22

The Evolution of Brain Mechanisms for Social Behavior

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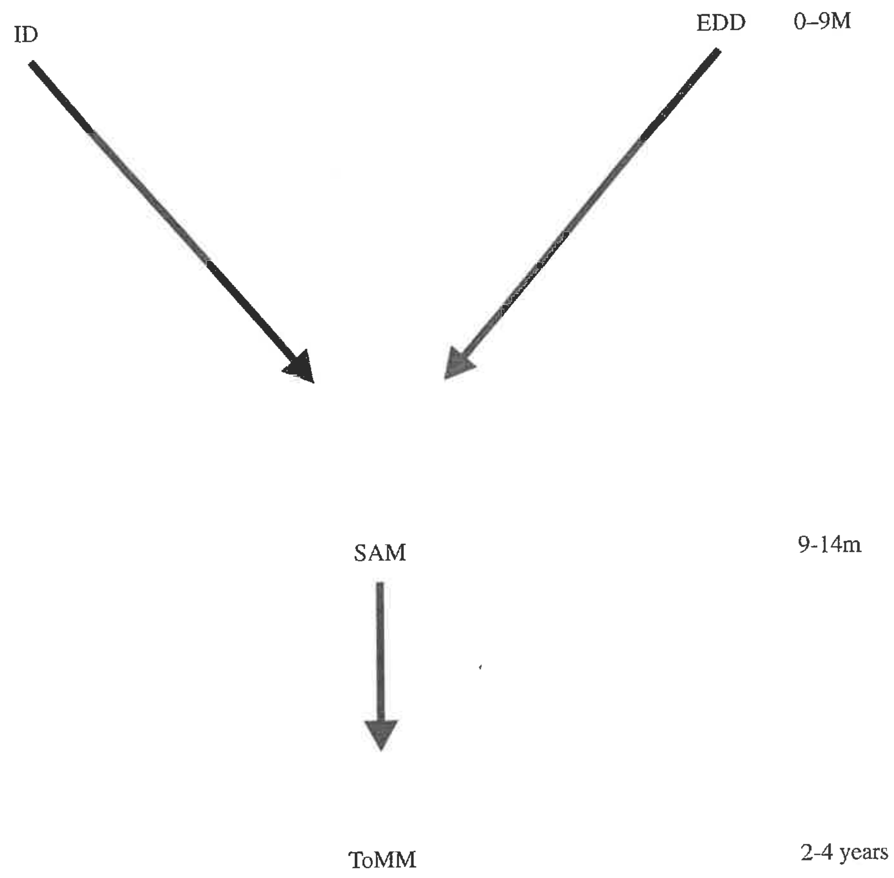
In this chapter, I discuss the evolution of two cognitive processes, empathizing and systemizing, and their relevance to the evolution and development of social behavior.

EMPATHIZING

Empathizing is the drive to identify another person's emotions and thoughts and to respond to these with an appropriate emotion (Davis, 1994). Empathy is a skill (or a set of skills). As with any other skill, we all vary in it. In the same way that we can think about why someone is talented, average, or even disabled in these other areas, we can also think about individual differences in empathy.

In 1994, I proposed a model to specify the neurocognitive mechanisms that comprise the "mind-reading system" (Baron-Cohen, 1994, 1995). *Mind reading* is defined as the ability to interpret one's own or another agent's actions as driven by mental states. The model was proposed in order to explain (a) ontogenesis of a theory of mind and (b) neurocognitive dissociations that are seen in children with or without autism. The model is shown in Figure 22.1 and contains four components: (a) ID or the intentionality detector; (b) EDD or the eye direction detector; (c) SAM or the shared attention mechanism; and finally, (d) ToMM or the theory of mind mechanism.

ID and EDD build "dyadic" representations of simple mental states. ID automatically interprets or represents an agent's self-propelled movement as a desire or goal-directed movement, a sign of its agency, or an entity with volition (Premack, 1990). For example, ID interprets an animate-like moving shape as "it wants x," or "it has goal y." EDD automatically interprets or represents eye-like stimuli as "looking at me" or "looking at something else." That is, EDD picks out that an entity with



Key: IDD = Intentionality Detector
EDD = Eye Direction Detector
SAM = Shared Attention Mechanism
ToMM = Theory of Mind Mechanism

Figure 22.1 Baron-Cohen's (1994) model of the mind-reading system.

eyes can perceive. Both ID and EDD are developmentally prior to the other two mechanisms and are active early in infancy.

SAM is developmentally more advanced, and it comes on line at the end of the first year of life. SAM automatically interprets or represents if the self and another agent are (or are not) perceiving the same event. SAM does this by building "triadic" representations. For example, where ID can build the dyadic representation "Mother wants the cup" and where EDD can build the dyadic representation "Mother sees the cup," SAM can build the triadic representation "Mother sees that I see the cup." As is apparent, triadic representations involve embedding or recursion. (A dyadic representation—"I see a cup"—is embedded within another dyadic representation—"Mum sees the cup"—to produce this triadic representation.) SAM takes its input from ID and EDD, and triadic representations are made out of dyadic representations. SAM typically functions from 9–14 months of age and allows "joint attention" behaviors such as protodeclarative pointing and gaze monitoring (Scaife & Bruner, 1975).

