THE ROYAL SOCIETY

Published online 8 January 2003

Understanding autism: insights from mind and brain

Elisabeth L. Hill* **and Uta Frith**

Institute of Cognitive Neuroscience, University College London, 17 Queen Square, London WC1N 3AR, UK

Autism is a developmental disorder characterized by impaired social interaction and communication as well as repetitive behaviours and restricted interests. The consequences of this disorder for everyday life adaptation are extremely variable. The general public is now more aware of the high prevalence of this lifelong disorder, with *ca.* 0.6% of the population being affected. However, the signs and symptoms of autism are still puzzling. Since a biological basis of autism was accepted, approaches from developmental cognitive neuroscience have been applied to further our understanding of the autism spectrum. The study of the behavioural and underlying cognitive deficits in autism has advanced ahead of the study of the underlying brain abnormalities and of the putative genetic mechanisms. However, advances in these fields are expected as methodological difficulties are overcome. In this paper, recent developments in the field of autism are outlined. In particular, we review the findings of the three main neuro-cognitive theories of autism: theory-of-mind deficit, weak central coherence and executive dysfunction.

Keywords: autism; Asperger syndrome; theory of mind; weak central coherence; executive dysfunction; phenotype

1. INTRODUCTION

Only a few decades ago very few people had heard of autism, but now it is widely known that autism entails an inability to engage in ordinary social interactions. Thanks to the film 'Rainman', everyone knows that not only are there children with autism but that these children grow up into adults and that apart from their communication difficulties they have strange obsessions and incredible talents. Of course, these impressions that are nurtured by fiction are far too sweeping, but they do convey something of the fascination of this disorder. Autism is a developmental disorder that is lifelong. It has a neurological basis in the brain and genetic causes play a major role. However, the precise causes are still not known, nor is the true prevalence. Hence, speculations abound and fears of an epidemic have been voiced. One of the difficulties facing genetic studies and studies of prevalence is the definition of autism.

Autism is defined using behavioural criteria because, so far, no specific biological markers are known. The clinical picture of autism varies in severity and is modified by many factors, including education, ability and temperament. Furthermore, the clinical picture changes over the course of development within one and the same individual. In addition, autism is frequently associated with other disorders such as attention deficit disorder, motor incoordination and psychiatric symptoms such as anxiety and depression. For these reasons the behavioural criteria have to be very wide. In line with the clinical recognition of the variability, there is now general agreement that there is a spectrum of autistic disorders, which includes individuals at all levels of intelligence and language ability and spanning all degrees of severity. This widening of the criteria has inevitably led to a dramatic increase in identified cases. Autism is no longer a rare disorder.

Part of the autism spectrum, but considered a special subgroup, is Asperger syndrome. This label, hardly known before 1980, is now widely used to refer to individuals with the typical social communication impairments of autism, but who nevertheless have fluent language and good academic ability alongside obsessions and narrow interests. Some confusion exists between the labels Asperger syndrome and high-functioning autism. By current criteria, the diagnosis of Asperger syndrome requires that there has been no delay in language and cognitive development. This requirement seems somewhat arbitrary, as it is not clear that there are significant differences in the core features of autism between such cases and those who showed significant language delay early on, but later acquired fluent language and a social interest (Prior *et al.* 1998; Gilchrist *et al.* 2001). Indeed, many an autistic adult who is now a fluent talker and is earnestly trying to make friends, was mute and socially withdrawn at preschool age.

What are the core features of autism? The chief criteria for autistic disorder, as set out in the diagnostic handbooks, such as ICD-10 (World Health Organization 1992) and DSM-IV (American Psychiatric Association 1994), are abnormalities of social interaction, impairments in verbal and non-verbal communication and a restricted repertoire of interests and activities, all present from early childhood. These criteria have been agreed worldwide and appear to be working well, to the benefit of clinical practice as well as research. Using these criteria, population studies have shown that autism in a wide range of manifestations affects at least 0.6% of people at a male : female ratio of *ca.* 3 : 1. They have also shown that mental retar-

*Author for correspondence (e.hill@ucl.ac.uk).

One contribution of 14 to a Theme Issue 'Autism: mind and brain'.

dation, which means an IQ under 70, is strongly associated with autism and is present in between 25% and 40% of cases of autism spectrum disorders (Baird *et al.* 2000; Chakrabarti & Fombonne 2001). Furthermore, additional medical conditions involving the brain are seen in *ca.* 10% of the population (Gillberg & Coleman 2000). Asperger syndrome is estimated to affect 0.3%, at an even higher male : female ratio, estimated as ranging from 4 : 1 to 10 : 1.

Not part of the diagnostic criteria, but part of the popular notion of autism are the savant skills. This is justified, as these skills are found to be present in at least 10% of the autistic population. Indeed, almost all savants are diagnosed as suffering from autistic disorder (Rimland & Fein 1988). The savant is an individual with an islet of outstanding skill in one area, which can include calendar calculation, musical or artistic competence, often in the presence of modest or even low general intellectual ability (Mottron & Belleville 1993; Hermelin 2002). We cannot ignore these special abilities when trying to understand the nature of autism, even if they are not present in all cases. We also cannot ignore the common reports of sensory abnormalities, which suggest heightened sensitivity to minute differences between stimuli, be they in sound, sight, taste or touch. These phenomena are little explored but give clues to the unusual mind of the individual with autism. For one thing, they indicate that there are cognitive strengths as well as weaknesses in autism.

In this paper, the term 'autism' is used to describe all individuals on the autistic spectrum, but the research evidence on cognitive and neurological findings is most robust for those without severe mental retardation. This is because, in this subgroup, the effects of mental retardation that lead to generally depressed test performance can be avoided, and also because individuals who suffer from additional mental retardation and other co-occurring disorders have a more limited range and repertoire of observable behaviour. This is why most of the currently available behavioural findings are based on able or high-functioning individuals. Unfortunately, many of the anatomical studies of the brain in autism are based on low-functioning individuals and this makes it difficult to establish links between brain and behaviour. As regards many behavioural and also some of the more recent brain imaging findings, the question remains whether we can generalize these to low-functioning individuals. We have no idea why some individuals are high-functioning and others not, or why some have fluent language and others do not.

