Sex differences in spatial abilities: An evolutionary explanation.

Rick O'Gorman

Dept. Of Biological Sciences, State University of New York at Binghamton, Binghamton, NY 13902-6000, USA.

Key words: Gender differences, sex differences, spatial cognition, evolution, evolutionary psychology.

Correspondence may be directed to Rick O'Gorman at the above address or by eMail: bg21429@binghamton.edu

Abstract

MacIntyre's (1997) review of gender differences in spatial abilities overlooked findings generated by the metatheory of evolutionary psychology. This oversight reflects an underlying hostility within the social sciences towards the use of evolutionary theory in the study of human behaviour and cognition. As a remedy, this paper outlines the theoretical background of evolutionary psychology, focusing on the insights evolutionary psychology offers for cognitive gender differences research, with particular reference to gender differences in spatial abilities.

Sex differences in spatial abilities: An evolutionary explanation.

In a recent review of gender differences in cognition, MacIntyre (1997) noted that there was a need for a theoretical framework to account for findings of gender differences in human cognitive spatial abilities. In his review, MacIntyre noted the relatively consistent finding that males performed better on spatial tests than did females and he commented on the lack of a theoretical framework to explain these findings. Surprisingly, he did not introduce the metatheory of evolutionary psychology, which not only accounts for the observed sex differences in spatial abilities[i], but has also led to additional hypotheses predicting that females should have superior spatial abilities for specific tasks.

Evolutionary psychology has been defined as the study of human behaviour and cognition informed by evolutionary theory (Daly & Wilson, 1988). It is an approach that uses the theory of evolution to synthesise psychological knowledge and brings the study of human behaviour and cognition within the fold of biology. Central to evolutionary theory is the theory of natural selection (Darwin, 1859), which predicts that organisms better adapted to their environment reproduce more successfully, thus making more copies of themselves than less well-adapted organisms[ii]. The theory of natural selection has been around for almost 140 years, yet only recently has it been used to generate hypotheses about human behaviour. Darwin (1872) himself wrote of humans in relation to his theory of natural selection; ironically, the title of his book, The Expression of Emotion in Man and Animals, gives a clue to the scientific attitudes that have perpetuated the divide between biology and the social sciences, separating the study of humans from the study of nonhuman animals. The social sciences have in large part been resistant to acknowledging that at least some aspects of human behaviour and cognition are likely due not primarily to socialisation processes, ill-defined as these are, but due instead to a result of the phylogenetic and evolutionary history of Homo sapiens. Tooby and Cosmides (1992) have labelled the approach of the social sciences to the study of human behaviour and cognition as the Standard Social Sciences Model (SSSM), and have been highly critical of it. Primarily, they portray the SSSM as assuming human cognitive abilities to be domain-general: Domain-general (also referred to as content-independent) psychological mechanisms are information-processing mechanisms that deal with all environmental information in a non-preferential manner. Such mechanisms do not process environmental information with regard to the biological fitness[iii] value of that information, which is contrary to what would be expected of mechanisms shaped by natural selection and in contrast to findings for every other animal. Furthermore, according to Tooby and Cosmides (1992), the SSSM incorporates as fact early anthropological claims that human behaviour is almost endlessly variable and that there are always cultural examples that counter any apparent cross-culturally consistent behavioural or cognitive findings, such as sex differences in behaviour or cognition. To this end, psychologists rely on the work of anthropologists such as Margaret Mead (e.g., Mead, 1935) to provide such evidence of these cultural reversals (Daly & Wilson, 1988). However, Mead's own work does not demonstrate that behavioural differences due to sex are arbitrary (Wilson & Daly, 1992; Daly & Wilson, 1988) and her work is actually discredited within anthropology (Daly & Wilson, 1988, Freeman, 1983). Daly and Wilson (1988) and Tooby and Cosmides (1992) both lay the blame for this acceptance of inadequate data with the ideology of social scientists. The myth that Margaret Mead demonstrated the arbitrary reversibility of gender roles “seems to demonstrate [to social scientists] that our social natures are pure cultural artifacts, as arbitrary as the name of the rose, and that we can therefore create any world we want, simply by changing our ‘socialization practices’ ” (Daly & Wilson, 1988, p.153). Such a view was promoted by none less than B.F. Skinner in his vision of utopia, Walden Two (Skinner, 1948), wherein he advocated developing a more harmonious society by the use of conditioning techniques. While many psychologists rejected such a vision, they nonetheless continue to subscribe to the idea of a cognitive tabla rasa, but with the explicit techniques of radical behaviourism substituted with nondescript ‘socialization processes’, which, when examined, consist of conditioning and social learning techniques, facilitated by a handful of domain-general cognitive mechanisms such as attention, memory and reasoning.