ToMM allows an epistemic mental states to be represented (e.g., "Mother thinks this cup contains water" or "Mother pretends this cup contains water"), and it integrates the full set of mental state concepts (including emotions) into a theory. ToMM develops between 2 and 4 years of age and allows pretend play (Leslie, 1987), understanding of false belief (Wimmer & Perner, 1983), and understanding of the relationships between mental states (Wellman, 1990). An example of the latter is the seeing-leads-to-knowing principle (Pratt & Bryant, 1990), where the typical 3-year-old can infer that, if someone has seen an event, then they will know about it.

The model shows the ontogenesis if a theory of mind in the first 4 years of life and justifies the existence of four components based on developmental competence and neuropsychological dissociation. In terms of developmental competence, joint attention does not appear possible until 9–14 months of age, and joint attention appears to be a necessary but not sufficient condition for understanding epistemic mental states (Baron-Cohen, 1991; Baron-Cohen & Swettenham, 1996). There appears to be a developmental lag between acquiring SAM and ToMM, suggesting that these two mechanisms are dissociable. In terms of neuropsychological dissociation, congenitally blind children can ultimately develop joint (auditory or tactile) attention, using the amodal ID rather than the visual EDD route. Children with autism appear able to represent the dyadic mental states of seeing and wanting but show delays in shared attention (Baron-Cohen, 1989b) and in understanding false belief (Baron-Cohen, 1989a; Baron-Cohen, Leslie, & U. Frith, 1985)—that is, in acquiring SAM and ultimately ToMM. This specific developmental delay suggests that SAM is dissociable from EDD.

The 1994 model of the mind-reading system was revised in 2005 because of certain omissions and too narrow of a focus. The key omission is that information about affective states, available to the infant perceptual system, has no dedicated neurocognitive mechanism. In Figure 22.2, the revised model (Baron-Cohen, 2005) is shown, and it now includes a new fifth component: TED or the emotion detector. A particular problem for any account of the distinction between autism and psychopathy is the fact that the concept of mind reading (or theory of mind) makes no reference to the affective state in the observer triggered by recognition of another's mental state. For this reason, the revised model no longer focuses on "mind reading" but rather focuses on "empathizing," and also includes a new sixth component: TESS or the empathizing system. Where the 1994 mind-reading system was a model of a passive observer (all of the components had simple decoding functions), the 2005 empathizing system is a model of an observer impelled toward action (because an emotion is triggered in the observer, which typically motivates the observer to respond to the other person).

Like the other infancy perceptual input mechanisms of ID and EDD, the new component of TED can build dyadic representations of a special kind, namely, it can represent affective states. An example would be "Mother—is unhappy" or even "Mother—is angry—with me." Formally, we can describe this as agent affective state proposition. We know that infants can represent affective states from as early as 3 months of age (Walker, 1982). As with ID, TED is amodal, in that affective information can be picked up from facial expression, or vocal intonation, "motherese" being a particularly rich source of the latter (Field, 1979). Another's affective state is presumably also detectable from their touch (e.g., tense vs. relaxed), which implies that congenitally blind infants should find affective information accessible through both auditory and tactile modalities. TED allows the detection of the basic emotions (Ekman & Friesen, 1969). The development of TED is probably aided by simple imitation that is typical of infants (e.g., imitating caregiver's expressions) which in itself would facilitate emotional contagion (Meltzoff & Decety, 2003).

When SAM becomes available at 9–14 months of age, it can receive inputs from any of the three infancy mechanisms—ID, EDD, or TED. Here, I focus on how a dyadic representation of an affective state can be converted into a triadic representation by SAM. An example would be that the dyadic representation "Mother is unhappy" can be converted into a triadic representation "I am unhappy that Mother is unhappy," "Mother is unhappy that I am unhappy," and so forth. Again, as