2. STUDIES TRYING TO EXPLAIN THE CAUSES OF AUTISM

Since autism was first described by the American psychiatrist Leo Kanner (1943) and by the Austrian paediatrician Hans Asperger (1944), many theories about its origin have been proposed. These have progressed from psychogenic ideas of the 'refrigerator mother' (Bettelheim 1967)—the idea that children become autistic in response to a threatening and unloving parent—through greater understanding of the behavioural characteristics of the disorder to a more detailed understanding at both cognitive and biological levels. Research has become focused gradually on genes, brain and mind and their interplay with environmental factors.

The heritability of autism has been one of the most important changes in our conception of the condition since the first pioneering descriptions. Twin studies provide particularly strong evidence. Taking a narrow definition of autism, if one member of a pair of MZ twins has the disorder, then in 36% of cases the other twin, who is genetically identical, also has it. By contrast, such concordance is hardly ever seen in DZ twin pairs. Furthermore, when a wider definition of autism is used the concordance rate more than doubles, with 90% for MZ versus 10% for DZ pairs (Bailey *et al.* 1995). The rate of autism in singleton siblings is 2–6%, *ca.* 10 times the prevalence rate found in the general population. It is assumed that multiple genes are involved (see Maestrini *et al.* (2000) for a review of susceptibility genes), and locations on several chromosomes, in particular 7 as well as 2, 16 and 17, have been replicated (International Molecular Genetic Study of Autism Consortium 1998). Some non-genetic factors are also considered, such as viral illness and immunological deficiency, originating either before birth or within the first two years of life. Many of the heated debates that occur in the public domain relate to putative environmental triggers, among them the so far unsubstantiated claim that the measles, mumps and rubella vaccination is a contributory cause. Similar claims relate to the measles virus in conjunction with gastric inflammatory disease. The balance of the evidence at present does not favour these hypotheses (Taylor *et al.* 1999; Farrington *et al.* 2001; Halsey & Hyman 2001).

How much is known about brain structure and function in autism? Post-mortem brains are scarce and cumbersome to analyse. Nevertheless, painstaking studies have provided firm evidence that structural abnormalities exist in the brains of people with autism (Bauman & Kemper 1994; Kemper & Bauman 1998). Of particular interest are the findings of reduced neuronal cell size and increased cell packing density in regions of the limbic system known to be critical to emotional and social behaviour. Outside the limbic system, abnormalities have also been found in the cerebellum and in various cortical regions (Bailey *et al.* 1998*a*). One concern about these studies is not only the scarcity of the material, but also the fact that it is difficult to relate the observed brain abnormalities to mental functions because good behavioural data on the individual cases are not usually available.

Brain imaging studies of blood flow in the living brain are still rather few but are steadily increasing. Two recent, well-controlled studies have revealed reduced blood flow in the medial temporal cortex in both brain hemispheres when at rest (Ohnishi *et al.* 2000; Zilbovicius *et al.* 2000). Unfortunately, it is hard to interpret this finding at present. A handful of studies have reported distinct functional abnormalities in a number of cortical (focusing on frontal and temporal lobes and the cerebellum) and subcortical regions (focusing on the amygdala and hippocampus), but the results are inconsistent (e.g. Courchesne *et al.* 1988; Abell *et al.* 1999; Aylward *et al.* 1999; Haznedar *et al.* 2001; Pierce *et al.* 2001). A useful review has been provided by Cody *et al.* (2002).

The most consistent finding about the autistic brain to have emerged in recent years is that it is on average larger

and heavier than the normal brain. Importantly, the increased size is not evident from birth, but from *ca.* 2–4 years (Lainhart *et al.* 1997; Courchesne *et al.* 2001). In a recent review, Frith (2003) speculated that a reason for this increase could be a failure of the normal pruning process that occurs several times during development after an initial wave of proliferation of synapses (Huttenlocher & Dabholkar 1997). Pruning eliminates faulty connections and optimizes coordinated neural functioning. Experience is important here but pruning will also show a genetic basis. Lack of pruning in autism might therefore lead to an increase in brain size and be associated with poor functioning of certain neural circuits. The following scenario can be envisaged: the synapses of the so-called feedback (top-down) systems fail to be pruned, while feed-forward (bottom-up) systems are normal. This possibility is suggested by analogy to the development of the visual system. Here, feed-forward systems are laid down at an early stage of brain maturation but feedback connections take much longer to develop and undergo a proliferation and pruning cycle (Burkhalter 1993).

If this is the case for other systems of the brain, then one and the same physiological failure could lead to several of the prominent non-social features of autism. Feedback-dependent control mechanisms might be dysfunctional and hence unable to act as top-down control on basic perceptual processes. One consequence could be executive function problems that are well documented in autism (see § 3c). Another consequence might be perceptual overload. In autism, such perceptual overload is often suspected, for instance, to explain the phenomenon of heightened sensitivity experienced by many individuals (e.g. Gerland 1997). Special talents that are based on apparently enhanced discrimination might also be explained in terms of a relative failure of top-down control. It is conceivable that failure of pruning might occur in different regions of the brain and at different times during development. This would result in a heterogeneous clinical picture with effects on diverse mental functions across individuals.

3. STUDIES TRYING TO EXPLAIN THE CAUSES OF THE SIGNS AND SYMPTOMS OF AUTISM

To explain the causes of specific behavioural signs in autistic individuals, their changes with age and their modification through remedial programmes, cognitive theories are needed. Cognitive explanations of the core features of autism have provided a vital interface between brain and behaviour. They attempt to provide explanations in terms of faults in basic mechanisms of the mind that normally underlie specific mental functions and facilitate learning in specific domains. The so-called 'theory of mind' deficit hypothesis proposes that a fault in just one of the many components of the social brain can lead to an inability to understand certain basic aspects of communication.

(a) *A failure to acquire an intuitive 'theory of mind'*

The assumption is that a neurologically based deficit in the understanding of minds lies at the origin of the specific social communication impairment of autism and can explain both aloofness and indiscriminate social approach. This assumption led to the testable claim that autistic children are impaired in their intuitive understanding of mental states, such as beliefs, and a lack of the attribution of mental states to themselves and to others that is automatic in normally developing children. This theory, sometimes referred to as 'mindblindness' or 'mentalizing failure', has been tested extensively (see chapters in Baron-Cohen *et al.* (1993, 2000)), and has proved fairly robust.

