levine, Vasilyeva, Lourenco, Newcombe & Huttenlocher, in press). The fact is notable because it can help us to target specific evidence-based interventions, but it does not tell us that differences are biological. In fact, there is recent evidence on early sex differences that suggests the importance of the environment in creating them. Sex differences in two spatial tasks, one involving rotation and the other involving map reading, were not observed in young elementary-school children from low-income backgrounds, although we saw the standard sex differences in middle- and high-income groups (Levine et al., in press; see also Noble, Norman & Farah, 2005 on early SES differences). The most natural explanation of this interaction is that boys in low-income environments lack access to experiences that enhance spatial skill, e.g., computer games, puzzles and building sets.

Do Sex-Related Differences Have an Evolutionary Explanation?

What does the list of failed or marginal hypotheses about biological causation of spatial sex differences leave in the way of support for the general idea that the differences are an essential aspect of being male or female? Probably the strongest reason that people believe in biological causation today is not empirical at all. Rather, their belief derives from the fact that the sex differences in spatial ability story seems to fit so neatly into an evolutionary-psychology framework. So it is important to take a moment to look at that framework with a critical eye.

Steven Pinker, John Tooby, Leda Cosmides, and many other proponents of evolutionary psychology often speculate about the reasons for sex-related differences in cognition, and their speculations are so often repeated that they have attained acceptance, without having been subjected to searching analysis or having been scientifically tested. I believe that there are untested assumptions, at best, and incoherence, at worst, in the sociobiological framework regarding these differences (see also Jones, Braithwaite & Healy, 2003). (Similar problems are evident in many other domains, such as analyses of romantic attraction; David Buller’s recent book, *Adapting Minds* (2005), provides a “scientific detective novel” analyzing these broader problems in sociobiology in fascinating detail.)

There are actually two evolutionary explanations of spatial sex differences. Both focus on the reproductive advantage that might accrue to men for having higher spatial ability, but that would not be relevant for women. One explanation focuses on Man the Hunter. Men are generally the hunters in hunting-gathering societies, and hunting seems to require spatial skill in several of its component activities, including tracking animals, aiming at them, and fashioning the weapons with which to take aim. The protein obtained from hunting helps to ensure the survival of a man's children, and prowess in hunting may also enhance a man's access to women (who wish to have their children provisioned by a skilled hunter). In addition, aiming may come in handy in any struggles for dominance with other males over sexual access to females.

However, there are problems with this story. Although Man the Hunter may need spatial skills, so does Woman the Gatherer. Gathering may require quite long trips away from home base to find various kinds of edible vegetation in their respective ripening seasons. True, animals move while vegetation sits still, but humans are far from the swiftest creatures around, and much hunting by our ancestors may have consisted of setting traps, waiting at waterholes and so on rather than tracking animals over meandering paths. In terms of manufacturing artifacts to use in hunting and gathering, note that spatial skill is required to weave or make baskets or pottery, as much as for fashioning arrows and spearheads.

Another explanation for sex differences focuses on the Man Who Gets Around. In this story, men need spatial skill in order to navigate around the territory required to have sexual access to as large a number of fertile women as possible. There is in fact beautiful observational and experimental evidence that this kind of effect is seen in voles, a small mammal that comes in two varieties (e.g., Gaulin, FitzGerald & Wartell, 1990). One species, the prairie vole, is pair-bonded while a very similar species, the meadow vole, has a mating system in which females occupy territories and, during the mating season, males make the rounds of females, attempting to reach as many as possible in time to impregnate them. Strikingly, spatial ability (assessed by the ability to navigate mazes) is equal for males and females in the pair-bonded prairie vole, but male meadow voles beat females at spatial tasks—during the mating season only, when the part of their brain that supports navigation (the hippocampus) actually enlarges to meet the reproductive challenge. But there's one big "sticky wicket", as the English say so bewilderingly, for extending this line of explanation to apply to human beings. Human females, unlike meadow voles, live in social groups rather than occupying widely-separated home territories. The skills it takes to impregnate many females probably include such abilities as charm and stealth, more than the ability to find one's way among a cluster of huts.

There’s another problem for a sociobiological explanation of sex differences in spatial ability, a question that is actually sociobiologically inspired. Why would there be a sex difference, from an evolutionary point of view, in a trait that has adaptive significance for both sexes (even if it were to be slightly greater for one sex), when there is no obvious metabolic cost for that trait? Most sex-specific traits that enhance reproductions involve attributes such as growing antlers or ornamental tails, things that are cumbersome and costly for the body to produce, that males have only because they enhance their ability to do combat with other males and/or attract females. There’s no reason both sexes shouldn’t have a cheap-to-produce trait that’s useful in a wide variety of settings.