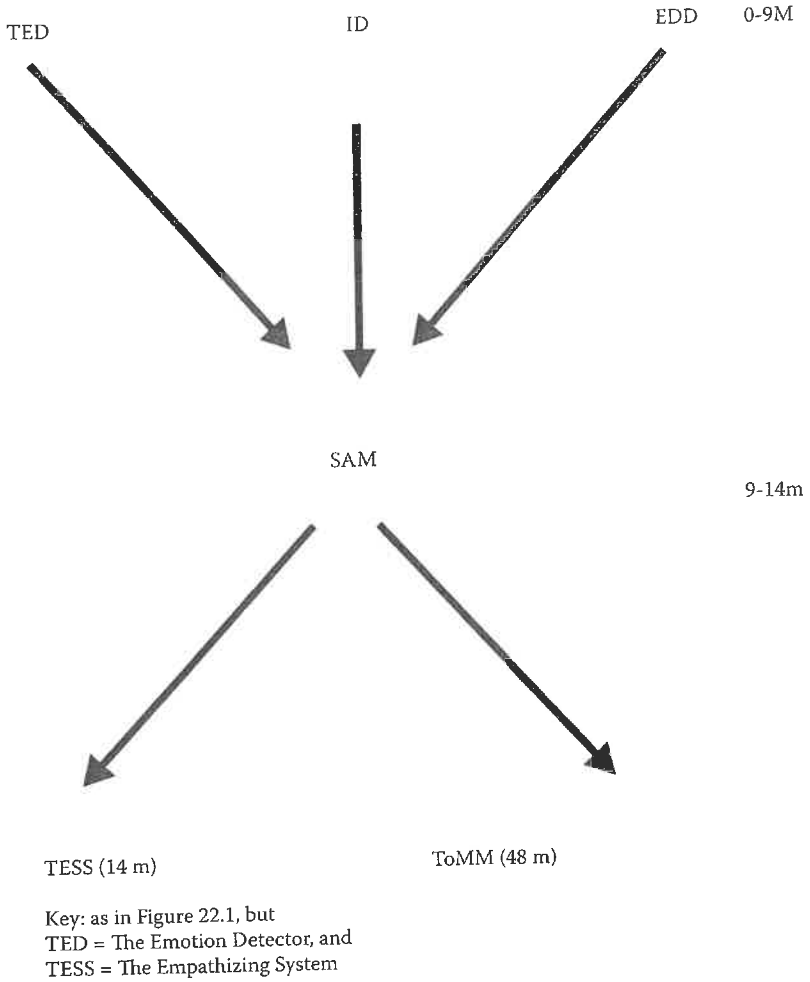


Figure 22.2 Baron-Cohen's (2005) model of empathizing.

with perceptual or volitional states, SAM's triadic representations of affective states have this special embedded, or recursive, property.

ToMM is of major importance in allowing the child to represent the full range of mental states, including epistemic ones (e.g., false belief) and is important in allowing the child to pull mentalistic knowledge into a useful theory with which to predict behavior (Baron-Cohen, 1995; Wellman, 1990). But TESS allows more than behavioral explanation and prediction (itself a powerful achievement). TESS allows an empathic reaction to another's emotional state. This, however, is not to say that these two modules do not interact. Knowledge of mental states of others made possible by TOMM could certainly influence the way in which an emotion is processed and/or expressed by TESS. TESS also allows for sympathy. This element of TESS gives it the adaptive benefit of ensuring that organisms feel a drive to help each other.

Before leaving this revision of the model, it is worth discussing why the need for this has arisen. First, emotional states are an important class of mental states to detect in others, and yet, the earlier model focused on only volitional, perceptual, informational, and epistemic states. Second, when it comes to pathology, it would appear that in autism TED may function, although its onset may be delayed (Baron-Cohen, Spitz, & Cross, 1993; Baron-Cohen, Wheelwright, & Jolliffe, 1997; Hobson, 1986), at least in terms of detecting basic emotions. Even high-functioning people with autism or Asperger Syndrome have difficulties both in ToMM (when measured with mental-age appropriate tests; Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Happe, 1994) and TESS (Attwood, 1997; Baron-Cohen, O'Riordan, Jones, Stone, & Plaisted, 1999; Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003; Baron-Cohen & Wheelwright, 2004; Baron-Cohen, Wheelwright, Stone, & Rutherford, 1999). I return to discuss autism further later in the chapter. But even at this point, this suggests TED and TESS may be fractionated.

In contrast, the psychiatric condition of psychopathy may entail an intact TED and ToMM, alongside an impaired TESS. The psychopath (or sociopath) can represent that you are in pain or that you believe he is the gasman, thereby gaining access to your house or your credit card. The psychopath can go on to hurt you or cheat you without having the appropriate affective reaction to your affective state. In other words, he or she does not care about your affective state (Blair, Jones, Clark, & Smith, 1997; Mealey, 1995). Lack of guilt or shame or compassion in the presence of another's distress are diagnostic of psychopathy (Cleckley, 1977; Hare, Hakstian, Ralph, Forth-Adelle, & Al, 1990). Separating TESS and ToMM thus allows a functional distinction to be drawn between the neurocognitive causes of autism and psychopathy.

DEVELOPMENTAL DISSOCIATIONS

Developmentally, one can also distinguish TED from TESS. We know that at 3 months of age, infants can discriminate facial and vocal expressions of emotion (Trevarthen, 1989; Walker, 1982) but that it is not until about 14 months that they can respond with appropriate affect (e.g., a facial expression of concern) to another's apparent pain (Yirmiya, Kasari, Sigman, & Mundy, 1989) or show "social referencing." Clearly, this account is skeletal in not specifying how many emotions TED is capable of recognizing. Our recent survey of emotions identities that there are 412 discrete emotion concepts that the adult English language user recognizes (Baron-Cohen, Wheelwright, Hill, & Golan, 2007). How many of these are recognized in the first year of life is not clear. It is also not clear exactly how empathizing changes during the second year of life. We have assumed the same mechanism that enables social referencing at 14 months old also allows sympathy and the growth of empathy across development. This is the most parsimonious model, though it may be that future research will justify further mechanisms that affect the development of empathy.

SEX DIFFERENCES IN EMPATHIZING—A CLUE TO ITS EVOLUTIONARY ORIGINS?

Many studies converge on the conclusion that there is a female superiority in empathizing. These are reviewed here:

1. *Sharing and turn taking.* On average, girls show more concern for fairness, while boys share less. In one study, boys showed 50 times more competition, while girls showed 20 times more turn taking (Charlesworth & Dzur, 1987).
2. *Rough and tumble play or "rough housing" (e.g., wrestling, mock fighting, etc.).* Boys show more of this than girls do. Although there is a playful component, it can hurt or be intrusive, so it needs lower empathizing to carry it out (Maccoby, 1999).
3. *Responding empathically to the distress of other people.* Girls from 1 year old show greater concern through more sad looks, sympathetic vocalizations, and comforting. More women than men also report frequently sharing the emotional distress of their

friends. Women also show more comforting, even of strangers, than men do (Hoffman, 1977).