In the first study testing the hypothesis, Baron-Cohen *et al.* (1985) showed children two dolls, one named Sally and the other Ann. Children were shown that Sally had a basket and Ann a box. Sally puts a marble in her basket and goes outside. While she is outside, naughty Ann moves Sally's marble to her own basket. Sally then comes back in and wants to play with her marble. Children were asked, 'where will Sally look for her marble?' To a normally developing 4-year-old child, the answer is clear: Sally will look for her marble where she *thinks* it is and not where it *really* is now. Furthermore, the normally developing child can reason that Sally will look in her basket because this is where she put it and she does not know that it has been moved. However, in Baron-Cohen *et al.*'s study, 80% of children with autism, with a mental age equivalent to a 4-year-old or above, failed to answer this question correctly. They stated that Sally would look for her marble in the box, despite saying that Sally had put the marble in her basket and that she did not know that the marble had been moved. By contrast, 86% of children with Down syndrome, with generally lower ability levels than the children with autism, passed the test question.

Theory of mind involves mental states other than false beliefs. Children and adults with autism have also been shown to have deficits in their understanding of pretence, irony, non-literal language (e.g. double bluff) and deception (e.g. white lies). Such concepts have been assessed in the laboratory using story understanding. In one task, a participant reads a passage and is asked to make a judgement about the normality of a character's behaviour in that story. For example, assessing the 'normality' of asking to borrow a stranger's comb (Dewey 1991). In another task, a participant reads a series of stories and must answer a question about why something happened. In order to respond appropriately, a participant must reason either about cause and effect or about a character's mental state in the story. For example, understanding that a burglar alarm was set off by an animal breaking the electronic detector beam versus understanding that a burglar gave himself up to the police because he *believed* that they knew he had committed a crime (Happé 1994). On this second set of stories, individuals with autism have been shown to lack an intuitive understanding of the motives of a character in a story in parallel to intact cause-and-effect reasoning about the stories (e.g. Happé *et al.* 1996). For these reasons it is now widely accepted that individuals with autism are impaired in the intuitive understanding that people have mental states. Furthermore, some highly able individuals with autistic disorder who have written insightful autobiographical accounts acknowledge this problem, even when they themselves have gained knowledge of mental states and how this can be used to predict and explain behaviour. They have acquired a conscious 'theory of mind', but still apparently lack the intuitive mentalizing ability that is abundant in normal everyday communication.

Recently, a handful of studies have been published investigating the neurophysiological substrate of mentalizing through the use of neuroimaging studies in both normal volunteers and in able individuals with autism. In this way relationships between specific brain function and behaviour have been investigated (for a review, see Frith (2001)). The neuroimaging studies of mentalizing in normal individuals have identified a network of brain regions that is consistently active during mentalizing over and above the other task demands. This network involves the medial prefrontal cortex (especially anterior paracingulate cortex), the temporal–parietal junction and the temporal poles (Fletcher *et al.* 1995; Brunet *et al.* 2000; Castelli *et al.* 2000; Gallagher *et al.* 2000; Vogeley *et al.* 2001).

Only a small handful of studies so far have compared individuals with autism with normal individuals on mentalizing tasks while being scanned. Happé *et al.* (1996) conducted a PET study that revealed that individuals with Asperger syndrome showed less activation in the medial prefrontal region than did normal individuals. Baron-Cohen *et al.* (1999*a*) conducted a fMRI study in which participants were asked to judge a person's emotional states from photographs of the eye region, deciding which two words best described their mental state. When reading the language of the eyes, individuals with autism, in contrast to the control group, showed less extensive activation in frontal regions and no activation in the amygdala. Castelli *et al.* (2002) conducted a PET study in which they showed silent animations of geometric shapes to high-functioning individuals with autism and controls. Contrasts were made between brain activation when watching two triangles moving randomly versus moving in a goal-directed fashion (e.g. chasing, fighting) versus moving interactively with implied intentions (e.g. coaxing, tricking). During mentalizing (the latter condition), the individuals with autism showed less activation than the controls in the three brain regions critical to mentalizing in normal individuals (medial prefrontal cortex, temporal–parietal junction and the temporal poles).

Interestingly, both groups in the study by Castelli *et al.* (2002) showed similar activation levels in the occipital gyrus, indicating that all participants devoted more intensive visual analysis to the mentalizing animations. However, there was less connectivity between occipital (V3) and temporal regions (superior temporal sulcus) in the autistic brains than in the normal brains. These findings support the notion of a dysfunction in the specific neural substrate for mentalizing in autism, although the reason for the dysfunction remains to be identified. In summary, there is both behavioural and physiological evidence for a deficit in mentalizing in autism and this cognitive theory can be said to account fairly well for the core social communication impairment in autism, whether these behavioural impairments manifest themselves as withdrawal from other people, or as indiscriminate approach.

The mentalizing deficit theory of autism can account less well for deficits in other aspects of social behaviour in autism, for instance a well-documented impairment in the recognition of faces. This has recently been confirmed also at the physiological level (Critchley *et al.* 2000; Schultz *et al.* 2000; Pierce *et al.* 2001). Individuals with autism do not activate the face area of the fusiform gyrus that is reliably activated by normal individuals when looking at faces as opposed to objects. One interpretation of this finding is that children with autism are not equipped with the normal preference for social stimuli, which is assumed to rest on dedicated brain circuits. An inability to regulate emotions or to respond to emotions in others has also been postulated as a primary deficit in autism (Hobson 1993). Such problems may be related to anatomical abnormalities of the limbic system. Other theories are being offered that revolve around further potentially primary neuro-cognitive deficits, for instance, documented impairments in imitation in autism that have been speculatively related to an abnormal functioning of mirror neurons (Williams *et al.* 2001). Another hypothesis postulates that the innate preferences for attending to social stimuli may be absent in autism (Klin *et al.* 2002). The face/affect recognition abnormalities in autism can also be explained within a developmental perspective on theory of mind (Tager-Flusberg 2001). All of these hypotheses are currently being explored. The results should lead to a better definition of the extent and nature of the social impairments in autism.

(b) *Weak central coherence and its variants*

The non-social features of autism are a varied and puzzling collection raising more questions than answers. They include repetitive and obsessive behaviour, which Kanner labelled 'insistence of sameness' and others variously describe as a restricted repertoire of behaviours, rigidity and perseveration. They also include a markedly uneven pattern of intelligence, such that tests tapping factual knowledge, rote memory and focused attention to detail can lead to peak performances, while tests tapping 'common sense' comprehension and working memory or strategic task planning can be surprisingly poor.

