*This paper appeared in Advances in Infancy Research, **11**, 193-217 (1997)*

# Is autism an extreme form of the "male brain"?

Simon Baron-Cohen and Jessica Hammer

Departments of Experimental Psychology and Psychiatry

University of Cambridge

Downing St, Cambridge, CB2 3EB, UK.

Acknowledgements Simon Baron-Cohen is supported by the MRC (UK), the Wellcome Trust, and the Gatsby Foundation. Jessica Hammer is currently a student at Harvard University, and was a visiting research student during the course of this work. We are grateful to the Cambridge Autism and Asperger Support Groups for their cooperation in our studies, and to Bridget Lindley, Geoff Sanders, Helena Cronin, Geoff Miller, Patrick Bolton,, and Therese Jolliffe, for discussion of these ideas.

## I. INTRODUCTION: COGNITIVE SEX DIFFERENCES

The sexes differ biologically. This much is uncontroversial. But the statement "the sexes differ psychologically" has weathered considerable controversy. This is without doubt because the scientific question ("do the sexes differ psychologically?") has been repeatedly confused with the political question ("should the sexes be treated as equals?"). We are clearly in favour of the two sexes being treated as equals as regards their political rights, but we wish to separate this from the scientific question, which is an empirical issue. After decades of research in this area, some sex differences at the psychological level are repeatedly found. Small but statistically significant differences persist on specific psychological tests, between males and females. Note in advance that these differences are not true of every male and female. Far from it. The differences only emerge when group means are compared.

Some of the key findings (for reviews, see Buffery and Gray, 1972; Kimura, 1992; Halpern, 1992; McGee, 1979; Geary, 1995, in press) are that (as a group) women are superior to men on:
(a) language tasks (such as the Controlled Association Task - eg: list as many word associations as you can for each target word in a list, in a limited time - Kimura, 1992). Females also show a faster rate of language development, and a lower risk for developmental dysphasia. (See Hyde and Linn, 1988, on sex differences in language; and Bishop, 1990, on language disorder);
(b) tests of social judgement (Hall, 1977; Halpern, 1992; Argyle and Cooke, 1976);
(c) measures of empathy and cooperation (Hutt, 1972);
(d) rapid identification of matching items (also known as “perceptual speed”: Kimura, 1992);

(e) ideational fluency (eg: list as many things as you can that are the same colour: Kimura, 1992);

(f) fine-motor coordination (eg: placing pegs in pegboard holes: Kimura, 1992);

(g) mathematical calculation tests (Kimura, 1992);

(h) pretend play in childhood (Hutt, 1972).

In contrast, men (as a group) are superior to women on:

(i) mathematical reasoning, especially geometry and mathematical word problems (Lummis and Stevenson, 1990; Stevenson et al, 1990; Marshall and Smith, 1987; Steinkamp et al, 1985; Johnson, 1984; Mills, Ablard, and Stumpf, 1993). Benbow and Stanley (1980, 1983) for example reports that at high-level mathematics, the male-female ratio is 13:1;

(ii) the Embedded Figures Task (ie: finding a part within a whole) (Witkin et al, 1971).

(iii) the Mental Rotation Task (ie: imagining how an object will look when it is rotated, or how a sheet of paper will look when it is folded: Masters and Sanders, 1993; Kalichman, 1989);

(iv) some (but not all[1]) spatial skills - mostly Euclidean geometric navigation (Linn and Petersen, 1985; Gilger and Ho, 1989; Law, Pellegrino, and Hunt, 1993; Voyer, Voyer, and Bryden, 1995; Witelson, 1976). Spatial superiority in males is even found in childhood (Kerns and Berenbaum, 1991)[2].

(v) target-directed motor skills, such as guiding or intercepting projectiles - irrespective of the amount of practice (Kimura, 1992; Buffery and Gray, 1972).

---

[1] Kimura (1992) for example reports that men are not superior over women on measures of recall of landmarks from a route.

[2] Hyde, Geringer, and Yen (1975) present data suggesing that the male superiority on the Embedded Figures Task is actually a function of general spatial ability.

We wish to underline that we are not arguing on the basis of the findings reviewed above that one sex is *better* than another. Rather, we simply wish to draw attention to the fact that there seem to be different cognitive styles associated with being male or female. It is important to keep clear that not every male will have a spatial advantage. (Indeed, the first author of this article readily admits he does not!) But the likelihood of having a spatial advantage is raised if you are male. Equally, not every female is spatially disadvantaged. (Indeed, the second author of this article readily admits she finds even complex spatial tasks effortless.) Yet the likelihood of showing a social and language-related advantage is raised if you are female.

Such sex differences could of course be the result of differential socialization, or different biological predispositions, or both. In this article, we examine the idea that such psychological differences are in part the result of biological differences in brain development, this itself being the product of genetic and endocrinal differences (see, for example, Halpern, 1992). Our main reason for pursuing this line of reasoning is the evidence from autism. It might initially seem strange to be arguing from one instance of developmental psychopathology to make claims about normal development, and about the biological evolution of psychological sex differences. Nevertheless, we invite readers to follow the trail, and then draw their conclusions based on what has been revealed.

## II. THE MODEL: DIFFERENT BRAIN TYPES

We have a working assumption, based on a large body of work (see reviews by Halpern, 1992; Kimura, 1992) that during foetal life, endocrine factors shape the brain as either:

(a) more "social[3]" and less "spatial[4]" (Moir and Jessel, 1989, in their popular book, for shorthand call this "the female brain type"); or

(b) more spatial and less social ("the male brain type").

In this article, we operationally define the male brain type as an individual whose spatial (SP) skills are in advance of his or her social (SOC) skills. That is, they show an SP>SOC discrepancy. This is regardless of their biological, chromosomal sex. (Thus, your mother could have a male brain type.) Similarly, we will define the female brain type as an individual whose social (SOC) skills are in advance of his or her spatial (SP) skills. That is, they show a SOC>SP discrepancy. Again, this is regardless of their biological sex (so your father could have the female brain type.) Clearly, this suggests that yet other people might have neither the male nor the female brain type, because their SOC skills are roughly equal to their SP skills. We will call this third possibility the "cognitively balanced brain type"[5]. Autism (and Asperger Syndrome), we will argue, are extreme forms of the male brain type. That is, the SP>SOC discrepancy is

---

[3] "Social" here refers specifically to `empathy' and `sensitivity to mental states in others'. It does not refer more broadly simply to `interacting with others'.

[4] "Spatial" here broadly covers `mathematical', `geometric', and `relational'. This therefore includes the skills that are involved in any of the following: construction, maths, architecture, visual design, music, etc.

[5] We could have called the male brain type "the spatial brain", and the female brain type "the social brain", to avoid the risks of stereotyping. However, this terminology would have been inadequate for several reasons. First, the female brain type includes not only a SOC>SP discrepancy, but also a clustering of other superior skills (eg: language), and may include yet other superior skills that have not been fully identified. Equally, the male brain type includes not only a SP>SOC discrepancy, but also a clustering of other superior skills (eg: narrowed attention), and again, it may include other superior skills that have not been fully identified.

