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IS AUTISM AN EXTREME FORM OF THE "MALE BRAIN"?*

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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 favor 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 between males and females persist on specific psychological tests. Note in advance that these differences are not true of every male and every female; far from it. The differences only emerge when group means are compared.

Some of the key findings (for reviews, see Buffery & Gray, 1972; Geary, 1995, 1996; Halpern, 1992; Kimura, 1992; McGee, 1979) are that (as a group) women are superior to men on (a) *language* tasks (such as the Controlled Association Task; e.g., list as many word associations as you can for each target word in a list, in a limited time; Kimura, 1992), and also show a faster rate of language development and a lower risk for developmental dysphasia (see Hyde & Linn, 1988, on sex differences in language; and Bishop, 1990, on language disorder); (b) tests of *social judgment* (Argyle & Cooke, 1976; Hall, 1977; Halpern, 1992); (c) measures of *empathy* and *cooperation* (Hutt, 1972); (d) rapid identification of *matching* items (also known as "perceptual speed;" Kimura, 1992); (e) *ideational fluency* (e.g., list as many things as you can that are the same color; Kimura, 1992); (f) *fine-motor coordination* (e.g., placing pegs in pegboard holes; Kimura, 1992); (g) mathematical *calculation* tests (Kimura, 1992); and (h) *pretend play* in childhood (Hutt, 1972).

In contrast, men (as a group) are superior to women on (a) *mathematical reasoning*, especially geometry and mathematical word problems (Johnson, 1984; Lummis & Stevenson, 1990; Marshall & Smith, 1987; Mills, Ablard, & Stumpf, 1993; Steinkamp, Harnisch, Walberg, & Tsai, 1985; Stevenson et al., 1990). (Benbow and Stanley [1980, 1983], for example, report that at high-level mathematics, the male–female ratio is 13:1); (b) the *Embedded Figures* Task (i.e., finding a part within a whole; Witkin, Oltman, Raskin, & Karp, 1971); (c) the *Mental Rotation* Task (i.e., imagining how an object will look when it is rotated, or how a sheet of paper will look when it is folded; Kalichman, 1989; Masters & Sanders, 1993); (d) some (but not all[1]) *spatial* skills—mostly Euclidean geometric navigation (Gilger & Ho, 1989; Law, Pellegrino, & Hunt, 1993; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995; Witelson, 1976). Spatial superiority in males is even found in childhood (Kerns & Berenbaum, 1991)[2]; and (e) *target-directed motor skills*, such as guiding or intercepting projectiles—irrespective of the amount of practice (Buffery & Gray, 1972; Kimura, 1992).

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 chapter readily admits he does not!), but the likelihood of having a spatial advantage is increased 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 increased if you are female.

Such sex differences could, of course, be the result of differential socialization, different biological predispositions, or both. In this chapter, 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 fetal life, endocrine factors shape the

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

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

brain as being (a) more developed in terms of 'folk psychology' than in terms of 'folk physics'. (Moir & Jessel, 1989, in their popular book, for shorthand, call this "the female brain type"); or (b) the reverse ("the male brain type"). Folk psychology is our everyday understanding of people in terms of mental states. It is also sometimes referred to as "theory of mind" (see Baron-Cohen, 1995). Folk physics is our everyday understanding of objects in terms of physical causality and spatial relations (see Wellman, 1990).

In this chapter, we operationally define the *male brain type* as an individual whose folk physics skills are in advance of his or her folk psychology skills. This is regardless of biological, chromosomal sex. (Thus, your mother could have a male brain type.) Similarly, we will define the *female brain type* as an individual whose folk psychology skills are in advance of his or her folk physics skills. Again, this is regardless of 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 folk psychology skills are roughly equal to their folk physics skills. We will call this third possibility the *cognitively balanced brain type*. Autism (and Asperger Syndrome), we will argue, are extreme forms of the male brain type. That is, the discrepancy is even larger than in the normal male brain type. These types of brain are summarized in Table 1. We begin by a brief review of the condition of autism and by introducing its relevance to the study of sex differences.