Non-social features of autism, then, comprise strengths as well as weaknesses and are still less well understood and researched than the social impairments seen in autistic disorder. These non-social features are currently explained by two major cognitive theories and their variants. One theory, labelled 'central coherence', is as yet non-specific as to the underlying neuro-physiological processes, but alludes to poor connectivity throughout the brain between more basic perceptual processes and top-down modulating processes, perhaps owing to failure of pruning. Central coherence refers to an information-processing style, specifically the tendency to process incoming information in its context: that is pulling information together for higher-level meaning. In the case of strong central coherence, this tendency would work at the expense of attention to and memory for details (Frith 1989; Happé 1999). In the case of weak central coherence this tendency would work at the expense of contextual meaning and in favour of piecemeal processing. Why is this relevant to features of autism? An illustration is given in Bartlett's (1932) now classic study of story recall. When retelling a story, individuals find it easier to recall accurately the gist of the story rather than its specific details. People with autism show the opposite profile, recalling the exact words of the story rather than its gist.

By this theory, individuals with autism are described as exhibiting 'weak central coherence'. A tendency to focus on the local, rather than global aspects of an object of interest may explain the uneven profile of assets and defi-

cits in intelligence test performance, regardless of whether the tests are verbal or non-verbal. An example is the block design test found in both the child and adult versions of the Wechsler intelligence scale (Shah & Frith 1993). Another example of the advantage of this processing style is the embedded figures test (Witkin *et al.* 1971) where a participant must locate a small part within a global picture. Here, people with autism have been shown to be superior to non-autistic controls (Shah & Frith 1983, 1993; Jolliffe & Baron-Cohen 1997). An explanation for such superior ability may be that individuals with autism are less influenced by the global shape (gestalt) and find the local parts of the gestalt more salient. An example where weak central coherence would be detrimental is a task in which one and the same stimulus has to be interpreted differently according to context. One test used homographs (words with one spelling but two meanings, such as 'tear' in the eye or in a piece of fabric), which individuals were asked to read aloud in the context of sentences. Frith & Snowling (1983), Happé (1997) and Jolliffe & Baron-Cohen (1999) all found that individuals with autism did not appear to integrate the sentence context when performing this task, being less likely than controls to pronounce the homograph correctly depending on the context of the sentence.

An important extension of the central coherence account postulates not poor integration of information in a gestalt, but rather enhanced discrimination of the individual elements (Mottron *et al.* 2000; Plaisted 2001). This variant explains savant abilities as being a result of highly developed abilities that often start with an obsessive interest in small details. Thus, focusing on the day and date of a birthday can lead to interest in other days and dates and eventually result in a phenomenal knowledge of calendar facts. Baron-Cohen's proposal of systemizing as a typical preference in autism can also be characterized as an activity that essentially starts with an interest in single facts, or single objects (Baron-Cohen 2002).

The brain basis of the processing bias identified as central coherence has been little explored. In a fMRI study, Fink *et al.* (1997) required normal individuals to attend to the global or local aspects of complex visual figures. Brain activation when attending to these different features differed. Processing of the global features of a figure was associated with right lingual gyrus activation while processing of the local features was associated with activation of left inferior occipital cortex. Electrophysiological evidence also indicates increased right hemisphere activity during the processing of global versus local features (Heinze *et al.* 1998).

Central coherence in autistic individuals has yet to be studied at the neurological level, with the exception of one brain imaging study. Ring *et al.* (1999) conducted a fMRI study in which adults with and without autism were scanned while undertaking the embedded figures test. Although several brain regions were similarly activated in the two groups, there were some intriguing differences. Specifically, the autistic individuals showed relatively greater activation of extra-striate regions of visual cortex, while the controls demonstrated relatively greater activation in the prefrontal cortex. These findings are consistent with the idea that the early stages of sensory processing (where emphasis is paid to the local features of a stimulus) are intact in autism while the top-down modulation of these early processing stages (requiring the extraction of the global features of a stimulus) is not functioning appropriately. Thus this study showed that an islet of preserved performance in individuals with autism may be subserved by neural systems that are qualitatively different from those activated in normal control subjects. In this way, a difference has been highlighted in the functional anatomy of autistic individuals in relation to the differential use of local and global cognitive strategies. The main problem of the central coherence theory of autism, and its variants, is a lack of plausible neuroanatomical mechanisms in which the nature of the abnormal activation could illuminate the observed behavioural features. Clearly, a great deal of neuroanatomical work must be done to investigate this.

How far can a weak central coherence account or its variants go in explaining some of the everyday behaviours that we see in individuals with autism? The attention of the autistic individual is often captured by fragments or surface features of objects and sensations that are usually of little interest to normal people within the 'real world' in a way that is demonstrated by the performance peaks observed in laboratory-based testing on tasks such as block design and embedded figures. However, there are other characteristics of autistic behaviour that are best explained by a third cognitive theory, that of executive dysfunction.

(c) *Executive dysfunction*

A widely accepted cognitive explanation for at least some of the behavioural problems in autism is a theory of executive dysfunction. This theory makes an explicit link to frontal lobe failure in analogy with neuropsychological patients who have suffered damage in the frontal lobes. The behavioural problems addressed by this theory are rigidity and perseveration, being explained by a poverty in the initiation of new actions and the tendency to be stuck in a given task set. At the same time, the ability to carry out routine actions can be excellent and is manifested in a strong liking for routines, repetitious behaviour and sometimes elaborate rituals. These problems are clear in the poor daily life management of people with autism, who benefit from prompts and externally provided structures to initiate well-learned routines.

Executive function is an umbrella term for functions such as planning working memory, impulse control, shifting set and the initiation and monitoring of action as well as for the inhibition of prepotent responses. All are thought to depend on systems that involve prefrontal activity in the brain in normal individuals. Furthermore, these functions are typically impaired in patients with acquired damage to the frontal lobes (e.g. Shallice 1988) as well as in a range of disorders that are likely to involve deficits in the frontal lobes. Such clinical disorders include attention deficit disorder, obsessive compulsive disorder, Tourette's syndrome, phenylketonuria and schizophrenia.

Poor performance on many tasks of executive function has been documented in autism (see papers in Russell (1997)). Using a variety of tasks, children with autism have been shown to have deficits in planning. One typical task is the Tower of Hanoi, or the related Tower of London, in which individuals must move discs from a prearranged sequence on three different pegs to match a goal state determined by the examiner in as few moves as poss-

ible and following a number of specific rules. Children with autism have been found to be impaired on such tasks (Ozonoff *et al.* 1991; Hughes *et al.* 1994; Ozonoff & McEvoy 1994; Ozonoff & Jensen 1999).

