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DOI: 10.1093/brain/122.7.1305 · Source: PubMed

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# Cerebral correlates of preserved cognitive skills in autism

## A functional MRI study of Embedded Figures Task performance

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### Summary

When considering the cognitive abilities of people with autism, the majority of studies have explored domains in which there are deficits. However, on tests of local processing and visual search, exemplified by the Embedded Figures Task (EFT), people with autism have been reported to demonstrate superiority over normal controls. This study employed functional MRI of subjects during the performance of the EFT to test the hypothesis that normal subjects and a group with autism would activate different brain regions and that differences in the patterns of these regional activations would support distinct models of cerebral processing underlying EFT performance in the two groups. It was found that several cerebral regions were similarly activated in the two groups. However, normal controls, as well as demonstrat-

ing generally more extensive task-related activations, additionally activated prefrontal cortical areas that were not recruited in the group with autism. Conversely, subjects with autism demonstrated greater activation of ventral occipitotemporal regions. These differences in functional anatomy suggest that the cognitive strategies adopted by the two groups are different: the normal strategy invokes a greater contribution from working memory systems while the autistic group strategy depends to an abnormally large extent on visual systems for object feature analysis. This interpretation is discussed in relation to a model of autism which proposes a predisposition towards local rather than global modes of information processing.

**Keywords:** autism; fMRI; visual analysis; working memory; componential analysis

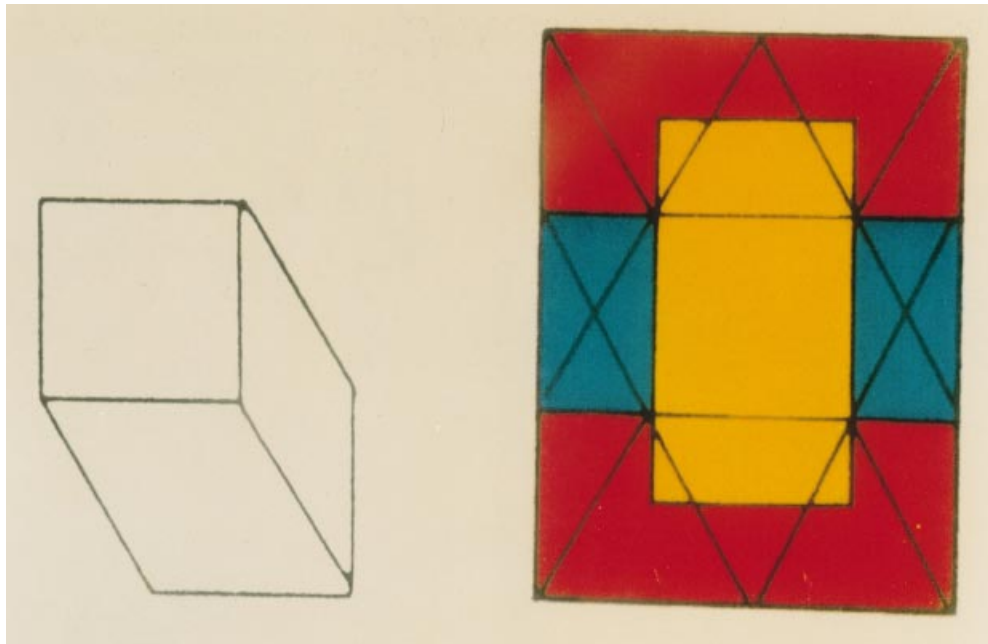
**Abbreviations:** AN(C)OVA = analysis of (co)variance; BA = Brodmann area; EFT = Embedded Figures Task; fMRI = functional MRI; FPQ = fundamental power quotient

### Introduction

Most psychological research into autism has investigated the nature of cognitive deficits, such as in the theory of mind (Happé, 1994; Baron-Cohen, 1995), pragmatics (Tager-Flusberg, 1993) and imagination (Wing and Gould, 1979; Scott and Baron-Cohen, 1996). However, a small but important set of studies has documented the presence of cognitive superiority in people with autism, restricted to specific 'islets of ability'. Such abilities have been recognized since autism was first described (Kanner, 1943), and more

recently have been elegantly studied in the condition of 'idiot savant' (Hermelin and O'Connor, 1986; O'Connor and Hermelin, 1990).