III. AUTISM

Autism is widely regarded to be the most severe of the childhood psychiatric conditions (Baron-Cohen & Bolton, 1993; Frith, 1989). It is diagnosed on the basis of abnormal social development; abnormal communicative development; the presence of narrow, restricted interests; and repetitive activity, along with limited imaginative ability (DSM-4, 1994). Such children mostly 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 children.

TABLE 1
Summary of the Brain Types

Brain Type	Cognitive Profile
The Cognitively Balanced Brain:	folk physics = folk psychology
The Normal Female Brain:	folk physics < folk psychology
The Normal Male Brain:	folk physics > folk psychology
Asperger Syndrome	folk physics >> folk psychology
Autism	folk physics >>> folk psychology

So much for the clinical description. Of more relevance to this chapter, autism is predominantly a 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).[3] 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 an increased risk of autism, compared to population baseline levels (Folstein & Rutter, 1988). For example, while estimates of autism in the general population range from 1 in 2,500 to 1 in 1,000 (Wing & Gould, 1979), the sib risk rate in families with a child with autism is 3%. This is significantly higher than the population baseline rate. Such family data could imply an environmental or hereditary cause. However, twin studies implicate a genetic etiology more persuasively. The concordance rate for autism among monozygotic (MZ) twins is at least 36%, while the concordance rate among dizygotic (DZ) twins is no higher than the sib risk rate (Bolton & Rutter, 1990; Folstein & Rutter, 1988). Steffenberg et al. (1989) found an even stronger difference between MZ and DZ concordance rates (91% vs. 0%). While such twin studies are not watertight evidence for hereditary factors, they are strongly suggestive of it.

A. Cognitive Profile

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 & Frith, 1983) and on the Block Design Subtest of the Weschler IQ tests (Shah & Frith, 1993). Frith (1989) puts this in the following terms: The normal child and adult have a disposition to "see the whole and not the parts," while children with autism instead "see the parts but not the whole." More precisely, it is not

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[3] Such individuals are described as having either "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, & Pennington, 1991), but for the present purposes, we will consider them as one group.

that children with autism cannot see whole objects or scenes; rather, they appear to be especially interested in details of a physical scene. On tasks like the Embedded Figures Test, and the Block Design Test, this expresses itself as a superior skill. Recall that the Embedded Figures Test is one on which normal males perform better than normal females.

Second, 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, & Frith, 1985; see Baron-Cohen, 1990, 1995, for a review). Earlier we referred to this as our folk psychology, but it is also referred to as using 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, and so on. This is also the strategy normal people use for decoding communication. Children with autism are correspondingly described as suffering from degrees of *mindblindness*, in failing to recognize mental states as underlying people's behavior and communication. Again, recall that social sensitivity is an area in which normal females are believed to perform at a level superior to that of normal males. It is now time to draw more explicitly the connections between autism and sex differences.

B. The Relevance of Autism to the Study of Psychological Sex Differences

We suggest that it may be no coincidence that (a) autism is considerably more common among males; (b) in autism, psychological strengths are on the Embedded Figures Test, an aspect of folk physics (spatial analysis) in which normal males are superior; and (c) in autism, psychological weaknesses are in social judgment, and specifically theory of mind (or folk psychology) 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 that "the autistic personality is an extreme variant of male intelligence" (p. 84, in Frith's 1991 translation). As far as we are aware, until now 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 reasoning and male superiority on the Embedded Figures Test. We also review current experiments from our laboratory that test the parents of children with Asperger Syndrome on both theory of mind skills and the Embedded Figures Test. Since in most cases at least one of each pair of such parents can 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 Test, and significantly worse on theory of mind tests. Expressed differently, the studies summarized below test the theory that affected parents show the male brain type more strongly than do sex-matched controls. In the final section of this chapter, 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 fetal and early infant development, and to have lifelong effects.