Calling them Brain Types 1 and 2 was another option open to us, but this simply ignores that if you are biologically male or female, you have an increased likelihood of having one brain type over the other. We have therefore decided to risk the accusation of being non-PC, and hope that our readers will give us a dispassionate enough reading to evaluate the arguments properly, and realize that we do not intend such terminology to have any sexist consequences.

even larger than in the normal male brain type. These types of brain are summarized in Figure 1. We begin by a brief review of the condition of autism and by introducing its relevance to the study of sex differences.

insert Figure 1 here

**III. AUTISM**

Autism is widely regarded to be the most severe of the childhood psychiatric conditions (Frith, 1989; Baron-Cohen and Bolton, 1993). It is diagnosed on the basis of abnormal social development, abnormal communicative development, and the presence of narrow, restricted interests, and repetitive activity, along with limited imaginative ability (DSM-4, 1994). Such children fail to become social, instead remaining on the periphery of any social group, and becoming absorbed in repetitive interests and activities, such as collecting unusual objects or facts. It is a tragedy for their families who work tirelessly to attempt to engage with and socialize their child, mostly with very limited results.

So much for the clinical description. Of more relevance to this article, autism is a predominantly *male* condition. If one takes the population of autism as a whole (75% of whom not only have autism but also have mental handicap), the sex ratio is 4:1 (m:f) (Rutter, 1978). If one takes just the 'pure' cases of autism (who are also sometimes referred to as having Asperger Syndrome), whose IQs are in the normal range, the sex ratio is even more dramatic: 9:1 (m:f) (Wing, 1981)[6]. Without doubt, then, autism (and Asperger Syndrome) has a strong relationship with being male. Precisely what this relationship is has received little research attention. The core aim of this article is to propose a model to explain the connection between autism and being male.

Autism (and Asperger Syndrome) appear to be strongly heritable. This will be important to our later argument that autism is an extreme form of the 'male brain-type'. Here is the heritability evidence. First, family studies have shown that first degree relatives of people with autism have a raised risk of autism, compared to population baseline levels (Folstein and Rutter, 1988). For example, whilst estimates of autism in the general population range from 1 in 2500, to 1 in 1000 (Wing and Gould, 1979), the sib risk rate in families with a child with autism is 3%. This is 50-100 times higher than the population baseline rate. Such family data could imply an environmental or hereditary cause. However, twin studies implicate a genetic aetiology more persuasively. The concordance rate for autism among monozygotic (MZ) twins is 36%, whilst the concordance rate among dizygotic (DZ) twins is no higher than the sib risk rate (Folstein and Rutter, 1988; Bolton and Rutter, 1990). Steffenberg et al (Steffenberg et al, 1989) found an even stronger difference between MZ and DZ concordance rates (91% vs 0%). Whilst such twin studies are not watertight evidence for hereditary factors, they are strongly suggestive of it.

**Cognitive Profile**

[6] Such individuals are either described as having "high functioning autism" or "Asperger Syndrome", after Hans Asperger (1944) who first described such a group of children. There may be a difference between these two conditions (Ozonoff, Rogers, and Pennington, 1991), but for the present purposes we will consider them as one group.

Regarding the cognitive profile of children with autism, consistent strengths and weaknesses have been reported and replicated. Here, we pick out one key strength and one key weakness, because of their importance to our later argument relating autism to cognitive sex differences. First, children with autism perform *better* than mental age matched control groups on the Embedded Figures Test (Shah and Frith, 1983) and on the Block Design Subtest of the Weschler IQ tests (Shah and Frith, 1993). (Examples of the Embedded Figures Test are shown later, in Figure 2.) Frith (1989) puts this in the following terms: the normal child and adult has a disposition to"see the whole and not the parts", whilst children with autism instead "see the parts but not the whole". More precisely, it is not that children with autism cannot see whole objects or scenes. Rather, they appear to be especially gifted at spatial analysis, and they focus in on detail. On tasks like the Embedded Figures Test, or the Block Design Test, this expresses itself as a superior skill. Whether this superior ability is specific to the global-local distinction, or is a more general spatial superiority, it not yet clear. Recall though that the Embedded Figures Test is one on which normal males perform better than normal females. More of that later.

Secondly, children with autism perform *worse* than mental-age matched control groups on selective aspects of social cognition, especially on tests involving the ascription of mental states to other people (Baron-Cohen, Leslie, and Frith, 1985; see Baron-Cohen, 1990, 1995, for a review). This latter capacity is referred to as the use of a "theory of mind", or "mindreading". Mindreading is held to be the normal way in which we make sense of and predict events in the social world. The normal person interprets actions in terms of what the agent's likely *intentions* are, and what the agent might be *thinking, intending, wanting* etc., This is also the strategy normal people use for decoding communication. Children with autism are correspondingly described as suffering from "mindblindness", in failing to recognize mental states as underlying people's behaviour and communication. (Again, recall that social sensitivity is an area in which normal females are believed to perform at a superior level to normal males.) It is now time to draw the connections between autism and sex differences more explicitly.

**The relevance of autism to the study of psychological sex differences**

We suggest that it may be no coincidence that (1) autism is considerably more common among males; (2) in autism, psychological strengths are on the Embedded Figures Test, a domain (spatial analysis) in which normal males are superior; and (3) in autism, psychological weaknesses are in social judgement, and specifically theory of mind tests, a domain in which normal females are superior. Rather than being coincidental patterns, it may be that these outcomes reflect the existence of sex-linked neurodevelopmental processes in the population, and that autism is an extreme form of the male neurodevelopmental pattern. This idea can be traced back to Hans Asperger (1944) who said "the autistic personality is an extreme variant of male intelligence" (p. 84, in Frith's [1991] translation). Until now, as far as we are aware, there have been no systematic tests of this idea.

In the next section we review some of our current experimental work that tests female superiority in theory of mind (SOC) reasoning and male superiority on the Embedded Figures

(SP) Test. We also review current experiments from our laboratory that test the parents of children with Asperger Syndrome on both theory of mind (SOC) skills, and the Embedded Figures (SP) Test[7]. Since at least one of each pair of such parents can in most cases be assumed to be carrying the gene(s) for Asperger Syndrome/ autism, these studies test the theory that, relative to normal controls, affected parents are superior on the Embedded Figures (SP) Test, and significantly worse on theory of mind (SOC) tests. Expressed differently, the studies summarized below test the theory that affected parents show the male brain type (SP>SOC) more strongly than sex-matched controls. In the final section of this paper, we return to the model of sex-linked brain development to consider possible neurobiological factors that might underpin the findings presented. This is relevant to infancy research in that the neurocognitive differences are postulated to originate during foetal and early infant development, and to have life-long effects.

[7] The experimental work summarized in the next section is part of work in progress. Hence most references are to unpublished laboratory reports at this stage. Copies of these are available from the authors on request.