Preserved or superior abilities on a task may arise from a more componential analysis of complex stimuli. For example, whilst in most domains of learning skill increases with increasing general development, the normal ability to acquire a native language peaks in early life and then declines (Karmiloff-Smith, 1992). One explanation to account for this



**Fig. 1** The Embedded Figure Task. Example of a simple target shape and the complex figure containing it. Modified and reproduced by special permission of the publisher (Consulting Psychologists Press, Palo Alto, CA) from *Embedded Figures Test*, by Herman A Witkin. Further reproduction is prohibited without the publisher's written consent.

is that young children may perceive and store only a limited number of component pieces of form and meaning, whilst adults store larger segments including whole words (Newport, 1990). The young child's limited capacity for cognitive processing thus presents an advantage in those parts of language acquisition that require componential analysis (e.g. complex morphological structure). Considering neurodevelopmentally disordered patients, it has been noted that children with Williams syndrome, despite serious deficits in spatial cognition, planning, number and problem-solving abilities (Arnold *et al.*, 1985), perform well on language- and face-processing tasks (Bellugi *et al.*, 1990) as well as on theory of mind problems (Tager-Flusberg *et al.*, 1998). It has been suggested that these children use their intact 'modules' for social interaction to 'bootstrap' (use existing abilities to develop previously absent skills) their language and theory of mind skills (Karmiloff-Smith *et al.*, 1995). Hence there is evidence from both normal development and patients with neurodevelopmental pathology, that apparently preserved or superior abilities may arise from componential or narrowly-focused cognitive processes.

Methods derived from experimental psychology have demonstrated that people with autism are quantitatively better at certain tasks (Frith, 1989). The clearest demonstration of this superiority has been on the Embedded Figures Task (EFT). This test involves the subject being shown a complex design and then a simple shape. The subject is asked to find the simple shape in its embedded form within the complex shape. An example of the adult EFT is shown in Fig. 1. Shah

and Frith found that children with autism were more accurate than controls on the children's EFT (Shah and Frith, 1983), and Jolliffe and Baron-Cohen found that adults with high-functioning autism or the related condition of Asperger's syndrome were also faster than normal on the adult version of this test (Jolliffe and Baron-Cohen, 1997). It is of considerable interest, given the strong heritability of autism (Folstein and Rutter, 1977; Bailey *et al.*, 1995), that the parents of children with autism or Asperger's syndrome are also faster on the EFT relative to matched controls (Baron-Cohen and Hammer, 1997).

The EFT has not previously been adapted for use in a functional neuroimaging experiment and the basis of its performance in normal subjects, both in terms of underlying cognitive processes and a putative functional neuroanatomy, has not been established. Studies of humans with various acquired brain insults have reported that both patients with left hemisphere damage with aphasia and patients with right hemisphere damage do poorly on this task (Teuber *et al.*, 1951; Russo and Vignolo, 1967). In a study of subjects with unilateral penetrating head injuries, it was concluded that the degree of impairment on the task was related to the size of the lesion regardless of laterality (Corkin, 1979). It has also been reported that patients with Korsakoff's syndrome do particularly poorly on the EFT (Talland, 1965), and this patient group has been noted to have impaired spatial working memory (Joyce and Robbins, 1991). These latter observations suggest a working memory component in normal EFT performance. An introspective analysis of the EFT suggests

several processes that may be involved in task performance. The most straightforward approach might be to look at the target as a whole, hold it in working memory and then try to match it *en bloc* to the complex design. If this global approach does not rapidly provide the correct solution, an alternative strategy could be employed in which a part of the simple design (such as a region of intersecting lines) is identified, again held in working memory, and searched for within the complex figure. These strategies share the tasks of holding of a relatively simple pattern in working memory, searching the complex figure for likely solutions, disembedding these from the complex design and comparing them with the target shape. In addition, if either the simple or the complex design resembles a recognizable real-world object, then this may interfere with the process of disembedding, since normal subjects have a tendency to look for meaning in the stimuli (Brian and Bryson, 1996; Jolliffe and Baron-Cohen, 1997). This latter observation, together with a consideration of the basic nature of the EFT, suggests that object feature analysis will also be involved in task performance by normal subjects.