The inhibition of a prepotent response has been reported in a number of studies. One illustration of this is given by Hughes & Russell's (1993) 'detour reaching task'. In the original task, participants could obtain a marble visible in a box, but only by turning a knob or flicking a switch at the side of the box, and not by reaching immediately into the box. Individuals with autism found it much more difficult to throw a switch in order to perform an object retrieval than children with moderate learning difficulties with whom they were matched for verbal mental age. Children with autism were less able to inhibit their prepotent response to reach immediately for the marble on this task. Further work manipulating this paradigm reported by Bíro & Russell (2001) indicates that it may be the apparently arbitrary nature of the rules involved that cause particular difficulty in this area of executive functioning for learning-disabled children with autism (see Russell 2002).

Perseveration is another aspect of executive functioning that appears to be a characteristic of autistic individuals. One example of this is seen when performing the Wisconsin card sorting task (Heaton *et al.* 1993). In this task, an individual must sort cards on one of three possible dimensions (colour, number, shape) according to a non-spoken rule and then shift to sort cards along a different dimension. On this task, the experimenter tells the participant whether she/he has placed the card correctly (i.e. followed the correct rule), but does not give the participant the rule explicitly. Several studies have reported that autistic individuals are highly perseverative in their response to the Wisconsin card sorting task compared with controls. That is, autistic individuals have difficulty in shifting to sort using the second of two rules, instead continuing to sort using the first rule (Rumsey & Hamburger 1988; Szatmari *et al.* 1989; Prior & Hoffmann 1990; Ozonoff *et al.* 1991; Ozonoff & McEvoy 1994; Ozonoff 1995; Bennetto *et al.* 1996). Such difficulties could be seen to reflect a deficit in mental flexibility. Poor performance on such tests of executive function is related directly to stereotyped and rigid behaviour in everyday life as shown in highly repetitive thought and action. Interestingly, it has proved difficult to identify executive dysfunction in preschool-aged children with autism (Griffith *et al.* 1999; Dawson *et al.* 2002). It remains to be seen whether more sensitive tasks would highlight an autism-specific impairment at a young age.

There is thus at least some evidence that individuals with autism experience deficits in areas of executive functioning, and this cognitive theory has gained much ground in recent years. However, there are some problems with this account. One difficulty arises from a lack of consensus as to which aspects of executive function are typical of autism. A more striking difficulty arises from the fact that executive dysfunction is found in clinical conditions other than autism (e.g. attention deficit disorder). Certainly this problem limits the potential to use executive dysfunction as a diagnostic marker for autism. It may be that this difficulty will be resolved in the light of future detailed work investigating executive functions in autism. A final difficulty with the executive dysfunction account of autism is that while such difficulties appear to be common, they may not be a universal feature of autism. Certain studies have found that the tests of executive function that they have employed have not been problematic for all autistic individuals with normal IQ levels (Baron-Cohen *et al.* 1999*b*; Russell & Hill 2001). However, the executive dysfunction account of autism should not be dismissed because remediation of autistic individuals' difficulties in the executive domain can help to improve the independent living skills of adults with autistic disorders.

We are aware of no studies where the brains of individuals with autism have been scanned while performing tasks of executive function. However, an integration of the behavioural findings in autism and the known brain abnormalities underlying similar behaviours in patients with acquired damage to the frontal lobes of the brain and other disorders that lead to executive dysfunction accords well with the notion of abnormalities in the prefrontal cortex and its connections with other brain structures such as the basal ganglia, striatum and cerebellum in individuals with autism (Robbins 1997). It remains to be seen whether structural magnetic resonance imaging and other neuroanatomical studies of the brains of autistic individuals will support this notion. Diffusion tensor imaging will be particularly suited to the assessment of abnormalities in connectivity.

4. THE BROADER PHENOTYPE OF AUTISM

In many ways, the greatest hope for elucidating the causes of autism lies in genetic studies. However, in our view, these studies are hampered by a lack of definition at the cognitive level. Given the current diagnostic criteria, ideas of the phenotype in autism are based on unsatisfactory behavioural criteria that change with age and the precision of parental report. A small, but increasing number of studies are highlighting the existence of a broader cognitive phenotype of autism (see Bailey *et al.* (1998*b*) for a review). In essence, a broader cognitive phenotype exists when close relatives of an individual with autism show a raised incidence of cognitive performance associated with the diagnosis of autism, but to a mild degree that does not put them into the category of being diagnosed with autism themselves. Aspects of the three main cognitive theories of autism have been investigated in relation to the broader phenotype providing good evidence for its existence across broad areas of its features. Baron-Cohen & Hammer (1997) reported that the parents of children with autism showed a similar profile to those with autism on a task claimed to involve mentalizing (inferior to controls)—the language of the eyes test—as well as on a test of weak central coherence—the embedded figures test—(superior to controls).

Happé *et al.* (2001) assessed the parents and brothers of boys with either autism, dyslexia or no developmental disorder on a series of tests of weak central coherence, block design, the embedded figures test and a visual illusion (the Ebbinghaus circles). Like the Baron-Cohen & Hammer (1997) study, the findings from the four tasks were similar: the performance of the fathers of boys with autism was significantly different from that of all other groups, showing a bias towards detail-focus across all tasks

administered. Furthermore, a similar profile has been found in studies that have investigated performance on tests of executive function and their relationship to the broader autism phenotype. Hughes *et al.* (1997) reported that the parents, and especially fathers, of children with autism showed relatively poor planning skills and attentional flexibility in comparison with the parents of children with learning disability and children with no disorder. Difficulties in executive function have also been identified in the non-autistic siblings of children with autism (Hughes *et al.* 1999). Thus, evidence of a broader autism phenotype is provided in the domains of each of the three key cognitive theories of autism.

At this stage in our understanding of autism, we have focused on the three cognitive theories—mentalizing deficit, weak central coherence and executive dysfunction. It would be wrong to consider these as rival theories and they certainly do not have to be seen to be mutually exclusive. While each cognitive theory has been tested in the broader phenotype—with positive findings—large-scale studies assessing all three theories in the same sample are still needed. The relationship between the cognitive phenotype (or endophenotype) and the broader phenotype remains to be investigated. Furthermore, this work needs to be widened to include the neuro-cognitive deficits that have as yet received insufficient attention. Such an approach may help us to pinpoint both diagnostic signs and genetic markers of the condition.

This work was supported by MRC Programme grant no. G9716841 awarded to U.F.