## IV. RECENT EXPERIMENTAL EVIDENCE ADDRESSING THE MODEL

### Experiment 1: Are males superior on the Embedded Figures Test?

This study summarized here is reported in Baron-Cohen and Hammer (1996). This aimed to replicate previous findings in the literature (Witkin et al, 1971). 15 males and 13 females were investigated, in the age range 20-65 years. They were given the Embedded Figures Test (Witkin et al, 1971), as described in the published manual (Set A only). In this test, the subject is first given a practice trial, in which it is explained that the subject must find the simple shape within the complex shape. The complex shape is presented for 15 seconds, and the subject is then invited to describe it, to ensure they are attending to it. This is then turned over, to show the simple shape for 10 seconds. The card is then turned back, thus re-presenting the complex shape, and the subject is given a maximum of 3 minutes (180 secs) to trace the simple shape within the complex shape. (The subject can turn back to look at the simple shape as often as they liked.) The task is thus one of spatial analysis of a visual design into its constituent segments. The subject is instructed to proceed as quickly as possible, and performance is timed. There are 12 items in the complete test.

Baron-Cohen and Hammer (1996) found that normal males were quicker than normal females at accurately identifying the simple shape within the complex shape. Mean speed for identifying the simple shape was 46.2 seconds for males (sd = 20.5), and 66.7 seconds for females (sd = 36.7). This difference is significant. This therefore successfully replicates the earlier findings by

Witkin et al (1971).

**Experiment 2: Are normal females superior on the "Reading the Mind in the Eyes" Test?**

This study was first reported in Baron-Cohen, Arunasalam, Patel, and Sharma (1996). The test is summarized here. Essentially, it is a test of theory of mind ability, pitched at an adult, sophisticated level[8]. In this new test, the subject is presented with 25 photographs of the eye region of the face alone, one stimulus at a time. After looking at the photo for 3 seconds, the photo is then turned over, and the subject is presented with a forced choice of two descriptors, and is asked to judge which word best describes what the person in the photograph is thinking or feeling. The subject has a maximum of 5 seconds to respond. Examples of the eye-stimuli are shown in Figure 2.

Results showed that females are indeed superior on this test of Reading the Mind in the Eyes. Thus, the mean number correct amongst 25 females was 20.24 (sd =3.52), whilst the mean number correct amongst 25 males was 18.1 (sd = 3.4). Again, this is significant statistically. Experiments 1 and 2 therefore confirm the female trend is for a SOC>SP discrepancy, and the male trend is for the opposite (a SP>SOC discrepancy).

---

[8] This is because most theory of mind tests are designed to measure a normal 4-6 year old level of ability, reflecting most researchers' interests in preschool development (eg: Wimmer and Perner, 1983; Wellman, 1990). Such tests are usually "one-shot" tests, with a pass-fail score only, making the search for individual differences and sex differences impossible, and usually leading to ceiling effects. For example, the majority of normal 4-5 year old children pass traditional theory of mind tests.

insert Figure 2 here

**Experiment 3: Are normal females superior on the Faux Pas Test?**

This study is reported in Baron-Cohen, O'Riordan, & Jones (1996) and is summarized here. This is an additional method for examining SOC sex differences in the use of a theory of mind, in this case as it applies to communication. Essentially, the task involves listening to 10 audiotaped short stories, each just 4 sentences long, in which one character commits a social faux pas. The subject is asked to identify which of 3 characters mentioned in a story "said something they shouldn't have said". The faux pas in each story hinges on one character saying something that another character should not *know* about, either because it is a secret, or because it would in some way be hurtful. 4 examples from the Faux Pas test are shown in Figure 3. The test was given to 20 children age 9 years olds (10 female, and 10 male). Results showed that girls scored higher than boys on the test (girls mean = 7.3, sd = 2.0; boys mean = 4.9, sd = 2.7). Again, this SOC sex difference was significant.

insert Figure 3 here

**Experiment 4: Are parents of children with Asperger Syndrome superior to normals on the Embedded Figures Task?**

This is also reported in Baron-Cohen and Hammer (1996). 30 parents of 15 children with Asperger Syndrome (AS) were tested on the Embedded Figures Test, as described in Experiment 1 above. As mentioned in the introduction of this article, the parents were tested because in most cases at least one of each pair (per family) could be assumed to be a carrier of the gene(s) for AS. We predicted that if AS and autism were extremes of the normal male brain type, then the phenotype for an *affected* parent should include a superiority on the Embedded Figures (SP) Test (relative to sex-matched normal controls).

This prediction was confirmed. After identifying affected parents (defined as parents who on a questionnaire clearly shared aspects of the symptomatology of AS, despite having no diagnosis of AS themselves), results showed that affected mothers were significantly faster than normal females on the Embedded Figures Test (affected mothers, mean = 31.1 seconds, sd = 5.8; normal females, mean = 66.7 seconds, sd = 36.7). Indeed, the affected mothers were also faster than normal males. Equally, affected fathers scored a mean of 32.8 (sd = 11.6), which was significantly faster than normal males (mean = 46.2, sd, = 20.5). Affected mothers and fathers did not differ from each other.

**Experiment 5: Are parents of children with Asperger Syndrome impaired on the Reading the Mind in the Eyes Test?**

This is also reported in Baron-Cohen and Hammer (1996). The same 30 parents of 15 children with Asperger Syndrome (AS) as took part in Experiment 4 were tested on the Reading the Mind in the Eyes Test, as described in Experiment 2 above. We predicted that if AS and autism were extremes of the normal male brain type, then the phenotype for an affected parent should include a deficit on the Reading the Mind in the Eyes (SOC) Test (relative to sex-matched normal controls).

This prediction was confirmed. Affected mothers scored a mean of 17.7 (sd = 3.4) on the Reading the Mind in the Eyes Test, and this was significantly worse than normal females (mean = 22.1, sd = 2.3). Equally, affected fathers scored a mean of 16.2 (sd = 2.9), which was significantly worse than normal males (mean = 18.1, sd = 3.03). Affected mothers and fathers did not differ from each other.

**Experiment 6: Are adults with autism/ Asperger Syndrome superior on the Embedded Figures Task?**

This is reported in Jolliffe and Baron-Cohen (1996). 17 subjects with high-functioning autism and 17 subjects with AS (all of normal IQ) took part. Results showed that these patients were significantly better than normal age and IQ matched controls on the Embedded Figures Test. The mean speed of the group with autism was 29.28 secs (sd =21.5), and the mean speed of the group with AS was 32.21 secs (sd = 32.1). This was as fast as affected parents of children with AS.

**Experiment 7: Are adults with autism/ Asperger Syndrome impaired on the Reading the Mind in the Eyes Test?**

This is reported in Baron-Cohen, Gilbert, Pickett, Rohrer, and Jolliffe (1996). 16 subjects with either high-functioning autism or AS (all of normal IQ, and of both sexes) took part. Results showed that, as predicted, both groups were significantly worse than normal age and IQ matched controls on the Reading the Mind in the Eyes (SOC) Test, as described in Experiment 2. Their mean score was 18.44 (sd = 2.71), whilst a control group of normal subjects (matched for sex, age, and IQ) scored 21.13 (sd = 2.05). This reveals a deficit of a more subtle but similar nature than has been found in children with autism (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, and Walker, 1995).