This cognitive analysis of the EFT suggests that normal subjects, although they are highly likely to use object feature analysis, may also employ visuospatial working memory systems when disembedding the whole target, or some feature of it, from the complex pattern. It has previously been proposed that superior performance on this and other visual analysis tasks by subjects with autism may be due to their adoption of a predominantly local processing strategy (Frith, 1989; Mottron and Belleville, 1993; Plaisted *et al.*, 1998a, b). We wished to test the hypothesis, using functional MRI (fMRI), that groups of control and autistic subjects activate different brain regions during performance of the EFT, and that these differences in functional anatomy are related to differential use of local and global cognitive strategies.

## Methods

### Subjects

Six subjects with autism or Asperger's syndrome were matched for mean age, handedness, IQ, socioeconomic status and educational level with 12 subjects in the normal control group. IQ was assessed with the National Adult Reading Test (Nelson and Willison, 1989). Subjects were included only if their IQ was in the normal range and they had well-developed speech abilities. Individuals in the clinical group had a diagnosis of autism or Asperger's syndrome, satisfying the criteria of both ICD-10 (World Health Organization, 1993) and DSM-IV (American Psychiatric Association, 1994). They had performance and verbal IQ scores above 85 on the full Wechsler Adult Intelligence Scale (WAIS-R). The control group comprised six females and six males and the clinical group comprised four males and two females. Further data describing the subjects are given in Table 1.

All subjects gave informed written consent according to

**Table 1** Age, IQ and handedness of subjects

|               | Autism           | Controls      |
|---------------|------------------|---------------|
| Age (years)   |                  |               |
| Mean $\pm$ SD | 26.3 $\pm$ 2.1   | 5.5 $\pm$ 2.8 |
| IQ            |                  |               |
| Mean $\pm$ SD | 108.5 $\pm$ 10.5 | 110 $\pm$ 8.5 |
| Handedness    |                  |               |
| Right : left  | 6 : 0            | 12 : 0        |

the declaration of Helsinki. The study was approved by the Research Ethics Committee of the Institute of Psychiatry, University of London.

### Experimental paradigm

Whilst fMRI images were acquired, subjects repeatedly performed the experimental and control tasks. The experimental task employed the standard adult EFT (Witkin *et al.*, 1962). This has two alternative versions (forms A and B) that do not differ in terms of number of stimuli or difficulty. Form A was therefore chosen. This consists of a set of 12 test cards, each depicting a different complex design. For each complex design there is a simple shape hidden somewhere within it. There are just eight different simple shapes, because some of these are common to several complex designs.

In the present study the administration of the EFT was adapted for use in the scanner. Ten complex designs were chosen at random for testing in the scanner. Before subjects went into the scanner, they were given an additional practice item to ensure that they fully understood the task. The task was introduced with the following instructions: 'You will see a colourful design with a simple shape next to it. You have to look for the simple shape in the larger design. The shape you find in the colourful design will always be exactly the same as the simple shape, so it will be the same size and proportions and the same way up'. The practice item was then shown. No subjects experienced any difficulty in finding the simple shape in this practice item. After the practice item, the subject was settled into the scanner and was reminded of the task using the same instructions with this addition: 'As soon as you've found the simple shape, press the button with your right hand index finger. After you have found one example of the simple shape, keep looking in case you can find any other examples, but you don't have to press the button again until the next design comes up. Go as quickly and as accurately as you can'.

We used a blocked periodic ABA... design involving repeated contrasts between a baseline (B) condition and an activation (A) condition. Each condition was visually presented for an epoch of 30 s, and the cycle of alternation between epochs was repeated five times in the course of each 5-min experiment.