REFERENCES

Abell, F., Krams, M., Ashburner, J., Passingham, R., Friston, K., Frakowiak, R., Happé, F., Frith, C. & Frith, U. 1999 The neuroanatomy of autism: a voxel-based whole brain analysis of structural scans. *Neuroreport* **10**, 1647–1651.

American Psychiatric Association 1994 *Diagnostic and statistical manual of mental disorders*. Washington, DC: American Psychiatric Association.

Asperger, H. 1944 'Autistic psychopathy' in childhood. In *Autism and Asperger syndrome* (ed. U. Frith), pp. 37–92. Cambridge University Press.

Aylward, E. H., Minshew, N. J., Goldstein, G., Honeycutt, N. A., Augustine, A. M., Yates, K. O., Barta, P. E. & Pearlson, G. D. 1999 MRI volumes of amygdala and hippocampus in non-mentally retarded autistic adolescents and adults. *Neurology* **53**, 2145–2150.

Bailey, A., Le Couteur, A., Gottesman, I., Bolton, P., Simonoff, E., Yuzda, E. & Rutter, A. 1995 Autism as a strongly genetic disorder: evidence from a British twin study. *Psychol. Med.* **25**, 63–77.

Bailey, A., Luthert, P., Dean, A., Harding, B., Janota, I., Montgomery, M., Rutter, M. & Lantos, P. 1998*a* A clinicopathological study of autism. *Brain* **121**, 889–905.

Bailey, A., Palferman, S., Heavey, L. & Le Couteur, A. 1998*b* Autism: the phenotype in relatives. *J. Autism Devl Disorders* **28**, 369–392.

Baird, G., Charman, T., Baron-Cohen, S., Cox, A., Swettenham, J., Wheelwright, S. & Drew, A. 2000 A screening instrument for autism at 18 months of age: a 6 year follow-up study. *J. Am. Acad. Child Adolescent Psychiatry* **39**, 694–702.

Baron-Cohen, S. 2002 The extreme male brain theory of autism. *Trends Cogn. Sci.* **6**, 248–254.

Baron-Cohen, S. & Hammer, J. 1997 Parents of children with Asperger syndrome: what is the cognitive phenotype? *J. Cogn. Neurosci.* **9**, 548–554.

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

Baron-Cohen, S. T., Tager-Flusberg, H. & Cohen, D. J. 1993 *Understanding other minds. Perspectives from autism*. Oxford University Press.

Baron-Cohen, S., Tager-Flusberg, H. & Cohen, D. J. 2000 *Understanding other minds. Perspectives from developmental cognitive neuroscience*. Oxford University Press.

Baron-Cohen, S., Ring, H., Williams, S., Wheelwright, S., Bullmore, E., Brammer, M. & Andrew, C. 1999*a* Social intelligence in the normal and autistic brain: a fMRI study. *Eur. J. Psychiatry* **11**, 1891–1898.

Baron-Cohen, S., Wheelwright, S., Stone, V. & Rutherford, M. 1999*b* A mathematician, a physicist and a computer scientist with Asperger syndrome: performance on psychology and folk physics tests. *Neurocase* **5**, 475–483.

Bartlett, F. C. 1932 *Remembering: a study in experimental social psychology*. Cambridge University Press.

Bauman, M. L. & Kemper, K. L. 1994 Neuroanatomical observations of the brain in autism. In *The neurobiology of autism* (ed. M. L. Bauman & K. L. Kemper), pp. 119–145. Baltimore, MA: The Johns Hopkins University Press.

Bennetto, L., Pennington, B. F. & Rogers, S. J. 1996 Intact and impaired memory functions in autism. *Child Devl* **67**, 1816–1835.

Bettelheim, B. 1967 *The empty fortress: infantile autism and the birth of the self*. New York: The Free Press.

Bíro, S. & Russell, J. 2001 The execution of arbitrary procedures by children with autism. *Devl Psychopathol.* **13**, 97–110.

Brunet, E., Sarfate, Y., Hardy-Bayle, M. C. & Decety, J. 2000 A PET investigation of the attribution of intentions with a nonverbal task. *Neuroimage* **11**, 157–166.

Burkhalter, A. 1993 Development of forward and feedback connections between areas V1 and V2 of human visual cortex. *Cerebral Cortex* **3**, 476–487.

Castelli, F., Happé, F., Frith, U. & Frith, C. D. 2000 Movement and mind: a functional imaging study of perception and interpretation of complex intentional movement patterns. *Neuroimage* **12**, 314–325.

Castelli, F., Frith, C., Happé, F. & Frith, U. 2002 Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain* **125**, 1839–1849.

Chakrabarti, S. & Fombonne, E. 2001 Pervasive developmental disorders in preschool children. *J. Am. Medical Association* **285**, 3093–3099.

Cody, H., Pelphrey, K. & Piven, J. 2002 Structural and functional magnetic resonance imaging of autism. *Int. Devl Neurosci.* **766**, 1–18.

Courchesne, E., Yeung-Courchesne, R., Press, G. A., Hesselink, J. R. & Jernigan, T. L. 1988 Hypoplasia of cerebellar vermal lobule-Vi and lobule-Vii in autism. *New England J. Med.* **318**, 1349–1354.

Courchesne, E. (and 15 others) 2001 Unusual brain growth patterns in early life in patients with autistic disorder: a MRI study. *Neurology* **57**, 245–254.

Critchley, H. D. (and 10 others) 2000 The functional neuroanatomy of social behaviour: changes in cerebral blood flow when people with autistic disorder process facial expressions. *Brain* **123**, 2203–2212.

Dawson, G., Munson, J., Estes, A., Osterling, J., McPartland, J., Toth, K., Carver, L. & Abbott, R. 2002 Neurocognitive function and joint attention ability in young children with autism spectrum disorder versus developmental delay. *Child Dev.* **73**, 345–358.

Dewey, M. 1991 Living with Asperger's syndrome. In *Autism and Asperger syndrome* (ed. U. Frith), pp. 184–206. Cambridge University Press.

Farrington, C. P., Miller, E. & Taylor, B. 2001 MMR and autism: further evidence against a causal association. *Vaccine* **19**, 3632–3635.

Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S. J. & Dolan, R. J. 1997 Neural mechanisms involved in the processing of global and local aspects of hierarchically organized visual stimuli. *Brain* **120**, 1779–1791.