4. *Using a "theory of mind."* By 3 years old, little girls are already ahead of boys in their abilities to infer what people might be thinking or intending (Happe, 1995). This sex difference appears in some but not all studies (Charman, Ruffman, & Clements, 2002).
5. *Sensitivity to facial expressions.* Women are better at decoding nonverbal communication, picking up subtle nuances from tone of voice or facial expression, or judging a person's character (Hall, 1978).
6. *Questionnaires measuring empathy.* Many of these find that women score higher than men do (Davis, 1994).
7. *Values in relationships.* More women value the development of altruistic, reciprocal relationships, which by definition require empathizing. In contrast, more men value power, politics, and competition (Ahlgren & Johnson, 1979). Girls are more likely to endorse cooperative items on a questionnaire and to rate the establishment of intimacy as more important than the establishment of dominance. Boys are more likely than girls to endorse competitive items and to rate social status as more important than intimacy (Knight, Fabes, & Higgins, 1989).
8. *Disorders of empathy.* Disorders of empathy (e.g., psychopathic personality disorder, or conduct disorder) are far more common among males (Blair, 1995; Dodge, 1980).
9. *Aggression, even in normal quantities, can only occur with reduced empathizing.* Here again, there is a clear sex difference. Males tend to show far more "direct" aggression (e.g., pushing, hitting, punching, etc.), while females tend to show more "indirect" (or "relational," covert) aggression (e.g., gossip, exclusion, bitchy remarks, etc.). Direct aggression may require an even lower level of empathy than indirect aggression. Indirect aggression needs better mind-reading skills than does direct aggression, because its impact is strategic (Crick & Grotpeter, 1995).
10. *Murder is the ultimate example of a lack of empathy.* Daly and Wilson (1988) analyzed homicide records dating back over 700 years, from a range of different societies. They found that "male-on-male" homicide was 30–40 times more frequent than "female-on-female" homicide.
11. *Establishing a "dominance hierarchy."* Males are quicker to establish these. This in part may reflect their lower empathizing skills, often because a hierarchy is established by one person pushing others around to become the leader (Strayer, 1980).
12. *Language style.* Girls' speech is more cooperative, reciprocal, and collaborative. In concrete terms, this is also reflected in girls being able to keep a conversational exchange with a partner going for longer. When girls disagree, they are more likely to express their different opinion sensitively, in the form of a question, rather than an assertion. Boys' talk is more "single-voiced discourse" (the speaker presents their own perspective alone). The female speech style is more "double-voiced discourse" (girls spend more time negotiating with the other person, trying to take the other person's wishes into account; Smith, 1985).
13. *Talk about emotions.* Women's conversation involves much more talk about feelings, while men's conversation with each other tends to be more object or activity focused (Tannen, 1991).
14. *Parenting style.* Fathers are less likely than mothers are to hold their infant in a face-to-face position. Mothers are more likely to follow through the child's choice of topic in play, while fathers are more likely to impose their own topic. And mothers fine-tune their speech more often to match what the child can understand (Power, 1985).

15. *Face preference and eye contact.* From birth, females look longer at faces, particularly at people's eyes, and males are more likely to look at inanimate objects (Connellan, Baron-Cohen, Wheelwright, Ba'tki, & Ahluwalia, 2001).
16. *Finally, females have also been shown to have better language ability than males have.* It seems likely that good empathizing would promote language development (Baron-Cohen, Baldwin, & Crowson, 1997) and vice versa, so these may not be independent.

NATURAL SELECTION OF GOOD EMPATHY AMONG FEMALES?

Why might this sex difference in empathy exist? One possibility is that it reflects natural selection of empathy among females over human evolution. If one considers that good empathizing would have led to better caregiving, then since caregiving can be assumed to have been primarily a female activity until very recent history, those mothers who had better empathy would have succeeded in tuning into their infant offspring's preverbal emotional and physical needs better, which may have led to a higher likelihood of the infant surviving to an age to reproduce. Hence, good empathy in the mother would have promoted her inclusive fitness.

A second explanation is that females with better empathy might have found it easier to socialize—chat, gossip, and network—with other females, thereby being more successful in creating social support for themselves while engaged in being a caregiver to their infant. Social support from other females is also likely to buffer mothers from the range of life events (e.g., illness, poverty, loss, physical attack, etc.) that might otherwise threaten her ability to care for her offspring and, so, increase the likelihood of her infant surviving to the age of reproduction, thereby increasing her inclusive fitness.

Having spent some time discussing empathizing, I want to now turn to a very different cognitive process, systemizing, because of the evidence for this being stronger in males.

SYSTEMIZING

Systemizing is a new concept. By a "system," I mean something that takes inputs and deliver outputs. To systemize, one uses "if-then" (correlation) rules. The brain zooms in on a detail or parameter of the system and observes how this varies. That is, it treats a feature of a particular object or event as a variable. Alternately, a person actively, or systematically, manipulates a given variable. One notes the effect(s) of operating on one single input in terms of its effects elsewhere in the system (the output). If I do x, a changes to b. If z occurs, p changes to q. Systemizing, therefore, requires an exact eye for detail.

Systemizing involves observation of *input-operation-output* relationships, leading to the identification of laws to predict that event x will occur with probability p (Baron-Cohen, 2002). Some systems are 100% lawful (e.g., an electrical light switch or a mathematical formula). Systems that are 100% lawful have zero variance or only 1 degree of freedom and, therefore, can be 100% predicted (and controlled). A computer might be an example of a 90% lawful system: The variance is wider, or there are more degrees of freedom. The social world may be only 10% lawful. This is why systemizing the social world is of little predictive value.