In contrast to the SSSM, evolutionary theory leads to the prediction that many psychological processes are likely to be domain-specific, and all organisms show domain-specificity in their interactions with the environment. For example, most people know that if one drags an object along the ground with a piece of string in front of a kitten, the kitten will pounce on the object. Yet no-one would play such a game with a pet rabbit! The difference, should it need elaboration, between the response of the kitten and rabbit is due to cats having been shaped by natural selection to be hunters; they are designed to capture small moving objects. On the other hand, rabbits evaluate moving objects so as to determine whether such objects pose a risk to life (e.g., is the object a predator). The behavioural differences between the cat and the rabbit are the result of underlying cognitive mechanisms which produce different behavioural responses to the same stimulus object. Such a commonplace example clearly illustrates the value of domain-specific cognitive traits. Environmental information is processed by different species differently, depending on the fitness needs of each species. Now, if other animals have domain-specific environmental interactions, why should it be assumed that human beings do not?

One of the great errors of psychology will prove to be that the burden of proof for accounting for the ontological causation of human behaviour and cognition lies with the evolutionary approach and not with the socialisation approach. Non-evolutionary psychologists may respond to such a statement by claiming that making the assumption that the human mind is domain-general is a more parsimonious approach. Furthermore, domain-general cognitive capacities appear more advantageous than domain-specific capacities: Surely a mental trait that can handle anything is better than one which only responds to specific input? However, such responses would indicate a failure to comprehend evolution as a process, and the place of humans within that process. Domain-general processes are highly unlikely to be able to replace domain-specific processes by natural selection. Organisms are usually localised in specific environments. The best adaptive design for one environment may be completely inadequate for another environment (e.g., consider adaptations best suited for the Arctic versus the Sahara desert). Similarly, even within a particular environment, different problems require different cognitive analysis. Figuring out how to woo a mate is a different challenge from finding a good source of carbohydrates! Both of these factors favour the evolution of domain-specific traits, adapted for specific ecological niches. Even if a general problemsolving system was biologically possible, organisms must compete for environmental resources, such as food, shelter and mates, all of which tend to be limited: Those organisms which function more efficiently will make better use of those resources, thus increasing their reproductive potential. This process results in organisms that become increasingly specialised in their designs. Generally, an organism that through a mutation becomes less specialised (and so relatively more domain-general) will be at a disadvantage relative to others and will have lower biological fitness: Competition leads to increasingly intense levels of specialisation[iv].

In addition to this, natural selection, being an 'ad hoc' process, is far more likely to produce an agglomeration of domain-specific mechanisms rather than a single domain-general mechanism. Natural selection does not neatly redesign structures that are needed for new tasks - natural selection is, to use the metaphor of Richard Dawkins (1986), a blind watchmaker, tinkering with what is at it's disposal, but without the ability of foresight. Natural selection produces mechanisms that work. As a process, it is the differential reproduction of organisms (Darwin, 1859) due to forces of selection acting on heritable variation in those organisms' populations (Sober and Wilson, 1998; Darwin, 1859). Human physiology presents examples of structures which were modified for new functions but would have been more effective if they had been redesigned from scratch. As an example, when hominids became bipedal, they switched from a horizontal spine alignment to a vertical one. The horizontal design has been in existence for several hundred million years, and has not needed to be extensively redesigned, until the advent of bipedalism. The modification of the spine to a dorso-vertical alignment is not ideal: A principal shortcoming is that such a design requires that the spine lean away from the body's centre of gravity, to counteract the unbalancing effect of the load being to one side of the spine; ideally, the spine would be in the centre of the torso, where the weight would be evenly distributed and the spine could be perfectly vertical. However, such a redesign was not possible, given the preceding design[v]. Thus, the argument that postulating the existence of domain-specific traits is less parsimonious than postulating the existence of a domain-general trait does not take into consideration the process that is involved[vi]. Furthermore, identifying the possibility of domain-specificity in human cognition leads to the recognition of a consequent possibility: The human mind is likely to consist of a series of domain-specific mechanisms or modules (Cosmides & Tooby, 1992)[vii].