**Experiment 8: Are children with Asperger Syndrome/ autism impaired on the Faux Pas Test?**

This is reported in Baron-Cohen, O'Riordan, and Jones (1996). 11 subjects with AS or high-functioning autism with an MA of 13 years old were tested using the Faux Pas Test, as described in Experiment 3. Results showed that, as predicted, they were significantly worse than normal, age and MA matched controls on this test. The subjects with AS scored a mean of 5.3 (sd = 1.1), which is equivalent to a performance of a normal 7-8 year old.

**Summary of the 8 experiments**

Experiment 1 confirms the male superiority on the Embedded Figures Task, whilst Experiments 2 and 3 confirm the female superiority in theory of mind tasks, at least at the more complex levels tested here. Expressed differently, Experiments 1-3 provide evidence for both the normal male brain type (SP>SOC), and the normal female brain type (SOC>SP). Experiments 4 and 5 confirm the prediction that affected parents of children with AS show the male brain type in stronger form (a SP>SOC discrepancy to a greater degree), and Experiments 6 - 8 confirm the prediction that people with AS/ high-functioning autism themselves show the male brain type in the most extreme form (a massive SP>SOC discrepancy). Figures 4 and 5 summarize the main findings visually. In the next section of this paper, we present a model in order to attempt to explain this pattern of results.

insert Figures 4 and 5 here

**V. NEUROBIOLOGICAL FACTORS**

If the sex differences reviewed above are neurobiological in origin, then one needs a model of brain function that can accommodate them. Here we extend the model outlined earlier, in neurodevelopmental directions, based on our reading of the literature (Halpern, 1992; Kimura, 1992; Geary, in press; and other work cited earlier). It is developmental simply because the sex differences that have been documented appear to be present from infancy onwards.

**Structural and endocrinal factors**

Post conception, the embryo undergoes cell differentiation. In a male embryo, the XY genotype controls the growth of testes, and at approximately 8 weeks gestational age, the testes are not only formed but release bursts of testosterone. Testosterone has frequently been proposed to have a causal effect on subsequent foetal brain development[9], such that by birth, clear sex differences are evident. In rats, the 'masculinizing' effects are confined to a critical or sensitive period of testosterone release, around gestational day 17 and postnatal days 8-10 (Rhees, Shryne, and Gorski, 1990). In humans, at birth, female babies attend for longer to **social** stimuli, such as faces and voices, whilst male babies will attend for longer to non-social, **spatial** stimuli, such as mobiles (Goodenough, 1957; Eibl-Ebelsfeldt, 1989; McGuiness and Pribam, 1979). Levels of prenatal testosterone (as assessed during amniocentesis) predict spatial ability at follow-up at age 7 (Grimshaw, Sitarenios, and Fenegan, 1995[10]). One suggestion is that the release of testosterone at this stage of foetal life may determine aspects of brain development, leading to either the male

[9] Perhaps the best known formulation of the testosterone model is by Geschwind and Galaburda (1987). Their model is far ranging, including predictions that testosterone in fetal life will impact on immune status, cerebral lateralization, handedness, risk for neurodevelopmental disorder, and many other factors. Evidence for it is mixed. See Bryden, McManus, and Bulman-Fleming (1994) for a critical review, and the commentaries on their target article for full debate. For more recent review of the role of both male and female sex hormones in development, see Grimshaw, Sitanerios, and Finegan, 1995, and Fitch and Dennenberg (in press).

[10] In the Grimshaw et al (1995) study, an association was only found between prenatal testosterone and spatial ability in girls, not boys. The authors of that paper interpret this finding in the context of the claim by Gouchie and Kimura (1991) that high levels of prenatal testosterone might have a *curvilinear* relationship with spatial ability.

or female brain type, as defined earlier in this paper.

Precisely which structures distinguish these two brain types is still controversial (see Fitch and Dennenberg, in press, for a review). In humans:

(a) Kimura (1992) reviews evidence for differences in cerebral lateralization. In particular, she reviews evidence by De Lacoste et al that at birth, in the human male foetus, the right hemisphere cortex is *thicker* than the left;

(b) Some reports show the corpus callosum is larger in females (De la Coste-Utamsing and Holloway, 1982), though reports are conflicting (Wittelson, 1989, 1991; Habib et al, 1991; Dennenberg, Kertesz, and Cowell, 1991). Hines (1990) reviews 13 studies and concludes that in females the corpus callosum is larger, and that this might cause the female superiority in verbal fluency (as a function of better interhemispheric transfer of information). It is of interest that in autism, a recent study shows the corpus callosum to be smaller even than age and sex matched controls (Egaas, Courchesne, and Saitou, 1994). This may be consistent with autism being an extreme form of the normal male brain type.

In rats, the differences between male and female brains are clearer:

(1) males have a larger SDN-POA (sexually dimorphic nucleus of the preoptic area - a region of the hypothalamus) (Dohler et al, 1984);

(2) Females have a larger hypothalamic anteroventral preoptic nucleus (AVPN) (Bloch and Gorski, 1987);

(3) Males have increased cortical thickness (Diamond, Johnson, and Ehlert, 1979). Female rats whose ovaries are removed at 90 days old (but not at 300 days old) show increased cortical thickness, implying that this neural difference is under time-limited hormonal control.

(4) Diamond, Johnson, Young, and Singh (1983) found male rats have a thicker right cerebral cortex, whilst females show no left-right difference;

(5) The corpus callosum is significantly larger in the adult male than female rat[11] (Berrebi et al, 1988; Zimmerberg and Scalzi, 1989). Note that a single injection of 1 mg of testosterone propionate to the 4 day old female pup significantly increases their adult corpus callosum area, to male levels (Fitch et al, 1990).

Finally, both in humans and rats, there is evidence that spatial abilities are affected by hormonal changes. For example, exposure to androgens prenatally increases spatial performance in human females and females of other species (Diamond et al, 1979; Resnick et al, 1986; see Hines and Green, 1991; and Halpern, 1992), and castration of the rat decreases spatial ability (Williams, Barnett, and Meck, 1990). The neuroendocrine evidence may be consistent with the notion of a male or female brain type being a function of the levels of circulating male or female hormones during critical periods of neural development[12].

**Laterality and sex differences**

---

[11] Note that the corpus callosum sexual dimorphism finding in the rat appears to be the opposite of that found in the human.

[12] Precisely when these critical periods are is left open here, though these are likely to be during foetal and early infant stages of development.

When considering neurocognitive sex differences, it is important to also consider the large literature on cerebral lateralization. Geschwind and Gallaburda's (1987) well-known model assumes that there is a "standard dominance pattern" (strong left hemisphere dominance for language and handedness, and strong right hemisphere dominance for non-linguistic functions such as visuospatial abilities). Their model predicted that elevated fetal testosterone levels push lateralization away from this standard pattern and toward an "anomalous" pattern. Their model has been criticized on many grounds (see Bryden et al, 1994, with peer commentary on their review), but certainly, important connections have been demonstrated between lateralization, sex, and handedness. This is true both in the normal population, and into the population with autism.