Systemizing involves 5 phases: Phase 1 is *analysis*: Single observations of input and output are recorded in a standardized manner at the lowest level of detail. Phase 2 is *operation*: An operation is performed on the input and the change to the output is noted. Phase 3 is *repetition*: The same operation is repeated to test if the same pattern between input and output is obtained. Phase 4 is *law derivation*: A law is formulated of the form if X (operation) occurs, A (input) changes to B. Phase 5 is *confirmation/disconfirmation*: If the same pattern of input-operation-output holds true for all

Table 22.1 Main Types of Analyzable Systems

- **Technical** systems (e.g., a computer, a musical instrument, a hammer)
- **Natural** systems (e.g., a tide, a weather front, a plant)
- **Abstract** systems (e.g., mathematics, a computer program, syntax)
- **Social** systems (e.g., a political election, a legal system, a business)
- **Organizable** systems (e.g., a taxonomy, a collection, a library)
- **Motoric** systems (e.g., a sports technique, a performance, a musical technique)

instances, the law is retained. If a single instance does not fit the law, phases 2–5 are repeated, leading to modification of the law or a new law.

Systemizing nonagentive changes are effective because these are *simple* changes: The systems are at least moderately lawful, with narrow variance (or limited degrees of freedom). Agentive change is less suited to systemizing because the changes in the system are *complex* (wide variance or many degrees of freedom).

There are at least six kinds of systems that the human brain can analyze or construct, as shown in Table 22.1. Systemizing works for phenomena that are ultimately lawful, finite, and deterministic. The explanation is exact, and its truth value is testable. Systemizing is of almost no use for predicting moment-to-moment changes in a person's behavior. To predict human behavior, empathizing is required. Systemizing and empathizing are wholly different kinds of processes.

SEX DIFFERENCES IN SYSTEMIZING

What Is the Evidence for a Stronger Drive to Systemize in Males?

1. *Toy preferences.* Boys are more interested than girls in toy vehicles, weapons, building blocks, and mechanical toys, all of which are open to being "systemized" (Jennings, 1977).
2. *Adult occupational choices.* Some occupations are almost entirely male. These include metalworking, weapon making, manufacture of musical instruments, and the construction industries, such as boat building. The focus of these occupations is on creating systems (Geary, 1998).
3. *Math, physics, and engineering.* All of these disciplines require high systemizing and are largely male dominated. The Scholastic Aptitude Math Test (SAT-M) is the mathematics part of the test administered nationally to college applicants in the United States. Males on average score 50 points higher than females on this test (Benbow, 1988). Considering only individuals who score above 700, the sex ratio is 13:1 (men to women; Geary, 1996).
4. *Constructional abilities.* On average men score higher than women in an assembly task in which people are asked to put together a three-dimensional (3-D) mechanical apparatus. Boys are also better at constructing block buildings from two-dimensional (2-D) blueprints. Lego bricks can be combined and recombined into an infinite number of systems. Boys show more interest than girls do in playing with Lego. Boys as young as 3 years of age are also faster at copying 3-D models of outsized Lego pieces. Older boys, from the age of 9 years, are better than girls are at imagining what a 3-D object will look like if it is laid out flat. Boys are also better at constructing a 3-D structure from just an aerial and frontal view in a picture (Kimura, 1999).

5. *The water level task.* Originally devised by the Swiss child psychologist Jean Piaget, the water level task involves a bottle that is tipped at an angle. Individuals are asked to predict the water level if the water level will be horizontal or aligned with the angle of the bottle. Women more often draw the water level aligned with the tilt of the bottle and not horizontal, as is correct (Wittig & Allen, 1984).
6. *The rod and frame test.* If a person's judgment of vertical is influenced by the tilt of the frame, he or she is said to be "field dependent"; that is, their judgment is easily swayed by extraneous input in the surrounding context. If they are not influenced by the tilt of the frame, they are said to be "field independent." Most studies indicate that females are more field dependent; that is, women are relatively more distracted by contextual cues, and they tend not to consider each variable within a system separately. They are more likely than men to state erroneously that a rod is upright if it is aligned with its frame (Witkin et al., 1954).
7. *Good attention to relevant detail.* This is a general feature of systemizing and is clearly a necessary part of it. Attention to relevant detail is superior in males. One measure of this is the embedded figures test. On average, males are quicker and more accurate in locating a target object from a larger, complex pattern (Elliot, 1961). Males, on average, are also better at detecting a particular feature (static or moving) than women are (D. Voyer, S. Voyer, & Bryden, 1995).
8. *The mental rotation test.* This test provides another example in which males are quicker and more accurate. This test involves systemizing because it is necessary to treat each feature in a display as a variable that can be transformed (e.g., rotated) and then predict the output or how it will appear after transformation (Collins & Kimura, 1997).
9. *Reading maps.* This is another everyday test of systemizing, because features from 3-D input must be transformed to a 2-D representation. In general, boys perform at a higher level than girls do in map reading. Men can also learn a route by looking at a map in fewer trials than women can, and they are more successful at correctly recalling detail about direction and distance. This observation suggests that men treat features in the map as variables that can be transformed into three dimensions. When children are asked to make a map of an area that they have visited only once, boys' maps have a more accurate layout of the features in the environment. More of the girls' maps make serious errors in the location of important landmarks. Boys tend to emphasize routes or roads, whereas girls tend to emphasize specific landmarks (e.g., the corner shop, the park, etc.). These strategies of using directional cues versus using landmark cues have been widely studied. The directional strategy represents an approach to understanding space as a geometric system. Similarly, the focus on roads or routes is an example of considering space in terms of another system, in this case a transportation system (Galea & Kimura, 1993).
10. *Motoric systems.* When people are asked to throw or catch moving objects (target directed tasks), such as playing darts or intercepting balls flung from a launcher, males tend to perform better than females. In addition, on average men are more accurate than women in their ability to judge which of two moving objects is traveling faster (Schiff & Oldak, 1990).
11. *Organizable systems.* People in the Aguaruna tribe of northern Peru were asked to classify 100 or more examples of local specimens into related species. Men's classification systems included more subcategories (i.e., they introduced greater differentiation) and were more consistent among individuals. Interestingly, the criteria that the Aguaruna men used to decide which animals belonged together more closely resembled the taxonomic criteria used by Western (mostly male) biologists (Atran, 1994). Classification