Non-evolutionary psychologists might argue that the human capacity for culture circumvents this evolutionary trend by facilitating the ability to share information that can be utilised by domain-general mechanisms. However, this capacity for culture is only a recently evolved trait (or complex of traits) and so our ancestors must have had other traits that addressed ecological pressures predating the 'capacity-for-culture' trait. Furthermore, when certain traits are consistently needed, evolved mechanisms may represent a more secure way to obtain such traits. Additionally, if the information required for making a decision is not easily obtained, those who 'possess' such information innately have an even greater advantage; as Sober and Wilson (1998) point out, "the human mind is too feeble to comprehend the consequences of behaviors in all their ramifications" (p.153). Natural selection can produce mechanisms that successfully procure the appropriate environmental information because there is selective retention of mechanisms - those that work best, however that may be, eventually tend to predominate in a population.[viii]

Take as an example the task of evaluating the health of a potential mate as an ecological problem faced by ancestral humans. This is an ability that would have had a strong impact on fitness[ix]. Individuals who selected healthier mates would have had higher fitness (i.e., more offspring) than those who did not. Now, how is an individual to determine which potential mate has a good immune system? What are the best indicators or predictors of a strong immune system? Natural selection provides organisms with access to this information: Individuals who mate with healthier individuals will have more offspring. Those individuals whose ‘choice’ was based on better criteria will have more descendants: The trait for selecting a healthy mate will spread in a population[x]. The alternative method for determining health would be by obtaining knowledge of appropriate criteria either through cultural means or by learning somehow. Yet even today, it is difficult to determine predictors of long-term health. Furthermore, individuals who were dependent upon obtaining the relevant information from others would have been open to the vagaries of cultural transmission. Thus, an ancestral human who did not innately have a particular, advantageous trait, such as the ability to select a healthy mate, would instead somehow have had to learn the trait, would have been at a disadvantage to those who possessed the trait innately and is likely to have been out-competed for access to the best mates. Of course, cultural preferences for mates that led to selection of healthier mates could also be propagated, by cultural evolution (Boyd & Richerson, 1985). For this current example, however, it is unlikely that cultural evolution would prove to be sufficiently robust in transmission to perpetuate relevant information for such a subtle ecological cue. Additionally, given the enduring nature of the ‘problem’, a genetic response is likely.

Let us now focus on sex differences in spatial cognitive abilities. In contrast to most cognitive abilities, which show little or no consistent sex differences, certain spatial abilities have demonstrated a consistent effect in favour of males (Geary, 1998). Furthermore, this advantage appears to be universal (Silverman & Philips, 1998). Interpretation of such results is not clear-cut, as MacIntyre (1997) noted, as the issue lacks a theoretical framework. In particular, MacIntyre points out problems with the concept of spatial ability, problems with the tests used, and an apparent decline in the size of the difference between males and females, though he also notes that this latter claim has been challenged (e.g., Halpern, 1992) and recent studies continue to show notable differences (Masters & Sanders, 1993; Stumpf & Eliot, 1995). With recent emphasis to encourage women to take up educational subjects that require spatial aptitudes and which have previously been pursued predominately by males, a decrease in sex differences in spatial abilities might be expected. Indeed, studies show that spatial ability has an experiential component (Halpern, 1992). However, observing a decrease in differences does not mean that there is no underlying difference: Spatial ability has been found to be correlated with the level of the sex hormones in humans (Geary, 1998), suggesting a biological component. Testosterone, for example, appears to have a curvilinear relationship with spatial ability, with both low levels and excessive levels of testosterone associated with a decrease in spatial ability. However, for most males, this puts them around the peak range.