*The normal population*

In the normal population, 95% of right handed people have language lateralized to the left hemisphere (as assessed by dichotic listening tasks), and only very rarely to the right (about 5% of cases). In left-handed people, lateralization of language to the right hemisphere is more common (about 25%). Bryden (1988) in his extensive review, concludes that left-handers show reduced language-laterality effects, ie: they show a smaller difference in how quickly they respond to stimuli presented to their right or left ear or visual field, relative to right-handers. Thus, he found 82% of right-handers, but only 62% of left handers, show a right-ear advantage in dichotic listening (verbal) tasks. Males have a much higher rate of left-handedness than females (Halpern, 1992). Thus, when Bryden analysed the same data by sex, he found that 81% of males, but only 74% of females, showed a right ear advantage. He concludes that in general, females have a more bilateral organization of cognitive abilities than males. Hines (1990) expresses the same idea differently: the degree of left-hemisphere dominance is greater in males than females.

Regarding the link between lateralization and spatial ability, Benbow (1986) reported an elevated incidence of left-handedness in children gifted mathematically. Hassler and Gupta (1993) also found left-handers score higher on a measure of musical talent, and (replicating the earlier work) show reduced right-ear advantage. In addition, Cranberg and Albert (1988) reported an elevated incidence of non-right handedness in high level male chess players. Rosenblatt and Winner (1988) found a very high rate of left-handedness and ambidextrality in children with exceptional drawing ability. Kimura and D'Amico (1989) found that non-right handed science students in university have higher spatial ability than right-handed controls. Sanders, Wilson, and Vandenberg (1982) found, in their family study, that left-handed men score higher than right-handed men on spatial tasks (though left-handed women were worse than right-handed women). Indeed, elevated rates of left-handedness occurs in the those working in the visuo-spatial arts (Mebert and Michel, 1980; Peterson, 1979), in architecture, and in engineering (Petersen and Lansky, 1974) - all 'spatial' fields[13]. Direction of handedness appears to be strongly familial (McManus, 1985).

[13] See Martino and Winner, 1995, for a recent study of this area.

The above review therefore suggests that the 'male brain type' (as defined earlier) is likely to involve complex sex-by-laterality interactions. Halpern (1992) summarizes some of the evidence for this: right-handed males perform better on spatial tests, but worse on verbal tests, relative to left-handed males. Right-handed females perform worse on spatial tests, but better on verbal tests, relative to left-handed females. The above evidence points to the importance of these two variables, but does not yet enable us to draw final conclusions about the brain basis of these different brain types.

*Autism*

What about cerebral lateralization in autism? We know that autism is more common among males, but in addition an elevated incidence of left-handedness in autism has been reported. For example, Fein, Humes, Kaplan, Lucci, and Waterhouse (1984) found an 18% incidence of left-handedness in autism. Fein et al also found that 36% of their sample showed no preference for either hand (ie: a reduced degree of handedness). Satz and colleagues (Satz, Soper, Orsini, Henry, and Zvi, 1985; Soper, Orsini, Henry, Zvi, and Schulman, 1986) found a very similar picture: in their autistic sample, 44% were right handed, 22% left handed, and 36% had no preference. Finally, McManus, Murray, Doyle, and Baron-Cohen (1992) found that even those children with autism who have a preferred hand nevertheless often show no difference in skill between the preferred and non-preferred hand[14].

---

[14] It should be noted though that anomalous handedness is also present in children with general developmental delay (irrespective of whether they have autism - see Bishop, 1990). It remains to be seen, then whether the

Studies looking at lateralization in autism using dichotic listening tasks and evoked auditory potentials also reveal abnormalities. Thus, Prior and Bradshaw (1979) found children with autism show no clear right-ear advantage in dichotic listening tasks; and Dawson, Finley, Phillips, and Galpert (1986) found they did not show the asymmetry of evoked response to auditory speech, unlike normal controls. The most recent relevant study is a SPECT neuroimaging investigation of autism reporting a lack of normal hemispheric asymmentry (Chiron, Leboyer, Leon, Jambaque, Nuttin, and Syrota, 1995). Satz concludes that children with autism are less strongly lateralized, compared to normal children. However, this conclusion may be premature, since there are currently so few studies of laterality in autism.

## VI. CONCLUSIONS: THE CONTINUUM OF MALE AND FEMALE BRAIN TYPES

An important assumption made in this paper is that all individuals fall on a **continuum** as regards male and female brain type. As stated in the introduction, we have referred to some individuals as "cognitively balanced", being equally good at Spatial (eg: Embedded Figures) and Social (eg: theory of mind) tasks. They show no SP-SOC discrepancy. Other individuals are better at Spatial (Embedded Figures)[15] than they are at Social (theory of mind) tests: this

---

anomalous handedness in autism is specific to this condition, or secondary to general developmental delay that is present in two-thirds of children with autism.

[15] The Embedded Figures Test is just one SP test that we have used here. Performance on the Embedded Figures Test correlates reasonably with other SP tests (Witkin et al, 1971).

corresponds to the male brain type. People with the male brain type might show this discrepancy just marginally (the normal male brain type), or just more than this (a touch of Asperger Syndrome), or more markedly still (frank Asperger Syndrome), or in an extreme way (classic autism). Such a model encompasses Lorna Wing's (1988) important notion of an autistic continuum, blurring into the normal population.[16] The work reviewed here constitutes preliminary but suggestive evidence for the notion of male and female brain types, defined in psychometric ways along the SP and SOC dimensions. The above psychological studies are also consistent with the claim that autism (and Asperger Syndrome) is an extreme form of the male brain. Currently, the neurobiological basis of such a model is still unclear.

This model raises a set of new questions. First, exactly what happens to cause an individual at the extreme end of the postulated continuum to develop autism? Is it early hormonal events? Are these themselves the result of the genetics of having two parents who both have the male brain type? And what does it mean in neurobiological terms for an individual to be an extreme form of the male brain? The cognitive profile (SP>>SOC) needs to be mapped onto its neurobiological substrate. These questions remain to be explored.

Secondly, is the continuum we have highlighted the same as the "field dependence-independence" continuum proposed by Witkin, Dyk, Faterson, Goodenough, and Karp (1962)? Witkin et al defined this dimension as the extent to which an individual is influenced by objects

[16] It is tempting to surmise that children with Williams Syndrome might have an extreme form of the *female* brain type, having a very marked SOC>SP discrepancy (Karmiloff-Smith et al, 1995).

in their visual field. Thus, in the Rod and Frame Test, the subject sits in a darkened room and views a luminous frame that has a luminous rod positioned inside it, positioned at an angle by the experimenter. The subject has to reposition the rod so that it is vertical. Subjects whose judgements are influenced by the tilt of the frame are labeled "field dependent", whilst those who are not are "field independent". A host of studies show that men are more field independent than women. Performance on the Rod and Frame Test are highly correlated with the EFT. A different description of the results in the present paper could be in terms of the male brain being more field independent, and people with autism/Asperger Syndrome (or their affected relatives) being extremes of field independence. Certainly, Witkin et al's concept was never confined to the visual domain, since field independent individuals were also found to be less socially conforming and more "self-reliant" than field dependent individuals. However, the concept of field independence takes us no closer to an understanding of the neurocognitive mechanisms underlying this. That said, it will be important for future work to investigate if the continuum of male and female brain types is the same as, or different to, the continuum of field dependence.