During each activation epoch, subjects were presented

with two randomly selected designs from form A of the EFT. Each complex design was shown for 15 s simultaneously and side by side with a simple shape which the subject was asked to identify in the complex design. Stimuli were presented on a video monitor ~8 feet from the subject's head. During each baseline epoch, the subjects were asked simply to fixate on a blank screen.

### **Image acquisition and analysis**

Single-shot gradient echo, echoplanar images were acquired using a 1.5 Tesla GE Signa system (General Electric, Milwaukee, Wis., USA) fitted with Advanced NMR hardware and software (ANMR, Woburn, Mass., USA) using a standard head coil. One hundred  $T_2^*$ -weighted images depicting BOLD contrast (Ogawa *et al.*, 1990) were acquired over 5 min at each of 14 near-axial, non-contiguous 7 mm thick planes parallel to the intercommissural (AC–PC) line, providing whole-brain coverage: TE (echo time), 40 ms; TR (repetition time), 3 s; in-plane resolution, 3 mm; interslice gap, 0.7 mm. At the same session an inversion recovery EPI (echo planar imaging) data set was also acquired from 43 near-axial, 3 mm thick slices parallel to the AC–PC line: TE, 80 ms; TI (time to inversion), 180 ms; TR, 16 s; in-plane resolution, 1.5 mm; number of signal averages = 8.

Periodic change in  $T_2^*$ -weighted signal intensity at the (fundamental) experimentally determined frequency of alternation between A and B conditions (= 1/60 Hz) was modelled by the sum of a sine wave and cosine wave at that frequency. The amplitudes of the sine and cosine waves,  $\gamma$  and  $\delta$ , respectively, were estimated by pseudogeneralized least-squares fitting to the movement-corrected fMRI series at each voxel. The sum of the squared amplitudes,  $\gamma^2$  and  $\delta^2$ , divided by its standard error provided a standardized estimate of experimentally determined power, the fundamental power quotient (FPQ) (Bullmore *et al.*, 1996). The sign of  $\gamma$  indicated the phase of the periodic signal change with respect to the input function: voxels with  $\gamma > 0$  had maximum signal during the first condition (task A); voxels with  $\gamma < 0$  had maximum signal during the second condition (task B). Maps were constructed to represent FPQ and  $\gamma$  at each voxel of each observed data set. Each observed time series was randomly permuted 10 times and FPQ was estimated as above in each randomized time series, to generate 10 parametric maps of randomized FPQ for each subject in each anatomical plane.

To construct generic brain activation maps, observed and randomized FPQ maps derived from each subject were transformed into the standard space of Talairach and Tournoux (1988) and smoothed by a 2D Gaussian filter (SD 4.5 mm). The median value of FPQ at each intracerebral voxel in standard space was then tested against a critical value of the randomization distribution for the median FPQ ascertained from the randomized FPQ maps. For a one-tailed test of size  $\alpha = 0.0008$ , the critical value was  $100 \times (1 - \alpha)$ th percentile value of the randomization distribution. If a voxel exceeded

this critical value it was considered to be generically activated. Maps of  $\gamma$  observed in each individual were likewise transformed into standard space and smoothed. The median value of  $\gamma$  was computed for each generically activated voxel. If median  $\gamma > 0$ , that voxel was considered to be generically activated by the EFT (A) and it was coloured against the grey-scale background of an inversion recovery EPI template image in the standard space of Talairach and Tournoux (Talairach and Tournoux, 1988) to form a generic brain activation map (Bullmore *et al.*, 1996b; Brammer *et al.*, 1997).

## **Results**

### **Task performance during scanning**

The six subjects with autism successfully identified a mean of 8.8 (SD 1.6) embedded figures whilst the twelve control subjects identified a mean of 7.7 (SD 2.0) figures (with no significant difference between the groups;  $t = 1.23$ , two-tailed  $P = 0.24$ ). Within the control group the males and females performed the task equally well, both sexes identifying a mean of 7.7 figures (males SD 2.3, females SD 2.0). Owing to a technical failure, reaction time data were not recorded for any of the subjects.