IV. RECENT EXPERIMENTAL EVIDENCE ADDRESSING THE MODEL

A. Experiment 1: Are Normal Males Superior on the Embedded Figures Test?

The study summarized here is reported in Baron-Cohen and Hammer (in press) and aimed to replicate previous findings in the literature (Witkin, Oltman, Raskin, & Karp, 1971). Fifteen males and 13 females in the age range of 20 to 65 years were investigated. 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 s, and the subject is then invited to describe it to ensure that he or she is attending to it. This is then turned over, to show the simple shape for 10 s. The card is then turned back, thus representing the complex shape, and the subject is given a maximum of 3 min (180 s) to trace the simple shape within the complex shape. (The subjects can turn back to look at the simple shape as often as they like.) 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 (in press) 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 s for males (*SD* = 20.5), and 66.7 s for females (*SD* = 36.7). This difference is significant. This therefore successfully replicates the earlier findings by Witkin et al. (1971).

B. Experiment 2: Are Normal Females Superior on the Reading the Mind in the Eyes Test?

This study is reported in Baron-Cohen, Mortimore, Robertson, and Jolliffe (in press). The test is summarized here. Essentially, it is a test of theory of mind ability, pitched at an adult, sophisticated level[4]. 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 the subject has looked at the photo for 3 s, the photo is then turned over. 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 s to respond. Examples of the eye stimuli are shown in Figures 1A-D. (In these examples, the correct descriptor appears first. In the actual test, the correct descriptor occurred in the first or second position randomly.)

Results showed that females are indeed superior on this test of Reading the Mind in the Eyes. Thus, the mean number correct among 25 females was 21.8 (SD = 1.8), while the mean number correct among 25 males was 18.8 (SD = 2.5). Again, this is significant statistically. Experiments 1 and 2 therefore confirm the female trend is for a folk psychology > folk physics discrepancy, and the male trend is for the opposite.

C. Experiment 3: Are Normal Females Superior on the Faux Pas Test?

This study is reported in O'Riordan, Baron-Cohen, Jones, Stone, & Plaisted (1996) and is summarized here. This is an additional method for examining 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 four sentences long, in which one character commits a social faux pas. The subject is asked to identify which of three 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. Four examples from the Faux Pas Test are shown in Table 2. The test was given to 20 9-year-old children (10 female and 10 male). Results showed that girls scored higher than boys on the test (girls' $M = 7.3$, $SD = 2.0$; boys' $M = 4.9$, $SD = 2.7$). Again, this sex difference was significant.

D. Experiment 4: Are Adults with Autism/Asperger Syndrome Superior on the Embedded Figures Task?

This is reported in Jolliffe and Baron-Cohen (in press). Seventeen subjects with high-functioning autism and 17 subjects with AS (all of normal IQ) took part.

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[4] This is because most theory of mind tests are designed to measure a normal 4–6-year-old's level of ability, reflecting most researchers' interests in preschool development (e.g., Wellman, 1990; Wimmer & Perner, 1983). 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.