Thirdly, if autism is an extreme of the male brain type, does this mean that <u>all</u> the symptoms of autism are present to a lesser degree in anyone with the male brain type? We think that this is unlikely, but that a weaker version of this merits further testing. Some symptoms in autism are probably independent of the male brain type (such as hypersensitivity to sound), whilst others may well be part of it.

For example, theory of mind development is deviant or delayed in autism; in the general population, we expect there may well be sex differences in rate of theory of mind development, with females being quicker than males; and sex differences in the ability to pretend, again with females being superior. Our tests on children and adults reported earlier already document sex differences in this domain (see Experiments 2 and 3), but these differences only emerge when subtle tests are used, which can highlight individual differences. Sex differences in pretend play have also been previously reported (Hutt, 1972).

Let us take another example. Children with autism show strong compulsions to collect objects, especially when these fit into well-defined categories (such as lists of cars, or small models of cars, or model trains, etc.,). Indeed, such repetitive behavior is a defining symptom in the diagnosis of autism (DSM-IV, 1992). We expect a mild counterpart to this behaviour - such as hobbies that involve collecting sets of objects - might be more common among boys in the general population, if indeed the autistic symptom is an extreme of the male brain type. Some authors have indeed documented that such collecting behaviour is more common in young boys than girls (Marks, 1987) .

The model of brain types discussed in this article also raises another question. If some sex differences in cognition arise for neurodevelopmental reasons, what sorts of evolutionary factors have shaped such sexual dimorphism? These issues are not explored here, though there is a large literature pertaining to this question[17]. The challenge to this neurobiological view will come from any cross-cultural evidence in which the reported sex-differences above are not found.

[17] See for example Buss (1995), Daly and Wilson (1983), Darwin (1859, 1871), Gaulin (1992), Trivers (1972), Hill

In closing, we wish to reiterate that we have not argued that males are impaired in their SOC skills, or females are impaired in their SP skills, in absolute terms. Rather, we have highlighted the relative discrepancies between these two domains, and have suggested that these may define two brain types. We are not in favour of our scientific model being used to reinforce traditional occupational, educational, and economic inequalities between the sexes. A detailed reading of the model should lead the reader to draw conclusions based on individuals' brain type rather than their sex.

(1982) and Kolakowski and Malina (1974).

**Figure 1**: Summary of the brain types.

| **BRAIN TYPE** | **COGNITIVE PROFILE** |
|---|---|
| **The Cognitively Balanced Brain:** | **SP = SOC** |
| **The Normal Female Brain:** | **SP < SOC** |
| **The Normal Male Brain:** | **SP > SOC** |
| **Asperger Syndrome** | **SP>>SOC** |
| **Autism** | **SP>>>SOC** |

**SP = Spatial skills**

**SOC = Social skills**

**Figure 2**: Examples of stimuli from the Eyes Theory of Mind Test (reproduced from Baron-Cohen, Aranasalam, et al, 1995).

Fig 3(a) SAD REFLECTION vs Happy Reflection

Fig 3(b) REFLECTIVE vs Unreflective

Fig 3(c) DOMINANT vs Submissive

Fig 3(d) SYMPATHETIC vs Unsympathetic

**Figure 3**: Examples of stories from the Faux Pas Mindreading Test, reproduced from Baron-Cohen, O'Riordan, & Jones, 1996).

**Figures 4 and 5**: Overlapping distributions for 3 groups (males, females, and parents of children with Asperger Syndrome), measured on Social (Mindreading) or Spatial (EFT) Tasks.

**References**

American Psychiatric Association (1994) Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Washington DC: American Psychiatric Association.

Argyle, M, & Cook, M, (1976) Gaze and Mutual Gaze. Cambridge: Cambridge University Press.

Asperger, H, (1944) Die "Autistischen Psychopathen" im Kindesalter. Archiv fur Psychiatrie und Nervenkrankheiten, **117**, 76-136. Reprinted in Frith, U, (1991) Autism and Asperger's Syndrome. Cambridge University Press.

Baron-Cohen, S, (1990) Autism: a specific cognitive disorder of "mind-blindness". International Review of Psychiatry, **2**, 79-88.

Baron-Cohen, S, (1995) Mindblindness: an essay on autism and theory of mind. MIT Press/Bradford Books.

Baron-Cohen, S, Arunasalam, K, Patel, R, & Sharma, P, (1996) Reading the mind in the face: Is there a "language of the eyes"? Unpublished ms, University of Cambridge.

Baron-Cohen, S, and Bolton, P, (1993) Autism: the facts. Oxford University Press.

Baron-Cohen, S, Campbell, R, Karmiloff-Smith, A, Grant, J, & Walker, J, (1995) Are children with autism blind to the mentalistic significance of the eyes? British Journal of Developmental Psychology, **13**, 379-398.

Baron-Cohen, S, Gilbert, A, Pickett, A, Rohrer, J, & Jolliffe, T, (1996) A study of adults with high functioning autism or Asperger Syndrome on an advanced Theory of Mind Test. Unpublished ms, University of Cambridge.

Baron-Cohen, S, & Hammer, J, (1996) Parents of children with Asperger Syndrome: what is the cognitive phenotype? Unpublished ms, University of Cambridge.

Baron-Cohen, S, Leslie, A.M., & Frith, U, (1985) Does the autistic child have a `theory of mind'? Cognition, **21**, 37-46.

Baron-Cohen, S, O'Riordan, M, & Jones, R (1996) Recognizing faux pas by normal children and children with Asperger Syndrome. Unpublished ms, University of Cambridge.

Benbow, C, (1986) Physiological correlates of extreme intellectual precocity. Neuropsychologia, **24**, 719-725.

Benbow, C, & Stanley, J, (1980) Sex differences in mathematical ability: fact or artifact? Science, **210**, 1262-1264.

Benbow, C, & Stanley, J, (1983) Sex differences in mathematical reasoning ability: more facts. Science, **222**, 1029-1031.

Berrebi, A, Fitch, R, Ralphe, D, Denenberg, J, Friedrich Jr, V, & Denenberg, V, (1988) Corpus callosum: region-specific effects of sex, early experience, and age. Brain Research, **438**, 216-224.

Bishop, D, (1990) Handedness and developmental disorder. Oxford: Blackwells.

Bloch, G, & Gorski, R, (1988) Estrogen treatment in adulthood affects the size of medial preoptic structures in the male rat. Society for Neuroscience Abstracts, **13**, 1165.

Bolton, P, & Rutter, M, (1990) Genetic influences in autism. International Review of Psychiatry, **2**, 67-80.

Bryden, M, (1988) An overview of the dichotic listening procedure and its relation to cerebral organization. In Hugdahl, K, (ed) Handbook of dichotic listening. Chichester, UK: Wiley.

Bryden, M, McManus, I.C., & Bulman-Fleming, M, (1994) Evaluating the empirical support for the Geschwind-Behan-Galaburda model of cerebral lateralization. Brain and Cognition, **26**, 103-167.

Buffery, A, & Gray, J, (1972) Sex differences in the development of spatial and linguistic skills. In Ounsted, C, & Taylor, D, (eds) Gender differences: their ontogeny and significance. Churchill Livingstone.