Evolutionary theory leads to specific predictions of sex differences between males and females such as differences in spatial abilities (Silverman & Eals, 1992). At this point, it is necessary to introduce the concept of the Environment of Evolutionary Adaptedness (EEA), which is the hypothetical environment which shaped a particular adaptation. The EEA for Homo sapiens is thought to have consisted of a hunter-gatherer lifestyle, with humans living in groups of perhaps a few hundred individuals, and with a sexual division of labour (Tooby & DeVore, 1987), with hunting primarily carried out by males and gathering done primarily by females. This would have been a likely use of resources, protecting women who would often have been nursing young infants, while applying the greater average strength and stamina of men to hunting. Of relevance to the issue of sex differences in spatial abilities is the fact that hunting requires a different set of spatial skills than does food-gathering (Silverman & Eals, 1992). In particular, hunting, which involves traversing extensive distances, requires an ability to maintain accurate directional orientation during excursions (i.e., a ‘sense of direction’), as well as the ability to spatially plan an ambush or hunt. Studies have shown that males are better than females at generating maps of novel environments (Matthews, 1987; Galea & Kimura, 1993; Holding & Holding, 1989). Linking this skill to male superiority in rotation tasks, Matthews (1987) found that overall route-learning scores were significantly related to the ability to rotate three-dimensional images (Vandenberg Mental Rotation Task, VMRT, Vandenberg & Kuse, 1978). Moffatt et al. (1998) have made similar findings.

Additionally, neurological evidence supports this notion as similar regions of the brain are activated by both tasks (Geary, 1998; Cabeza & Nyberg, 1997; Maguire et al., 1997; Tagaris et al., 1997). There is also evidence for sex differences in the structure and functioning of brain systems that support at least some spatial abilities, and that those differences are influenced by prenatal exposure to sex hormones (Geary, 1998). Before continuing, it should be noted that other researchers have put forward alternative hypotheses to explain the sex differences being discussed. Geary (1998) suggests that the development of projectile weapons resulted in the heightening of male spatial abilities: Geary notes that the two greatest sex differences relate to male throwing ability and throwing distance, as well as male superiority in evading projectiles. However, these physical differences could be accounted for without relating them to superior male spatial ability, although the two hypotheses of hunting and projectile selective pressures are complementary rather than exclusive. In contrast, Gaulin and Hoffman (1990) claim that males of many species have superior spatial abilities, due to the necessity to obtain mates, and this is why human males have superior spatial abilities. However, there are inconsistencies in Gaulin and Hoffman's argument and it shall not be considered further here.

In contrast to hunting, food-gathering requires an ability to recall the fixed locations of resources. Thus, Silverman and Eals (1992) predicted that females would possess a superior capacity to quickly learn and remember the contents of object arrays and the spatial relationships of objects. To this end, Silverman and Eals first tested male and female participants on mental rotation tasks, and found that males in their participant pool were superior in performance, in agreement with previous findings (e.g., Linn & Petersen, 1986). They then tested participants' abilities to recall the location of objects: a series of studies were performed first using a visual array of object images, then using a room with objects located within it. In both studies, females demonstrated significantly superior abilities to recall the objects that were presented, and the location of objects relative to each other. In fact, females in incidental learning tasks performed up to 70% better than males (Silverman & Eals, 1992), clearly supporting the hunter-gatherer explanation for gender differences in spatial abilities. These findings have been replicated for object location recall (Eals & Silverman, 1994; James & Kimura, 1997; McBurney et al., 1997) though findings are less consistent for recall of objects present (Eals & Silverman, 1994; Geary, 1998; McBurney et al., 1997). Reinforcing the idea that object location tasks require different spatial skills than do mental rotation tasks is the finding that the two tasks activate different brain structures: Cabeza and Nyberg (1997) found that the object location tasks do not appear to activate the hippocampus, unlike mental rotation tasks and route learning.