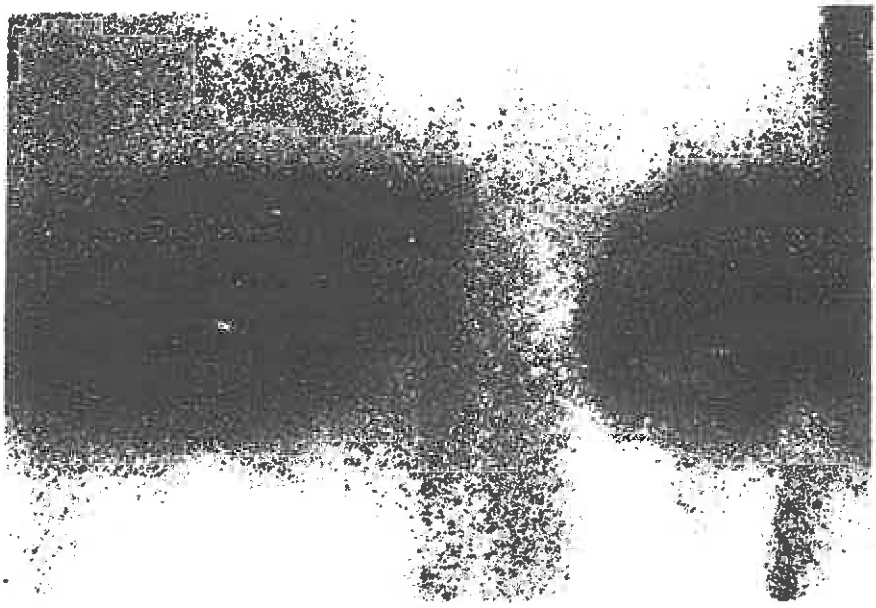

Fig. 1A. Sad Reflection vs. Happy Reflection

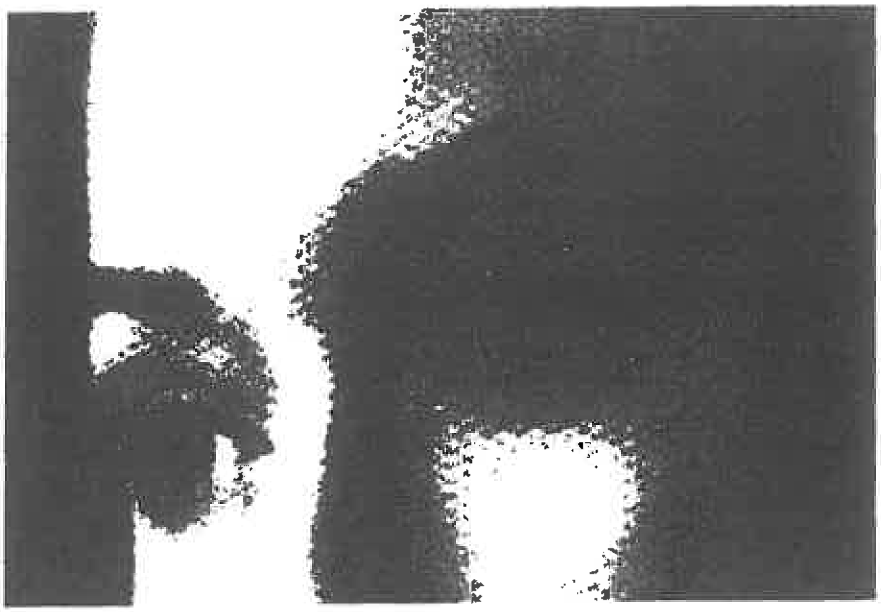

Fig. 1B. Reflective vs. Unreflective

Fig. 2C. Dominant vs. Submissive

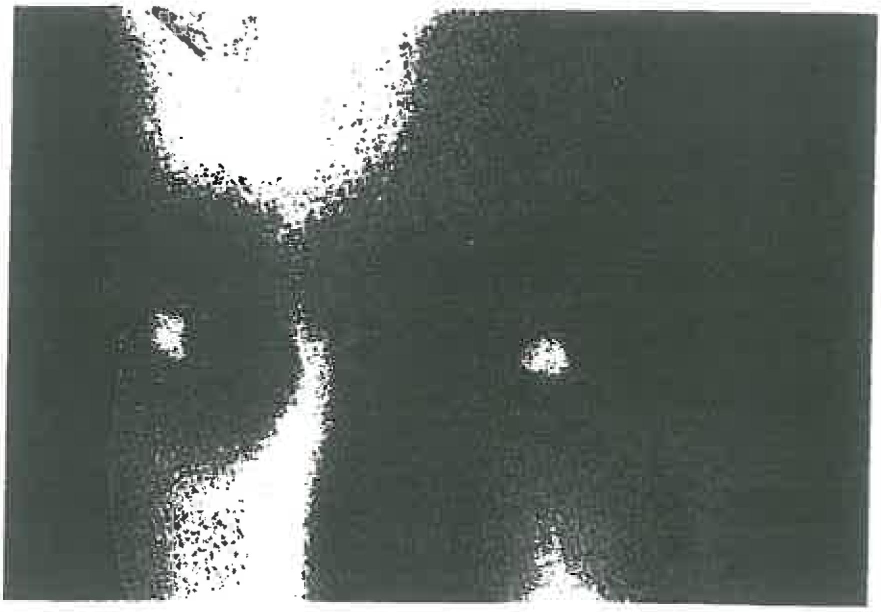

Fig. 2D. Sympathetic vs. Unsympathetic

TABLE 2

Examples of stories from the Faux Pas Mindreading Test, reproduced from O'Riordan et al. (1996)