Buss, D, (1995) Psychological sex differences: origins through sexual selection. American Psychologist, **50**, 164-168.

Chiron, C, Leboyer, M, Leon, F, Jambaque, I, Nuttin, , & Syrota, A, (1995) SPECT study of the brain in childhood autism: evidence for a lack of normal hemispheri asymmetry. Developmental Medicine and Childhood Neurology, **37**, 849-861.

Cranberg, L, & Albert, M, (1988) The chess mind. In Obler, L, & Fein, D, (eds) The exceptional brain: neuropsychology of talent and special abilities. New York: Guilford Press.

Daly, M, & Wilson, M, (1983) Sex, evolution, and behaviour. 2nd edition. PSW Publishers.

Darwin, C, (1859) The origins of species by means of natural selection. John Murray.

Darwin, C, (1871) The descent of man and selection in relation to sex. Modern Library.

Dawson, G, Finley, C, Phillips, S, & Galpert, L, (1986) Hemispheric specialization and the language abilities of autistic children. Child Development, **57**, 1440-1453.

De Lacoste-Utamsing, C, & Holloway, R, (1982) Sexual differences in the human corpus callosum. Science, **216**, 1431-1432.

Denenberg, V, Kertesz, A, & Cowell, P, (1991) A factor analysis of the human's corpus callosum. Brain Research, **548**, 126-132.

Diamond, M, Johnson, R, & Ehlert, J, (1979) A comparison of cortical thickness in male and female rats - normal and gonadectomized, young and adult. Behavioural Neurology, **26**, 485-491.

Diamond, M, Johnson, R, Young, D, & Singh, S, (1983) Morphological hemispheric differences in the rat brain: male-female; right-left. Experimental Neurology, **81**, 1-13.

Dohler, K, Srivasta, S, Shryne, J, Jarzab, B, Sipos, A, & Gorski, R, (1984) Differentiation of the sexually dimorphic nucleus in the preoptic area of the rat brain is inhibited by postnatal treatment with an estrogen antagonist. Neuroendocrinology, **38**, 297-301.

Egaas, B, Courchesne, E, & Saitoh, O, (1995) Reduced size of the corpus callosum in autism, Archives of Neurology, **52**, 794-801.

Eibl-Eibesfeldt, I, (1989) Human ethology. aldine de Gruyter.

Fein, D, Humes, M, Kaplan, E, Lucci, D, & Waterhouse, L, (1988) The question of left-hemisphere dysfunction in infantile autism. Psychological Bulletin, **95**, 258-281.

Fitch, R, Berrebi, A, Cowell, P, Schrott, L, & Denenberg, V, (1990) Corpus callosum: effects of neonatal hormones on sexual dimorphism in the rat. Brain Research, **515**, 111-116.

Fitch, R, & Denenberg, V, (in press) A role for ovarian hormones in sexual differentiation of the brain. Psycholoquy.

Folstein, S, & Rutter, M, (1988) Autism: familial aggregation and genetic implications. Journal of Autism and Developmental Disorders, **18**, 3-30.

Frith, U, (1989) Autism: explaining the enigma. Oxford: Basil Blackwell.

Frith, U, (1991) Asperger and his syndrome. In Frith, U, (ed) Autism and Asperger's Syndrome. Cambridge: Cambridge University Press.

Gaulin, S, (1992) Evolution of sex differences in spatial ability. Yearbook of Physical

Anthropology, **35**, 125-151.

Geary, D, (1995) Reflections on evolution and culture in children's cognition: implications for mathematical development and instruction. American Psychologist, **50**, 24-37.

Geary, D, (in press) Sexual selection and sex differences in mathematical abilities. Behaviour and Brain Sciences.

Geschwind, N, & Galaburda, A, (1987) Cerebral lateralization. Cambridge, MA: MIT Press.

Gilger, J, & Ho, H, (1989) Gender differences in adult spatial information processing: their relationship to pubertal timing, adolescent activities, and sex-typing of personality. Cognitive Development, **4**, 197-214.

Goodenough, E, (1957) Interest in persons as an aspect of sex differences in the early years. Genetic Psychology Monographs, **55**, 287-323.

Gouchie, C, & Kimura, D, (1991) The relationship between testosterone level and cognitive ability patterns. Psychoneuroendocrinology, **16**, 323-334.

Grimshaw, G, Sitarenios, G, & Finegan, J, (1995) Mental rotation at 7 years: relations with prenatal testosterone levels and spatial play experiences. Brain and Cognition, **29**, 85-100.

Habib, M, Gayraud, D, Olivia, A, Regis, J, Salamon, G, & Khalil, R, (1991) Effects of handedness and sex on the morphology of the corpus callosum: a study with brain magnetic resonance imaging. Brain and Cognition, **16**, 41-61.

Hall, J, (1977) Gender effects in decoding non-verbal cues. Psychological Bulletin, **85**, 845-857.

Halpern, D, (1992) Sex differences in cognitive ability. Second edition.

Hasler, M, & Gupta, D, (1993) Functional brain organization, handedness, and immune vulnerability in musicians and non-musicians. Neuropsychologia, **31**, 655-660.

Hines, M, (1990) Gonadal hormones and human cognitive development. In Balthazart, J, (ed) Hormones, brain and behaviour in vertebrates: I. Sexual differentiation, neuroanatomical aspects, neurotransmitters, and neuropeptides. Basel: Karger.

Hines, M, & Green, R, (1991) Human hormonal and neural correlates of sex-typed behaviours. Review of Psychiatry, **10**, 536-555.

Hill, K, (1982) Hunting and human evolution. Journal of Human Evolution, **11**, 521-544.

Hutt, C (1972) In Ounsted, C, & Taylor, D, (eds) Gender differences: their ontogeny and significance. Churchill Livingstone.

Hyde, J, Geiringer, E, & Yen, W, (1975) On the empirical relationship between spatial ability and sex differences in other aspects of cognitive performance. Multivariate Behavioural Research, **10**, 289-309.

Hyde, J, & Linn, M, (1988) Gender differences in verbal ability: a meta-analysis. Psychological Bulletin, **104**, 53-69.

Jolliffe, T, & Baron-Cohen, S, (1996) The Embedded Figures Test in high functioning adults with Autism and Asperger Syndrome. Unpublished ms, University of Cambridge.

Johnson, E, (1984) Sex differences in problem-solving. Journal of Educational Psychology, **76**, 1359-1371.

Kalichman, S, (1989) The effects of stimulus context on paper and pencil spatial task performance. Journal of General Psychology, **116**, 133-139.

Karmiloff-Smith, A, Klima, E, Bellugi, U, Grant, J, & Baron-Cohen, S, (1995) Is there a social module? Language, face-processing and theory of mind in subjects with William's Syndrome and autism. Journal of Cognitive Neuroscience, **7**, 196-208.

Kerns, K, & Berenbaum, S, (1991) Sex differences in spatial ability in childhood. Behaviour Genetics, **21**, 383-396.

Kimura, D, (1992) Sex differences in the brain. Scientific American, **September**, 119-125.

Kimura, D, & D'Amico, C, (1989) Evidence for subgroups of adextrals based on speech lateralization and cognitive patterns. Neuropsychologia, **27**, 977-986.