and organization involves systemizing because categories are predictive. With more fine-grained categories, a system will provide more accurate predictions.

12. *The systemizing quotient.* This questionnaire has been tested among adults in the general population. It includes 40 items that ask about a subject's level of interest in a range of different systems that exist in the environment, including technical, abstract, and natural systems. Males score higher than females on this measure (Baron-Cohen et al., 2003).
13. *Mechanics.* The Physical Prediction Questionnaire (PPQ) is based on an established method for selecting applicants to study engineering. The task involves predicting which direction levers will move when an internal mechanism of cogwheels and pulleys is engaged. Men score significantly higher on this test, compared with women (Lawson, Baron-Cohen, & Wheelwright, 2004).

Evolutionary accounts for the male advantage in systemizing include the argument that males were primarily involved in hunting and tracking of prey, and that a male who was a good systemizer would have had greater success in both using and making tools for hunting, or navigating space to explore far afield, Both could have affected a male's reproductive success. Secondly, a good systemizer would have been better placed to acquire wealth or status through being expert in making things, and wealth/status is correlated with reproductive success because of sexual selection.

Some might argue that socialization may have caused these sex differences in both empathizing and systemizing. Although evidence exists for differential socialization contributing to sex differences, this is unlikely to be a sufficient explanation. Connellan and colleagues (2001) showed that, among one-day-old babies, boys look longer at a mechanical mobile, which is a system with predictable laws of motion, than at a person's face, an object that is next to impossible to systemize. One-day-old girls show the opposite profile. These sex differences are therefore present very early in life. This raises the possibility that, while culture and socialization may partly determine the development of a male brain with a stronger interest in systems or a female brain with a stronger interest in empathy, biology may also partly determine this. There is ample evidence to support both cultural determinism and biological determinism (Eagly, 1987; Gouchie & Kimura, 1991). For example, the amount of time a one-year-old child maintains eye contact is inversely related to the prenatal level of testosterone (Lutchmaya, Baron-Cohen, & Raggatt, 2002). The evidence for the role of fetal testosterone (FT) is reviewed next and more extensively elsewhere (Baron-Cohen, 2003).

FETAL TESTOSTERONE AS AN ORGANIZER OF BRAIN DEVELOPMENT AND SEXUAL DIMORPHISM

Both male and female fetuses produce some testosterone. In males, the main source is the testes. Females are exposed to small amounts of testosterone from the fetal adrenal glands and from the maternal adrenals, ovaries, and fat. Testosterone can be measured in amniotic fluid collected during midtrimester amniocentesis. Testosterone is thought to enter the amniotic fluid via diffusion through the fetus' skin in early pregnancy and later from fetal urination. Although the exact correlation between testosterone levels in the fetal serum and the amniotic fluid is unknown, the maximal sex difference in amniotic testosterone between males and females occurs between weeks 12 and 18, closely paralleling peak serum levels. In animal models, the general critical period for sexual differentiation of the brain usually occurs when sex differences in serum testosterone are highest. Therefore, this is likely an important period for sexual differentiation of the human brain as well. This is supported by the study that found that only prenatal androgen exposure in the 2nd trimester related to adult gendered behavior and by the study that found a relationship between gendered play and testosterone in maternal blood during pregnancy at a mean gestational age of 16 weeks.

The amniocentesis design has several strengths. As with the measurement of testosterone in maternal blood, it involves quantitative measures of hormone levels and measures normal variability. For example, Addenbrooke's Hospital, which analyzes amniocentesis samples from six hospitals in East Anglia, United Kingdom, processes approximately 1,000 samples a year. Amniocentesis takes place in midgestation, which is thought to be an important period for sexual differentiation of the human brain and, unlike studies using maternal blood, testosterone exposure can be measured in both boys and girls. A significant limitation of research using this method is that a truly random sample cannot be collected, since one can include in a study only those individuals who have decided/been advised to have an amniocentesis due to late maternal age or other factors that increase the risk of fetal abnormality. In the following section, I review the results of a longitudinal study examining the relationship between amniotic testosterone, social development, and other traits.