1. All the class took part in a story competition. Emma really wanted to win. She worked really hard on her story, and then gave it in. The next day she got flu and had to miss school for a week. While she was away, the results of the competition were announced: Alice was the winner. The next day, Emma was better and on her way to school she bumped into Alice. Alice said, "I'm sorry about your story." "What do you mean?" said Emma. "Oh nothing," said Alice.
   Control question: In the story, who won the story competition?
   Belief question: Did Alice remember Emma hadn't heard the results of the competition?
2. Robert had just started at a new school. One day in the playground he was talking to his new friend, Andrew. "My Mum is a dinner lady at this school," he told Andrew. Then Claire came over, looking grumpy. "I hate dinner ladies," she told them. "They're horrible." "Do you want to come and play rounders?" Andrew asked Claire. "No," she replied. "I'm not feeling very well."
   Control question: In the story, what job does Robert's mum do?
   Belief question: Did Claire know Robert's Mum was a dinner lady?
3. Mike was in one of the cubicles in the toilets at school. Joe and Peter were at the sinks nearby, and were talking. Joe said, "You know that new boy in the class—you know, his name is Mike. Doesn't he look really weird! And he's so short." Mike then came out of the cubicles, and the two boys saw him. Peter said, "Oh hello, Mike, are you going to play football now?"
   Control question: In the story, where were Joe and Peter when they were talking?
   Belief question: Did Joe know Mike was in the cubicles?
4. Kim helped her mum make an apple pie especially for her uncle, who was coming to visit. She carried it out of the kitchen and set it on the table. "I made it just for you," said Kim. "Mmm," replied Uncle Tom. "That looks lovely—I love pies, except apple, of course!"
   Control question: In the story, what kind of pie had Kim made?
   Belief question: Did Uncle Tom know what kind of pie it was?

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 s (*SD* = 21.6), and the mean speed of the group with AS was 32.21 s (*SD* = 27.0). The mean speed of the normal group was 52.6 s (*SD* = 32.6).

E. Experiment 5: Are adults with Autism/Asperger Syndrome Impaired on the Reading the Mind in the Eyes Test?

This is reported in Baron-Cohen et al. (in press). Sixteen 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 Test, as described in Experiment 2. Their mean score was 16.3 (*SD* = 2.9), while a control group of normal subjects (matched for sex, age, and IQ) scored 20.3 (*SD* = 2.63). 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, & Walker, 1995).

F. Experiment 6: Are Children With Asperger Syndrome/Autism Impaired on the Faux Pas Test?

This is reported in O'Riordan et al. (1996). Eleven subjects with AS or high-functioning autism with an MA of 13 years 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- to 8-year-old.

G. Experiment 7: Are Parents of Children with Asperger Syndrome Superior to Normals on the Embedded Figures Task?

This is reported in Baron-Cohen and Hammer (in press). Thirty 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, 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 a parent should include a superiority on the Embedded Figures Test (relative to sex-matched normal controls).

This prediction was confirmed. Results showed that mothers were significantly faster than normal females on the Embedded Figures Test (mothers, *M* = 48.6 s, *SD* = 31.8; normal females, *M* = 66.7 s, *SD* = 36.7). Equally, fathers scored a mean of 32.8 (sd = 17.7), which was significantly faster than normal males (mean = 46.2, *SD*, = 20.5).

H. Experiment 8: 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 (in press). The same 30 parents of 15 children with Asperger Syndrome (AS) that took part in Experiment 7 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 a parent should include a deficit on the Reading the Mind in the Eyes Test (relative to sex-matched normal controls).