In conclusion, the central message of this paper is that evolutionary theory offers a framework for the study of human behaviour and cognition that encompasses existing psychological research and knowledge while embedding that body of knowledge within a larger paradigm that accounts for the behaviour of all forms of life. The discussion in the present paper of sex differences in spatial abilities demonstrates the shortcomings of current psychological theory and serves to provide an example of how evolutionary psychology can explain findings that are incongruous with conventional psychological theory. The advantage that evolutionary psychology presents is that it relies not on intuition for the generation of hypotheses but rather on the fact that hypotheses emerge as logical extrapolations from evolutionary theory (Cosmides & Tooby, 1994). Such questions as 'What is something designed to do?' and 'What would be adaptive to have or do?' lead to empirical studies that progress methodically and integrate with other findings produced within the same general paradigm. Furthermore, studies such as Silverman and Eals (1992), as well as others not discussed here (e.g., Cosmides & Tooby, 1992; Buss, 1989; Daly & Wilson, 1988) demonstrate the general need for psychology to recognise the shortcomings of an approach to research on human behaviour and cognition that assumes domain-generality, utilises information-neutral tasks and tests, and lacks real-world validity. That evolutionary psychology is the only approach available to psychologists which is consistent with other related scientific disciplines and provides a theory that can link those disciplines only further augments the need for its adoption. All sciences must strive to integrate their knowledge, both within the discipline and with other sciences: the time has come for psychology to abandon its ideologies and to embrace a multifaceted paradigm capable of <u>fully</u> explaining human behaviour and cognition.

---

[i] Throughout this paper, I shall refer to 'sex differences' rather than 'gender differences'. MacIntyre (1997) notes that there has been a shift to using 'gender differences' to emphasize differences between males and females other than biological ones. However, for the purposes of discussing human behaviour from an evolutionary perspective, it is important to recognise that there are inherent biological differences between males and

---

females that will impact upon behaviour. For further discussion, refer to an evolutionary biology textbook such as Ridley (1996) or Futuyma (1997).

[ii] The process of reproduction is generally not one of self-cloning. Thus, evolutionary biologists such as Richard Dawkins (1976) discuss the process of natural selection at the level of the physical element that is replicated, which is the gene. Genes code for traits in organisms. When an organism reproduces, it is essentially random as to which genes are passed on (replicated). This conceptual approach suggests that natural selection is best understood as differential replication of the genes and that the organisms are simply vehicles which facilitate gene replication, giving rise to the notion of <u>selfish genes</u>. However, genes are simply a reliable medium for propagating information that codes for construction of biological organisms: Genes are not directly selected, usually. If you were to copy a computer program that, for example, allows you to store names and addresses of friends, you copy a set of code in the form of zeros and ones (in fact, it is actually a pattern of ‘marks’ (ones) and ‘non-marks’ (zeros) on a computer disk, translated into electrical current (1) and non-current (0) within the computer, then retranslated into the pattern of marks on another disk). But the <u>reason</u> that you copied this program is because of what happens when the code on the disk is utilised by a computer; the code in and of itself, without a computer, is of no value to you. In natural selection, it is the organism, the phenotype, that is selected. Dawkins’ concept of organisms as vehicles for genes is not wrong, but is not helpful for fully understanding the selection process. Sober and Wilson (1998), expanding previous theoretical views, discuss how selection acts at multiple levels, such as the gene level, the individual level, and the group level. In the

present paper, we are interested in selection of traits at the level of the organism (individual).

[iii] Fitness is a concept that represents the relative adaptedness of organisms: It is usually equated with reproductive success.

[iv] There is a limit to how specialised any organism can become, of course: There will be a level of specialisation beyond which specialisation will not pay. As organisms become increasingly specialised, fluctuations in environmental conditions become increasingly capable of imposing fitness costs.