The Cambridge Fetal Testosterone Project

At Cambridge University, we have been following up a group of approximately 100 children whose fetal testosterone level had been measured in amniotic fluid. Their mothers had undergone amniocentesis in the Cambridge region between June 1996 and June 1997 and had given birth to the healthy singleton infants between December 1996 and December 1997. The children were first seen at 12 months of age when the infants and parents were filmed and the amount of eye contact made by the infant to the parent was recorded. Eye contact is of major importance in normal social development. Infants as young as 2 months of age spend more time looking at the eye region of the face than any other part of the face. This may also be relevant to autism, which is defined by marked social impairment, including abnormal eye contact. Girls made significantly more eye contact than boys did. The amount of eye contact varied quadratically with amniotic testosterone level when data from both sexes was examined together and when the data for the boys was examined alone. This suggests that testosterone may shape the neural mechanisms underlying social development.

The children were next followed up 18 and 24 months after birth and their vocabulary size was assessed using the Oxford Communicative Development Inventory. Girls were found to have a significantly larger vocabulary than boys did at both ages. This replicates previous findings of a female advantage in language ability but reveals this sex difference at the earliest point of development. Additionally, amniotic testosterone was an inverse predictor of vocabulary size when data from both sexes was examined together but not within sex. The lack of a significant correlation between testosterone and vocabulary within each sex may reflect the relatively small sample size. However, the significant correlation between testosterone and vocabulary when the sexes were combined suggests testosterone might be involved in shaping the neural mechanisms underlying communicative development.

The children were next followed up at 48 months. Their mothers completed the Children's Communication Checklist, a questionnaire assessing language, quality of social relationships and restricted interests. Amniotic testosterone was negatively correlated to quality of social relationships and directly correlated with restricted interests, taking into account sex differences. Testosterone was also positively correlated with restricted interests when boys were examined separately. These findings implicate testosterone in both social development and attentional focus. Causal interpretations are, of course, unjustified from these correlational studies, but the results suggest that high levels of fetal testosterone could produce a behavioral profile of lower empathy alongside stronger systemizing. (Full details of this study are available in Simon Baron-Cohen's *Prenatal Testosterone in Mind*, MIT Press, 2005.)

Table 22.2 The Main Brain Types

Profile	Shorthand Equation	Type of Brain
Individuals in whom empathizing is more developed than systemizing	E > S	Type E: more common in females
Individuals in whom systemizing is more developed than empathizing	S > E	Type S: more common in males
Individuals in whom systemizing and empathizing are both equally developed	S = E	"balanced" or Type B
Individuals in whom systemizing is hyper-developed while empathizing is hypo-developed	S > > E	Extreme Type S: the extreme male brain; more common in people with an autism spectrum condition
Individuals who have hyper-developed empathizing skills, while their systemizing is hypo-developed	E > > S	Extreme Type E: the extreme female brain (postulated)

BRAIN TYPES

We all have both systemizing and empathizing skills. One can envisage five broad types of brain, as Table 22.2 shows. The evidence reviewed here suggests that not all men have the male brain and not all women have the female brain. Expressed differently, some women have the male brain, and some men have the female brain. My claim here is only that *more* males than females have a brain of type S, and *more* females than males have a brain of type E. Data relevant to this claim is summarized elsewhere (Goldenfeld, Baron-Cohen, & Wheelwright, 2005).

AUTISM: HYPER-SYSTEMIZING ALONGSIDE IMPAIRED EMPATHIZING?

The autistic spectrum comprises four subgroups: Asperger Syndrome (AS; Asperger, 1944; U. Frith, 1991) and high-, medium-, and low-functioning autism (Kanner, 1943). They all share the phenotype of social difficulties and obsessional interests (American Psychiatric Association [APA], 1994). In AS, the individual has normal or above average IQ and has no language delay. In the three autism subgroups, there is invariably some degree of language delay, and the level of functioning is indexed by overall IQ. These four subgroups are known as autism spectrum conditions (ASC).

In terms of causes, the consensus is that ASC have a genetic etiology (Bailey et al., 1995), which leads to altered brain development (Baron-Cohen, Ring, et al., 1999; Courchesne, 2002; C. Frith & U. Frith, 1999; Happe et al., 1996) affecting social and communication development and leading to the presence of unusual narrow interests and extreme repetitive behavior (APA, 1994). I have already reviewed some evidence for empathy impairments in ASC (but for an extensive review, see Baron-Cohen, 1995). In the next section, I review evidence for hyper-systemizing in autism and in first-degree relatives of people with autism. Such findings are then discussed for their significance for the evolution of systemizing in the general population.

THE SYSTEMIZING MECHANISM

The hyper-systemizing theory of ASC posits that all human brains have a systemizing mechanism (SM), and this is set at different levels in different individuals. In people with ASC, the SM is set too high. The SM is like a volume control. Evidence suggests that within the general population, there are eight degrees of systemizing.

Level 1. Such individuals have little or no drive to systemize, and consequently, they can cope with rapid, unlawful change. Their SM is set so low that that they hardly notice if the input is structured or not. While this would not interfere with their ability to socialize, it would lead to a lack of precision over detail when dealing with structured information. We can think of this as *hypo-systemizing.* Such a person would be able to cope with agentive change easily but may be challenged when dealing with highly lawful, nonagentive systems.

Levels 2 and 3. Most people have *some* interest in lawful, nonagentive systems, and there are sex differences in this. More females in the general population have the SM set at Level 2, and more males have it set at Level 3 (see the evidence for sex differences reviewed earlier).

Level 4. Level 4 corresponds to individuals who systemize at a higher level than average. There is some evidence that above average systemizers have more autistic traits. Thus, scientists (who by definition have the SM set above average) score higher than nonscientists on the Autism Spectrum Quotient (AQ). Mathematicians score highest of all scientists on the AQ (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Parents of children with ASC also have their SM set higher than average (Baron-Cohen & Hammer, 1997; Happe, Briskman, & U. Frith, 2001) and have been described as having the "broader phenotype" of autism. At Level 4, one would expect a person to be talented at understanding systems with moderate variance or lawfulness.