This prediction was confirmed. Mothers scored a mean of 18.9 (*SD* = 2.1) on the Reading the Mind in the Eyes Test, and this was significantly worse than normal females (*M* = 22.1, *SD* = 2.0). Equally, fathers scored a mean of 17.3 (*SD* = 1.6), which was significantly worse than normal males (*M* = 19.5, *SD* = 2.6).

I. Summary of the Eight Experiments

Experiment 1 confirms the male superiority on the Embedded Figures Task, while 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 to 3 provide evidence for both the normal male brain type and the normal female brain type. Experiments 4 to 6 confirm the prediction that people with AS/high-functioning autism show the male brain type in the most extreme form and Experiments 7 and 8 confirm the prediction that affected parents of children with AS show the male brain type in stronger than normal form. Figures 2 and 3 summarize the main findings schematically. In the next section of this chapter, we present a model in order to attempt to explain this pattern of results.

V. NEUROBIOLOGICAL FACTORS

If the sex differences reviewed above are in part neurobiological in origin, then a model of brain function is needed that can accommodate them. Here we extend the model outlined earlier in neurodevelopmental directions, based on our reading of the literature (Geary, 1996; Halpern, 1992; Kimura, 1992; and other work, cited earlier). It is developmental simply because the sex differences that have been documented appear to be present from infancy onward.

A. Structural and Endocrinal Factors

Postconception, 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 fetal brain development,[5] 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 to 10 (Rhees, Shryne, & Gorski, 1990). In humans, at birth, female babies attend for longer to social stimuli, such as faces and voices, while male babies will attend for longer to nonsocial, spatial stimuli, such as mobiles (Eibl-Ebelsfeldt, 1989; Goodenough, 1957; McGuiness & Pribam, 1979). Levels of prenatal testosterone (as assessed

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[5] 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 Denenberg (in press).

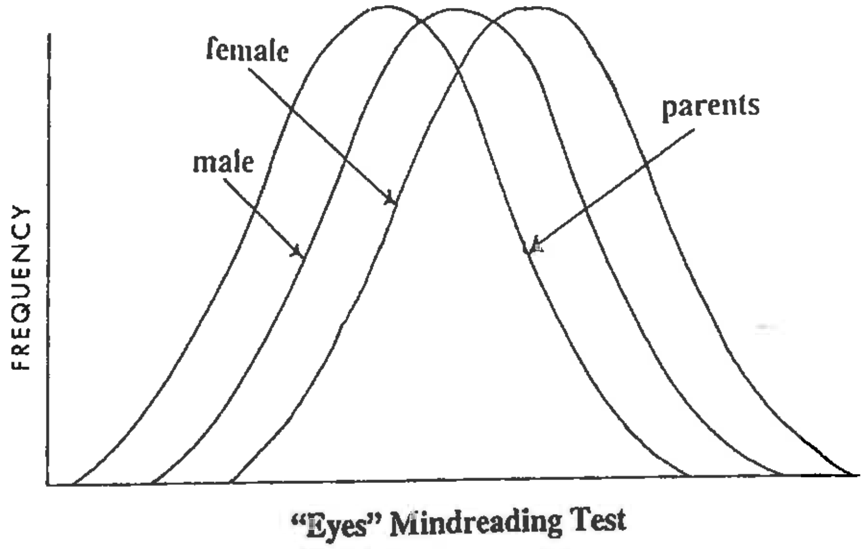

Fig. 2. Overlapping distributions for three groups (males, females, and parents of children with Asperger Syndrome), measured on the Eyes/Mindreading Task.