[v] Or at least was not possible in the short period of time for which the need has existed.

[vi] The idea of domain-specific psychological mechanisms is no different to the recognition that many organisms have appendages that are specifically designed for those organisms' ecological needs, rather than being general-purpose appendages.

[vii] William James (1890) suggested over a hundred years ago that humans are likely to have more instincts than other organisms, not fewer.

[viii] Models have been developed (Boyd & Richerson, 1985; Bowles, 1998) showing that cultural evolution could work in a similar manner, i.e., evolution of a 'cultural milieu' by selective retention of cultural elements. However, this does not argue against the case for evolutionary psychology: The two possible causal agents can be evaluated for any particular behaviour, making predictions about the robustness of each causal agent and the likelihood of each producing the effect under consideration.

[ix] Other traits less immediately concerned with reproductive success nevertheless will impact tangibly on fitness over a sufficient time period.

[x] To provide an example, it has been argued that body symmetry is an indicator of a strong immune system (Gangestad, Thornhill & Yeo, 1994), and appears to be perceptible to humans at some cognitive level, despite instruments such as calipers being necessary to determine the asymmetry of experimental participants because differences within individuals are so small!

References

Bowles, S. (1998). Cultural group selection and human social structure: The effects of segmentation, egalitarianism, and conformism. Unpublished manuscript, University of Massachusetts at Amherst.

Boyd, R. & Richerson, P. (1985). Culture and the evolutionary process. Chicago: University of Chicago Press.

Buss, D.M. (1989). Sex differences in human mate preferences: Evolutionary hypotheses tested in 37 cultures. Behavioral and Brain Sciences, 12, 1-49.

Cabeza, R., & Nyberg, L. (1997). Imaging cognition: An empirical review of PET studies with normal subjects. Journal of Cognitive Neuroscience, 9, 1-26.

Cosmides, L., & Tooby, J. (1992). Cognitive adaptations for social exchange. In J.H. Barkow, L. Cosmides, & J. Tooby, The adapted mind: Evolutionary psychology and the generation of culture. New York: Oxford University Press.

Cosmides, L. & Tooby, J. (1994). Beyond intuition and instinct blindness: Toward an evolutionarily rigorous cognitive science. Cognition, 50, 41-77.

Daly, M. & Wilson, M. (1988). Homicide. Hawthorne, NY: Aldine De Gruyter.

Darwin, C. (1859). On the origin of species by means of natural selection or the preservation of favoured races. London: Murray.

Darwin, C. (1872). The expression of emotion in man and animals. London: Murray.

Dawkins, R. (1976). The selfish gene. New York: Oxford University Press.

Dawkins, R. (1986). The blind watchmaker. New York: Norton.

Eals, M., & Silverman, I. (1994). The hunter-gatherer theory of spatial sex differences: Proximate factors mediating the female advantage in recall of object arrays. Ethology and Sociobiology, 15, 95-105.

Freeman, D.F. (1983). Margaret Mead and Samoa. The making and unmaking of an anthropological myth. Cambridge, MA: Harvard University Press.

Futuyma, D.J. (1997). Evolutionary biology (3rd ed.). Sunderland, MA: Sinauer Associates.

Galea, L.A., & Kimura, D. (1993). Sex differences in route learning. Personality and Individual Differences, 14, 53-65.

Gangestad, S.W., Thornhill, R., & Yeo, R.A. (1994). Facial attractiveness, developmental stability, and fluctuating asymmetry. Ethology and Sociobiology, 15, 73-85.

Gaulin, S.J.C., & Hoffman, H.A. (1990). Evolution and development of sex differences in spatial ability. In L. Betzig, M. Borgerhoff-Mulder, & P. Turke, Human reproductive behaviour: A darwinian perspective. Cambridge: Cambridge University Press.

Geary, D. (1998). Male, female: The evolution of human sex differences. Washington, D.C: American Psychological Association.