So, why is there a biologically-based sex difference in spatial ability, if there is one at all? One clue comes from data that indicate (although sometimes inconsistently as I noted above) that spatial ability fluctuates with hormone levels, within sex. In the hormone literature, women often (but not always) show better spatial skills when at the menstruation phase of their cycle. Men often show better spatial skill when they have relatively low testosterone levels. But, while correlations with hormone levels support some kind of biological explanation, they are puzzling within the sociobiological frameworks we have sketched. There’s no obvious reproductive advantage for women having enhanced spatial skill at the infertile part of their cycle, and no obvious reason why spatial skill should vary at all with testosterone level for men—or if it did, why it wouldn’t be a direct rather than inverse relationship, as is true for other behavioral traits such as aggression.

Sex differences in spatial ability, if they are linked to hormones in any consistent way at all, may exist because they are accidentally linked to hormone levels—they are a “spandrel”, to use Stephen Jay Gould’s term. After all, hormones account both for the appearance of acne at adolescence and for the fact that acne is typically more severe for males than females, but no one would suggest that acne confers a reproductive advantage. Acne is a clear example of a sex difference that seems likely to be accidental, and spatial ability may well be another.

Spatial Ability Can (Fairly Easily) Be Vastly Improved

Now let’s take a look at the issue of malleability. Even though sex differences in spatial ability are substantial, mean levels of spatial ability do not seem to be biologically fixed. Like other intellectual abilities, and possibly more so, spatial ability has increased in the past century faster than the gene can change, a phenomenon that has been called the Flynn effect after its discoverer (Flynn, 1987). Some time ago, I collaborated on a meta-analysis of studies done through the late eighties that showed very clear effects of simple practice and also of training on improvements in spatial ability, and that also showed sensible gradients of the size of the effects

as a function of the time devoted to practice or training and the potential of the activities to lay the foundation for generalizability (Baenninger & Newcombe, 1989). Research subsequent to the meta-analysis has supported its broad thesis. For example, it has been shown that being in school is associated with greater spatial growth in elementary school children than being on summer vacation (Huttenlocher, Levine, & Vevea, 1998), and that various manipulations can help children learn spatial tasks (Taylor, Uttal, Fisher, & Mazepa, 2001; Uttal, Fisher, & Taylor, in press).

Most recently, I have collaborated on a new meta-analysis that again shows substantial improvements in spatial skill, for both children and adults, that emerge from academic coursework, task-specific practice, musical training (not simply musical exposure—not the so-called Mozart effect), and playing computer games (Marulis, Warren, Uttal & Newcombe, 2005). I have also been involved in two studies that gave undergraduates extended practice or training on mental rotation. In one study, we found that, after a semester of work, people were still improving their rotation ability with no sign of asymptote, that training (playing the computer game Tetris) led to greater improvement than simple practice, that training effects lasted for months and generalized to other spatial tasks (such as mental paper-folding tasks), and that both practice and training effects were massive—far larger than the typical sex difference (Terlecki & Newcombe, 2005). Similar data emerged from a subsequent study, this time with evidence of symmetric transfer between mental rotation and paper folding, and using stimuli that ruled out the possibility that the effects involved simply memory for the particular stimuli (Wright, Thompson, Ganis, Kosslyn & Newcombe, in preparation).

Can Sex Differences Be Eliminated and Does It Matter?

For many people, evidence that spatial skill can improve is less important than the answer to the question of whether improvements are more marked for women than for men, so that women can catch up to men and eliminate their deficit in this intellectual ability. The current evidence is somewhat equivocal, but I read it to indicate that convergence is hard to get. We did not find sex differences in gains in the early meta-analysis, Terlecki and I did not find that women caught up to men even with extended practice and training, and the more recent meta-analysis also fails to find reliable sex differences in gains (although there is a hint of this effect and more data are needed). Now, failure to get convergence using current methods does not necessitate concluding it is impossible—we would hardly conclude that we can never find an AIDS vaccine just because one has not yet materialized. Whether or not men and women would converge in their abilities in more supportive or more carefully designed educational environments remains to be determined.

Let's suppose for the moment, however, that women do not catch up with men even when both sexes show enormous gains. Some investigators might argue that we would expect a disparity in elite achievement in science and technical fields to remain in this case. I am not so sure. There are multiple factors that determine success at the highest levels of science, and beyond some (high) threshold, I doubt that extra increments of the same cognitive ingredients explain much variance. Thinking creatively, explaining one's data, or inspiring a research team may be pretty important as well! Remember that relatively short and easy interventions greatly improve spatial skill—actually by the equivalent of 10 IQ points. If we want to maximize the human capital available for occupations that draw in spatial skill, such as mathematics, engineering, architecture, physical science and computer science, we would do better to concentrate on understanding how to educate for spatial skill, rather than focus solely on the explanation of sex differences (Newcombe, Mathason & Terlecki, 2002).

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