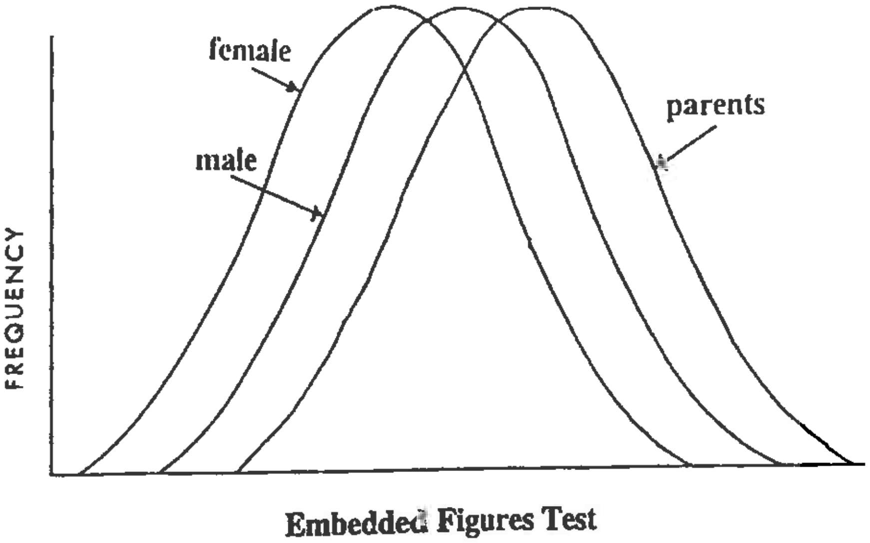

Fig. 3. Overlapping distributions for three groups (males, females, and parents of children with Asperger Syndrome), measured on the Embedded Figures Task.

during amniocentesis) predict spatial ability at follow-up at age 7 (Grimshaw, Sitarenios, & Fenegan, 1995[6]). One suggestion is that the release of testosterone at this stage of fetal life may determine aspects of brain development, leading to either the male or the female brain type, as defined earlier in this chapter.

Precisely which structures distinguish these two brain types is still controversial (see Fitch and Denenberg, in press, for a review). In humans, Kimura (1992) reviews evidence for differences in cerebral lateralization. In particular, she reviews evidence by De Lacoste-Utamsing et al. that at birth, in the human male fetus, the right hemisphere cortex is thicker than the left. Some reports show the corpus callosum is larger in females (De Lacoste-Utamsing & Holloway, 1982), though reports are conflicting (Dennenberg, Kertesz, & Cowell, 1991; Habib et al., 1991; Wittelson, 1989, 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 even smaller than in age- and sex-matched controls (Egaas, Courchesne, & Saiton, 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. Males have a larger SDN-POA (sexually dimorphic nucleus of the preoptic area—a region of the hypothalamus; Dohler et al., 1984); females have a larger hypothalamic anteroventral preoptic nucleus (AVPN; Bloch & Gorski, 1988); and males have increased cortical thickness (Diamond, Johnson, & Ehlert, 1979). Female rats whose ovaries are removed at 90 days of age (but not at 300 days of age) show increased cortical thickness, implying that this neural difference is under time-limited hormonal control. Diamond, Johnson, Young, and Singh (1983) found that male rats have a thicker right cerebral cortex, while females show no left–right difference; and the corpus callosum is significantly larger in the adult male than female rat (Berrebi et al. 1988; Zimmerberg & Scalzi, 1989).[7] 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, prenatal exposure to androgens increases spatial performance in human females and females of other species (Diamond et al., 1979; Resnick, Berenbaum, Gottesman, & Bouchard, 1986; see also Halpern, 1992, and Hines & Green, 1991), and castration of the rat decreases spatial ability (Williams, Barnett, & Meck, 1990). The neuroendocrine evidence

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[6] In the Grimshaw et al. (1995) study, an association between prenatal testosterone and spatial ability was found only 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.

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

may be consistent with the notion of a male or female brain type's being a function of the levels of circulating male or female hormones during critical periods of neural development.[8]

B. Laterality and Sex Differences

When considering neurocognitive sex differences, it is important to consider also 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 nonlinguistic 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, McManus, & Bulman-Fleming, 1994, with peer commentary on their review), but important connections have been demonstrated between lateralization, sex, and handedness. This is true both in the normal population and in the population with autism.

1. 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, that is, 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 do females (Halpern, 1992). Thus, when Bryden analyzed the same data by sex, he found that 81% of males, but only 74% of females, showed a right-ear advantage. He concluded that, in general, females have a more bilateral organization of cognitive abilities than do males. Hines (1990) expresses the same idea differently: The degree of left-hemisphere dominance is greater in males than in females.