Kolakowski, D, & Malina, R, (1974) Spatial ability, throwing accuracy, and mans's hunting heritage. Nature, **251**, 410-412.

Law, D, Pellegrino, J, & Hunt, E, (1993) Comparing the tortoise and the hare: gender differences and experiences in dynamic spatial reasoning tasks. Psychological Science, **4**, 35-40.

Linn, M, & Petersen, A, (1985) Emergence and characterization of sex differences in spatial ability: A meta-analysis. Child Development, **56**, 1479-1498.

Lummis, M, & Stevenson, H, (1990) Gender differences in beliefs and achievement: a cross-cultural study. Developmental Psychology, **26**, 254-263.

McGee, M, (1979) Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. Psychological Bulletin, **86**, 889-918.

McGuinness, D, & Pribam, K, (1979) The origins of sensory bias in the development of gender differences in perception and cognition. In Bortner, M, (ed) Cognitive Growth and development: essays in memory of Herbert Birch. Brunner/Mazel.

McManus, I.C., (1985) Handedness, language dominance, and aphasia: a genetic model. Psychological Medicine, Monograph Supplement 8.

McManus, I.C., Murray, B, Doyle, K, & Baron-Cohen, S, (1992) Handedness in childhood autism shows a dissociation of skill and preference. Cortex, **28**, 373-381.

Marks, I, (1987) Fears, phobias and rituals. Oxford University Press.

Martino, G, & Winner, E, (1995) Talents and disorders: relationships among handedness, sex, and college major. Brain and Cognition, **29**, 66-84.

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

Marshall, S, & Smith, J, (1987) Sex differences in learning mathematics: a longitudinal study with item and error analyses. Journal of Educational Psychology, **79**, 372-383.

Mebert, C, & Michel, G, (1980) Handedness in artists. In Herron, L, (ed) Neuropsychology of left-handedness. New York: Academic Press.

Mills, C, Ablard, K, & Stumpf, H, (1993) Gender differences in academically talented young students' mathematical reasoning: patterns across age and subskills. Journal of Educational Psychology, **85**, 340-346.

Moir, A, & Jessel, D, (1989) Brainsex.

Ozonoff, S, Rogers, S, & Pennington, B, (1991) Asperger's Syndrome: evidence of an empirical distinction from high-functioning autism. Journal of Child Psychiatry and Psychology, **32**, 1107-1122.

Peterson, J, (1979) Left-handedness: difference between student artists and scientists. Perceptual and Motor Skills, **48**, 961-962.

Peterson, J, & Lansky, L, (1974) Left-handedness among architects: some facts and speculations. Perceptual and Motor Skills, **38**, 547-550.

Prior, M, & Bradshaw, J, (1979) Hemispheric functioning in autistic children.Cortex, **15**, 73-81.

Resnick, S, Berenbaum, S, Gottesman, I, & Bouchard, T, Jr (1986) Early hormonal influences on cognitive functioning in congenital adrenal hyperplasia. Developmental Psychology, **22**, 191-198.

Rhees, R, Shryne, J, & Gorski, R, (1990) Onset of the hormone-sensitive perinatal period for sexual differentiation of the sexually dimorphic nucleus of the preoptic area. Journal of Neurobiology, **21**, 781-786.

Rosenblatt, E, & Winner, E, (1988) Is superior visual memory a component of superior drawing ability? In In Obler, L, & Fein, D, (eds) The exceptional brain: neuropsychology of talent and special abilities. New York: Guilford Press.

Rutter, M, (1978) Diagnosis and definition. In Rutter, M, & Schopler, E, (eds) Autism: a reappraisal of concepts and treatment. New York: Plenum Press.

Satz, P, Soper, H, Orsini, D, Henry, R, & Zvi, J, (1985) Handedness subtypes in autism. Psychiatric Annals, **15**, 447-451.

Shah, A, & Frith, U, (1983) An islet of ability in autism: a research note. Journal of Child Psychology and Psychiatry, **24**, 613-620.

Shah, A, & Frith, U, (1993) Why do autistic individuals show superior performance on the block design test? Journal of Child Psychology and Psychiatry, **34**, 1351-1364.

Soper, H, Satz, P, Orsini, D, Henry, R, Zvi, J, & Schulman, M, (1986) Handedness patterns in autism suggests subtypes. Journal of Autism and Developmental Disorders, **16**, 155-167.

Steffenberg, S, Gillberg, C, Hellgren, L, Andersson, L, Gillberg, C, Jakobsson, G, & Bohman, M, (1989) A twin study of autism in Denmark, Finland, Iceland, Norway, and Sweden. Journal of Child Psychology and Psychiatry, **30**, 405-416.

Steinkamp, M, Harnisch, D, Walberg, H, & Tsai, S, (1985) Cross national gender differences in mathematics attitude and achievement among 13 year olds. The Journal of Mathematical Behaviour, **4**, 259-277.

Stevenson, H, Lee, S, Chen, C, Lummis, M, Stigler, J, Fan, L, & Ge, F, (1990) Mathematics achievement of children in China and the United States. Child Development, **61**, 1053-1066.

Trivers, R, (1972) Parental investment and sexual selection. In Campbell, B, (ed) Sexual selection and the descent of man: 1871-1971. Aldine.

Voyer, D, Voyer, S, & Bryden, M, (1995) Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. Psychological Bulletin, **117**, 250-270.

Wellman, H, (1990) Children's theories of mind. Bradford, MIT Press.

Williams, C, Barnett, A, & Meck, W, (1990) Organizational effects of early gonadal secretions on sexual differentiation in spatial memory. Behavioural Neuroscience, **104**, 84-97.

Wimmer, H. & Perner, J. (1983) Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. Cognition, 13, 103-128.

Wing, L, (1981) Asperger Syndrome: a clinical account. Psychological Medicine, **11**, 115-130.

Wing, L, (1988) The Autistic Continuum. in Wing, L (ed) Aspects of Autism: biological research. Gaskell/Royal College of Psychiatrists, London.

Wing, L, & Gould, J, (1979) Severe impairments of social interaction and associated abnormalities in children: epidemiology and classification. Journal of Autism and Developmental Disorders, **9**, 11-29.

Witelson, S, (1976) Sex and the single hemisphere: specialization of the right hemisphere for spatial processing. Science, **193**, 425-427.

Witelson, S, (1989) Hand and sex differences in the isthmus and genu of the human corpus callosum. Brain, **112**, 799-835.

Witelson, S, (1991) Neural sexual mosaicism: sexual differentiation of the human tempero-parietal region for function asymmetry. Psychoneuroendocrinology, **16**, 131-153.

Witkin, H, Dyk, R, Faterson, H, Goodenough, D, & Karp, S, (1962) Psychological Differentiation. New York: Wiley.

Witkin, H, Oltman, P, Raskin, E, & Karp, S, (1971) A manual for the Embedded Figures Test. Consulting Psychologists Press, Inc.

Zimmerberg, B, & Scalzi, L, (1989) Commissural size in neonatal rats: effects of sex and prealcohol exposure. International Journal of Developmental Neuroscience, **7**, 81-86.

**INDEX**