Level 5. People with AS have their SM set at Level 5: The person can easily systemize lawful systems such as calendars or train timetables (Hermelin, 2002). Experimental evidence for hypersystemizing in AS includes the following: (a) People with AS score higher than average on the Systemizing Quotient (SQ; Baron-Cohen et al., 2003); (b) people with AS perform at a normal or high level on tests of intuitive physics or geometric analysis (Baron-Cohen, Wheelwright, Scahill, Lawson, & Spong, 2001; Jolliffe & Baron-Cohen, 1997; Lawson et al., 2004; Shah & U. Frith, 1983); (c) people with AS can achieve extremely high levels in domains such as mathematics, physics, or computer science (Baron-Cohen, Wheelwright, Stone, et al., 1999c); and (d) people with AS have an "exact mind" when it comes to art (Myers, Baron-Cohen, & Wheelwright, 2004) and show superior attention to detail (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998).

Levels 6–8. In people with high-functioning autism (HFA), the SM is set at Level 6; in those with medium-functioning autism (MFA), it is at Level 7; and in low-functioning autism (LFA), it is at the maximum setting (Level 8). Thus, people with HFA try to socialize or empathize by "hacking" (i.e., systemizing; Happe, 1996), and on the picture-sequencing task, they perform above average on sequences that contain temporal or physical-causal information (Baron-Cohen, Leslie, & U. Frith, 1986). People with MFA perform above average on the false photograph task (Leslie & Thaiss, 1992). In LFA, their obsessions cluster in the domain of systems, such as watching electric fans go round (Baron-Cohen & Wheelwright, 1999); and given a set of colored counters, they show extreme "pattern imposition" (U. Frith, 1970).

The evidence for systemizing being part of the phenotype for ASC includes the following: Fathers and grandfathers of children with ASC are twice as likely to work in the occupation of engineering (a clear example of a systemizing occupation), compared to men in the general population (Baron-Cohen, Wheelwright, Stott, Bolton, & Goodyer, 1997). The implication is that these fathers and grandfathers have their SM set higher than average (Level 4). Students in the natural sciences (engineering, mathematics, and physics) have a higher number of relatives with autism than do students in the humanities (Baron-Cohen et al., 1998). Mathematicians have a higher rate of AS compared to the general population, and so do their siblings (Baron-Cohen, Wheelwright, Burtenshaw, & Hobson, 2006).

The evidence that autism could be the genetic result of having *two* high systemizers as parents (assortative mating) includes the following: (a) Both mothers *and* fathers of children with AS have been found to be strong in systemizing on the embedded figures test (Baron-Cohen & Hammer, 1997); (b) both mothers and fathers of children with autism or AS have elevated rates of systemizing occupations among their fathers (Baron-Cohen, Wheelwright, Stott, et al., 1997); and (c) both mothers and fathers of children with autism show hyper-masculinized patterns of brain activity during a systemizing task (Baron-Cohen et al., 2006). Whether the current high rates of ASC simply reflect better recognition, growth of services, and widening of diagnostic categories to include AS, or also reflect the increased likelihood of two high systemizers have children, is a question for future research.

It is important to stress that the term *assortative mating* here may not be entirely accurate. What the available evidence allows us to conclude is that parents of children with an ASC share a common psychological trait: hyper-systemizing. How they came to share this is not at all clear. Assortative mating would imply that the two parents were attracted to and chose their partners based on this common psychological trait. While this may be the case (e.g., each may have been impressed by the remarkable mind of the other, displayed as excellent attention to detail and in depth knowledge of how a system works), it is equally possible that the two individuals formed a couple because of some other factor (e.g., proximity, due to both of them working in a field that required good systemizing; availability, due to both of them being single because those with higher levels of empathy had already formed couples; awareness levels, due to both of them being relatively oblivious of the eccentricities of the other because of their lower levels of social awareness; or immunity to convention, due to both of them being less interested in what others in the social group might think about their partner choice). Future research will need to test these alternatives against each other. The important point for the transmission and mixing of the genes related to systemizing is that through whatever means, mating of such couples (which cannot be random) may have increased the likelihood of having a child with an ASC.

CONCLUSIONS

This chapter has reviewed the development of neurocognitive mechanisms underpinning two key psychological processes: empathizing and systemizing. These show strong sex differences and, therefore, might reflect natural selection operating differently on the two sexes. Also reviewed is the evidence that individuals on the autistic spectrum, which has a genetic basis, have degrees of empathizing difficulties alongside hyper-systemizing. According to the hyper-systemizing theory, ASC are the result of a normative SM—the function of which is to serve as a change-predicting mechanism—being set too high. While ASCs are disabling in the social world, hyper-systemizing can lead to talent in areas that are systemizable. In this sense, it is likely that the genes for increased systemizing have made remarkable contributions to human history (Fitzgerald, 2000, 2002; James, 2003). Finally, the assortative mating theory proposes that the cause of ASC is the genetic combination of having two strong systemizers as parents. This theory remains to be fully tested, but if confirmed, may help explain why the genes that can cause social disability have also been maintained in the gene pool, as they confer all the fitness advantages that strong systemizing can bring on the first-degree relatives of people with such conditions.

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