Regarding the link between lateralization and spatial ability, Benbow (1986) reported an elevated incidence of left-handedness in children gifted mathematically. Hasler and Gupta (1993) also found that 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

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

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 ambidexterity in children with exceptional drawing ability. Kimura and D'Amico (1989) found that non-right-handed science students in college had higher spatial ability than right-handed controls. Sanders, Wilson, and Vandenberg (1982) found, in their family study, that left-handed men scored higher than right-handed men on spatial tasks (though left-handed women were worse than right-handed women). Indeed, elevated rates of left-handedness occur in those working in the visuospatial arts (Mebert & Michel, 1980; Peterson, 1979), in architecture, and in engineering (Peterson & Lansky, 1974)—all 'folk physics' fields.[9] Direction of handedness appears to be strongly familial (McManus, 1985).

This review suggests, therefore, 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. This evidence points to the importance of these two variables, but it does not yet enable us to draw final conclusions about the brain basis of these different brain types.

2. 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 (i.e., a reduced degree of handedness). Satz and colleagues (Satz, Soper, Orsini, Henry, & Zvi, 1985; Soper et al., 1986) found a very similar picture: In their autistic sample, 44% were right-handed, 22% were 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.[10]

Studies looking at lateralization in autism using dichotic listening tasks and evoked auditory potentials also reveal abnormalities. Thus, Prior and Bradshaw (1979) found that children with autism show no clear right-ear advantage in

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[9] See Martino and Winner (1995) for a recent study of this area.

[10] It should be noted 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 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.

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 asymmetry (Chiron et al., 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 of this chapter is that all people fall on a continuum as regards male and female brain type. As stated in the Introduction, we have referred to some people as cognitively balanced, being equally good at folk physics (e.g., Embedded Figures) and folk psychology (e.g., theory of mind) tasks. They show no discrepancy. Other people are better at folk physics than they are at folk psychology tests; this 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 Wing's (1988) important notion of an autistic continuum, blurring into the normal population.[11] The work reviewed here constitutes preliminary but suggestive evidence for the notion of male and female brain types, defined in psychometric ways. These 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 someone 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, both of whom have the male brain type? What does it mean in neurobiological terms for someone to be an extreme form of the male brain? The cognitive profile needs to be mapped onto its neurobiological substrate. These questions remain to be explored.

Second, 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. (1962) defined this dimension as the extent to which individuals are influenced by physical objects 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 at an angle

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[11] It is tempting to surmise that children with Williams Syndrome might have an extreme form of the *female* brain type. (Karmiloff-Smith, Klima, Bellugi, Grant, & Baron-Cohen, 1995)

by the experimenter. The subject has to reposition the rod so that it is vertical. Subjects whose judgments are influenced by the tilt of the frame are labelled "field dependent," while those who are not are "field independent." A host of studies shows that men are more field independent than women. Performance on the Rod and Frame Test is highly correlated with the EFT. A different description of the results in this chapter 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 (1962) 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. It will be important for future work to investigate if the continuum of male and female brain types is the same as, or different from, the continuum of field dependence.

Third, if autism is an extreme of the male brain type, does this mean that all of 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), while 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, 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-4, 1992). We expect that a mild counterpart to this behavior—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 behavior is more common in young boys than in young 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.[12] The challenge to this neurobiological view will come from any cross-cultural evidence in which the sex-differences reported above are not found.

In closing, we wish to reiterate that we have not argued that either males are impaired in their folk psychology skills or that females are impaired in their folk physics 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 favor 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. Finally, brain types in this chapter are defined quite specifically in terms of cognitive discrepancies. We hope to have avoided simplistic misunderstandings, such as autism being an extreme of "maleness," loosely defined. Such simplification might predict increased levels of aggression or hirsutism, for example, which would constitute a misinterpretation of the theory.

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[12] See, for example, Buss (1995), Daly and Wilson (1983), Darwin (1859, 1871), Gaulin (1992), Hill (1982), Kolakowski & Malina (1974), and Trivers (1972).

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