Halpern, D.F. (1992). Sex differences in cognitive abilities. Hillsdale, NJ: Erlbaum.

Holding, C.S., & Holding, D.H. (1989). Acquisition of route network knowledge by males and females. Journal of Genetic Psychology, 116, 29-41.

James, T.W., & Kimura, D. (1997). Sex differences in remembering the locations of objects in an array: Location-shifts versus local exchanges. Evolution and Human Behavior, 18, 155-163.

James, W. (1890). Principles of psychology. New York: Henry Holt.

Linn, M.C., & Petersen, A.C. (1986). Emergence and characterization of sex differences in spatial ability: A meta-analysis. Child Development, 56, 1479-1498.

MacIntyre, T. (1997). Gender differences in cognition: A minefield of research issues. The Irish Journal of Psychology, 18(4), 386-396.

Maguire, E.A., Frackowiak, R.S.J., & Frith, C.D. (1997). Recalling routes around London: Activation of the right hippocampus in taxi drivers. Journal of Neuroscience, 17, 7103-7110.

Masters, M.S., & Sanders, B. (1993). Is the gender difference in mental rotation disappearing? Behavior Genetics, 23, 337-341.

Matthews, M.H. (1987).Sex differences in spatial competence: The ability of young children to map 'primed' unfamiliar environments. Educational Psychology, 7, 77-90.

McBurney, D.H., Gaulin, S.J.C., Devineni, T., & Adams, C. (1997). Superior spatial memory of women: Stronger evidence for the gathering hypothesis. Evolution and Human Behavior, 18, 165-174.

Mead, M. (1935). Sex and temperament in three primitive societies. New York: Morrow.

Moffatt, S.D., Hampson, E., & Hatzipantelis, M. (1998). Navigation in a 'virtual' maze: Sex differences and correlation with psychometric measures of spatial ability in humans. Evolution and Human Behavior, 19, 73-87.

Ridley, M. (1996). Evolution (2nd ed.). Cambridge, MA: Blackwell Science.

Silverman, I, & Philips, K. (1998). The evolutionary psychology of spatial sex differences. In C. Crawford & D.L. Krebs (Eds.), Handbook of evolutionary psychology: Ideas, issues, and applications. Mahwah, NJ: Lawrence Erlbaum Associates.

Silverman, I., & Eals, M. (1992). Sex differences in spatial abilities: Evolutionary theory and data. In J.H. Barkow, L. Cosmides, & J. Tooby (Eds.), The adapted mind: Evolutionary psychology and the generation of culture. New York: Oxford University Press.

Skinner, B.F. (1948). Walden two. New York: MacMillan.

Sober, E. & Wilson, D.S. (1998). Unto others: The evolution and psychology of unselfish behavior. Cambridge, MA: Harvard University Press.

Stumpf, H., & Eliot, J. (1995). Gender-related differences in spatial ability and the k factor of general spatial ability in a population of academically talented students. Personality and Individual Differences, 19, 33-45.

Tagaris, G.A., Kim, S.-G., Strupp, J.P., Andersen, P., Ugurbil, K., & Georgopoulos, A.P. (1997). Mental rotation studied by functional magnetic resonance imaging at high field (4 tesla): performance and cortical activation. Journal of Cognitive Neuroscience, 9, 419-432.

Tooby, J. & DeVore, (1987). The reconstruction of hominid behavioral evolution through strategic modeling. In W. Kinzey (Ed.), Primate models of hominid behavior. New York: SUNY Press.

Tooby, J., & Cosmides, L. (1992). The psychological foundations of culture. In J.H. Barkow, L. Cosmides, & J. Tooby, 1992, The adapted mind: Evolutionary psychology and the generation of culture. New York: Oxford University Press.

Vandenberg, S.G. & Kuse, A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. Perceptual and Motor Skills, 47, 599-604.

Wilson, M. & Daly, M. (1992). The man who mistook his wife for a chattel. In J.H. Barkow, L. Cosmides, & J. Tooby, The adapted mind: Evolutionary psychology and the generation of culture. New York: Oxford University Press.