Fletcher, P. C., Happé, F., Frith, U., Baker, S. C., Dolan, R. J., Frackowiak, R. S. J. & Frith, C. D. 1995 Other minds in the brain: a functional imaging study of 'theory of mind' in story comprehension. *Cognition* **57**, 109–128.

Frith, C. D. 2003 What do imaging studies tell us about the neural basis of autism? In *Autism: neural basis and treatment possibilities* (ed. M. Rutter), Novartis Foundation. Chichester, UK: Wiley.

Frith, U. 1989 *Autism. Explaining the enigma*. Oxford: Blackwell.

Frith, U. 2001 Mindblindness and the brain in autism. *Neuron* **32**, 969–979.

Frith, U. & Snowling, M. 1983 Reading for meaning and reading for sound in autistic and dyslexic children. *J. Devl Psychol.* **1**, 329–342.

Gallagher, H., Happé, F., Brunswick, N., Fletcher, P. C., Frith, U. & Frith, C. D. 2000 Reading the mind in cartoons and stories: a fMRI study of 'theory of mind' in verbal and non-verbal tasks. *Neuropsychologia* **38**, 11–21.

Gerland, G. 1997 *A real person: life on the outside*. (trans. J. Tate). London: Souvenir.

Gilchrist, A., Green, J., Cox, A., Burton, D., Rutter, M. & Le Couteur, A. 2001 Development and current functioning in adolescents with Asperger syndrome: a comparative study. *J. Child Psychol. Psychiatry* **42**, 227–240.

Gillberg, C. & Coleman, M. 2000 *The biology of the autistic syndromes*, 3rd edn. London: MacKeith Press.

Griffith, E. M., Pennington, B. F., Wehner, E. A. & Rogers, S. J. 1999 Executive functions in young children with autism. *Child Dev.* **70**, 817–832.

Halsey, N. A. & Hyman, S. L. 2001 Measles–mumps–rubella vaccine and autistic spectrum disorder: report from the New Challenges in childhood immunizations conference convened in Oak Brook, Illinois, June 12–13. *Pediatrics* **107**, E84.

Happé, F. G. E. 1994 An advanced test of theory of mind: understanding of story characters' thoughts, and feelings by able autistic, mentally handicapped, and normal children and adults. *J. Autism Devl Disorder* **24**, 129–154.

Happé, F. G. E. 1997 Central coherence and theory of mind in autism: reading homographs in context. *Br. J. Devl Psychol.* **15**, 1–12.

Happé, F. 1999 Autism: cognitive deficit or cognitive style? *Trends Cogn. Sci.* **3**, 216–222.

Happé, F., Briskman, J. & Frith, U. 2001 Exploring the cognitive phenotype of autism: weak 'central coherence' in parents and siblings of children with autism: I. experimental tests. *J. Child Psychol. Psychiatry* **42**, 299–307.

Happé, F., Ehlers, S., Fletcher, S., Frith, U., Johannsson, M., Gillberg, C., Dolan, R., Frackowiak, R. & Frith, C. 1996 'Theory of mind' in the brain. Evidence from a PET scan study of Asperger syndrome. *Neuroreport* **8**, 197–201.

Haznedar, M. M., Buchsbaum, M. S., Wei, T. C., Hof, P. R., Cartwright, C., Bienstock, C. A. & Hollander, E. 2001 Limbic circuitry in patients with autism spectrum disorders, studies with positron emission tomography and magnetic resonance imaging. *Am. J. Psychiatry* **157**, 1994–2001.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G. & Curtiss, G. 1993 *Wisconsin card sorting test manual: revised and expanded*. Odessa, FL: Psychological Assessment Resources.

Heinze, H. J., Hinrichs, H., Scholz, M., Burchert, W. & Mangun, R. 1998 Neural mechanisms of global and local processing: a combined PET and ERP study. *J. Cogn. Neurosci.* **10**, 485–498.

Hermelin, B. 2002 *Bright splinters of the mind. A personal story of research with autistic savants*. London: Jessica Kingsley.

Hobson, R. P. 1993 *Autism and the development of mind*. Hove, Sussex: Lawrence Erlbaum Associates.

Hughes, C. & Russell, J. 1993 Autistic children's difficulty with mental disengagement from an object: its implications for theories of autism. *Devl Psychol.* **29**, 498–510.

Hughes, C., Russell, J. & Robbins, T. W. 1994 Evidence for executive dysfunction in autism. *Neuropsychologia* **32**, 477–492.

Hughes, C., Leboyer, M. & Bouvard, M. 1997 Executive function in parents of children with autism. *Psychol. Med.* **27**, 209–220.

Hughes, C., Plumet, M.-H. & Leboyer, M. 1999 Towards a cognitive phenotype for autism: increased prevalence of executive dysfunction and superior spatial span amongst siblings of children with autism. *J. Child Psychol. Psychiatry* **40**, 705–718.

Huttenlocher, P. R. & Dabholkar, A. S. 1997 Regional differences in synaptogenesis in human cerebral cortex. *J. Comp. Neurol.* **387**, 167–178.

International Molecular Genetic Study of Autism Consortium 1998 A full genome screen for autism with evidence for linkage to a region on chromosome 7q. *Hum. Mol. Genet.* **7**, 571–578.

Jolliffe, T. & Baron-Cohen, S. 1997 Are people with autism or Asperger syndrome faster than normal on the embedded figures test? *J. Child Psychol. Psychiatry* **38**, 527–534.

Jolliffe, T. & Baron-Cohen, S. 1999 A test of central coherence theory: linguistic processing in high-functioning adults with autism or Asperger syndrome: is local coherence impaired? *Cognition* **71**, 149–185.

Kanner, L. 1943 Autistic disturbances of affective contact. *Nervous Child* **2**, 217–250.

Kemper, K. L. & Bauman, M. L. 1998 Neuropathology of infantile autism. *J. Neuropathol. Exp. Neurol.* **57**, 645–652.

Klin, A., Jones, W., Schultz, R., Volkmar, F. & Cohen, D. 2002 Defining and quantifying the social phenotype in autism. *Am. J. Psychiatry* **159**, 895–908.

Lainhart, J. E., Piven, J., Wzorek, M., Landa, R., Santangelo, S. L., Coon, H. & Folstein, S. E. 1997 Macrocephaly in children and adults with autism. *J. Am. Acad. Child Adolescent Psychiatry* **36**, 282–290.

Maestrini, E., Paul, A., Monaco, A. P. & Bailey, A. 2000 Identifying autism susceptibility genes. *Neuron* **28**, 19–24.

Mottron, L. & Belleville, S. 1993 A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. *Brain Cogn* **23**, 279–309.

Mottron, L., Peretz, I. & Ménard, E. 2000 Local and global processing of music in high-functioning persons with autism: beyond central coherence? *J. Child Psychol. Psychiatry* **41**, 1057–1065.

Ohnishi, T., Matsuda, H., Hashimoto, T., Kunihiro, T., Nishikawa, M., Uema, T. & Sasaki, M. 2000 Abnormal regional cerebral blood flow in childhood autism. *Brain* **123**, 1838–1844.

Ozonoff, S. 1995 Reliability and validity of the Wisconsin card sorting test in studies of autism. *Neuropsychology* **9**, 491–500.

Ozonoff, S. & Jensen, J. 1999 Brief report: specific executive function profiles in three neurodevelopmental disorders. *J. Autism Devl. Disorders* **29**, 171–177.

Ozonoff, S. & McEvoy, R. E. 1994 A longitudinal study of executive function and theory of mind development in autism. *Dev. Psychopathol.* **6**, 415–431.

Ozonoff, S., Pennington, B. F. & Rogers, S. J. 1991 Executive function deficits in high-functioning autistic individuals: relationship to theory of mind. *J. Child Psychol. Psychiatry* **32**, 1081–1105.

Pierce, K., Muller, R. A., Ambrose, J., Allen, G. & Courchesne, E. 2001 Face processing occurs outside the fusiform 'face area' in autism: evidence from functional MRI. *Brain* **124**, 2059–2073.

Plaisted, K. 2001 Reduced generalization in autism: an alternative to weak central coherence. In *The development of autism: perspectives from theory and research* (ed. J. A. Burack, T. Charman, N. Yirmiya & P. Zelazo), pp. 149–169. Mahwah, NJ: Lawrence Erlbaum Associates.

Prior, M. R. & Hoffmann, W. 1990 Brief report: neuropsychological testing of autistic children through an exploration with frontal lobe tests. *J. Autism Devl Disorders* **20**, 581–590.

Prior, M., Eisenmajer, R., Leekam, S., Wing, L., Gould, J., Ong, B. & Dowe, D. 1998 Are there subgroups within the autistic spectrum? A cluster analysis of a group of children with autistic spectrum disorder. *J. Child Psychol. Psychiatry* **39**, 893–902.

Rimland, B. & Fein, D. 1988 Special talents of autistic savants. In *The exceptional brain* (ed. L. K. Obler & D. Fein), pp. 474–492. New York: Guildford.

Ring, H. A., Baron-Cohen, S., Wheelwright, S., Williams, S. C. R., Brammer, M., Andrew, C. & Bullmore, E. T. 1999 Cerebral correlates of preserved cognitive skills in autism: a functional MRI study of embedded figures task performance. *Brain* **122**, 1305–1315.

Robbins, T. W. 1997 Integrating the neurobiological and neuropsychological dimensions of autism. In *Autism as an executive disorder* (ed. J. Russell), pp. 21–53. Oxford University Press.

Rumsey, J. M. & Hamburger, S. D. 1988 Neuropsychological findings in high-functioning men with infantile autism. *J. Autism Devl Disorders* **20**, 155–168.

Russell, J. 1997 *Autism as an executive disorder*. Oxford University Press.

Russell, J. 2002 Cognitive theories of autism. In *Cognitive deficits in brain disorders* (ed. J. E. Harrison & A. M. Owen), pp. 295–323. London: Martin Dunitz.

Russell, J. & Hill, E. L. 2001 Action-monitoring and intention reporting in children with autism. *J. Child Psychol. Psychiatry* **42**, 317–328.

Schultz, R. T., Gauthier, I., Klin, A., Fulbright, R. K., Anderson, A. W., Volkmar, F., Skudlarski, P., Lacadic, C., Cohen, D. J. & Gore, J. C. 2000 Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Arch. Gen. Psychiatry* **57**, 331–340.

Shah, A. & Frith, U. 1983 An islet of ability in autistic children: a research note. *J. Child Psychol. Psychiatry* **24**, 613–620.

Shah, A. & Frith, U. 1993 Why do autistic individuals show superior performance on the block design task? *J. Child Psychol. Psychiatry* **34**, 1351–1364.

Shallice, T. 1988 *From neuropsychology to mental structure*. Cambridge University Press.

Szatmari, P., Bartolucci, G., Bremner, R., Bond, S. & Rich, S. 1989 A follow-up study of high-functioning autistic children. *J. Autism Devl Disorders* **19**, 213–225.

Tager-Flusberg, H. 2001 A re-examination of the theory of mind hypothesis of autism. In *The development of autism: perspectives from theory and research* (ed. J. A. Burack, T. Charman, N. Yirmiya & P. Zelazo), pp. 173–193. Mahwah, NJ: Lawrence Erlbaum Associates.

Taylor, B., Miller, E., Farrington, C. P., Petropoulos, M.-C., Favot-Mayaud, I., Li, J. & Wraight, P. A. 1999 Autism and measles, mumps, and rubella vaccine: no epidemiological evidence for a causal association. *Lancet* **353**, 2026–2029.

Vogeley, K., Bussfeld, P., Newen, A., Herrmann, S., Happé, F., Falkai, P., Maier, W., Shah, N. J., Fink, G. R. & Zilles, K. 2001 Mind reading: neural mechanisms of theory of mind and self-perspective. *Neuroimage* **14**, 170–181.

Williams, J. H. G., Whiten, A., Suddendorf, T. & Perrett, D. I. 2001 Imitation, mirror neurons and autism. *Neurosci. Biobehav. Rev.* **25**, 287–295.

Witkin, H. A., Oltman, P. K., Raskin, E. & Karp, S. 1971 *A manual for the embedded figures test*. Palo Alto, CA: Consulting Psychologists Press.

World Health Organization 1992 *The ICD-10 classification for mental and behavioural disorders: clinical descriptions and diagnostic guidelines*. Geneva, Switzerland: WHO.

Zilbovicius, M., Boddaert, N., Belin, P., Poline, J. B., Remy, P., Mangin, J. F., Thivard, L., Barthelemy, C. & Samson, Y. 2000 Temporal lobe dysfunction in childhood autism: a PET study. *Am. J. Psychiatry* **157**, 1988–1993.

GLOSSARY

DZ: dizygotic
fMRI: functional magnetic resonance imaging
IQ: intelligence quotient
MZ: monozygotic
PET: positron emission tomography