### **Commonalties in generic brain activation**

Generic brain activation maps separately computed from control and autism group data, with voxel-wise probability of type I error  $\alpha = 0.0008$ , indicated that a number of brain regions were similarly activated in association with EFT performance across the two groups. These sites are listed in Table 2.

The autism and control groups shared activation of the middle and inferior temporal gyri [BA (Brodmann area) 21, 37], supramarginal gyrus (BA 40) and precuneus (BA 7), inferior frontal gyrus (BA 44) and middle occipital gyrus (BA 18 and 19).

### **Direct comparison between autism and control group activations**

To estimate between-group differences in mean power of periodic response, we fitted a two-way analysis of variance (ANOVA) model, including sex as the second factor, at each intracerebral voxel. The null hypothesis of zero between-group difference was tested by permutation (Edgington, 1980; Bullmore *et al.*, 1999) at the 4701 voxels that were generically activated by one group or both with two-tailed probability of type I error  $P < 0.01$ . The control group demonstrated a significantly more powerful response in bilateral parietal regions (BA 7), the right dorsolateral prefrontal cortex (BA 9, 44) and bilateral occipital cortex (BA 18, 19) (Table 3 and Fig. 2).

To assess between-group differences in regional response

**Table 2** Brain regions that were significantly activated in both control and autism groups during Embedded Figures Task performance, and approximate coordinates

| Region                     | Brodmann areas | Talairach coordinates |             |          |
|----------------------------|----------------|-----------------------|-------------|----------|
|                            |                | x                     | y           | z        |
| L fusiform gyrus           | 37             | 43,                   | -56,        | -12      |
| R inferior temporal gyrus  | 37             | 27 to 47              | -45 to -75, | -7       |
| R middle occipital gyrus   | 18, 19         |                       |             |          |
| L inferior temporal gyrus  | 37             | -17 to -34            | -42 to -69  | -7       |
| L middle occipital gyrus   | 18, 19         | -18 to -25            | -64 to -77  | -7       |
| R middle temporal gyrus    | 21, 37         | 18 to 33              | -32 to -51  | -2 to 4  |
| L middle temporal gyrus    | 21, 37         | -24 to -28            | -49 to -58  | -2 to 4  |
| L middle occipital gyrus   | 19             | -9 to -21             | -72 to -83  | -2 to 4  |
| R middle temporal gyrus    | 37, 39         | 54                    | 45          | 10       |
| R middle occipital gyrus   | 18, 19         | 15 to 38              | -66 to -83  | 10       |
| L middle temporal gyrus    | 37, 39         | -45                   | -59         | 10       |
| L middle occipital gyrus   | 18, 19         | -13 to -26            | -79 to -84  | 10       |
| R inferior frontal gyrus   | 44             | 43                    | 7           | 32       |
| L inferior frontal gyrus   | 44             | -31                   | 7           | 32       |
| R premotor cortex          | 6              | 44                    | 2           | 32       |
| L premotor cortex          | 6              | -34                   | 3           | 32       |
| R middle frontal gyrus     | 9              | 38                    | 12          | 37       |
| L middle frontal gyrus     | 9              | -45                   | 10          | 37       |
| L supramarginal gyrus      | 40             | -43                   | -40         | 37       |
| L inferior parietal lobule | 40             | -24 to -43            | -25 to -43  | 43 to 48 |
| R precuneus                | 7, 19          | 24                    | -60         | 43 to 54 |
| L precuneus                | 7, 19          | -19                   | -63         | 43 to 54 |
| R inferior parietal lobule | 40             | 39 to 46              | -22 to -44  | 48       |
| R superior parietal lobule | 7              | 14 to 26              | -43 to -58  | 54       |
| L superior parietal lobule | 7              | -15 to -37            | -37 to -58  | 54       |

Coordinates are given according to the stereotaxic atlas of Talairach and Tournoux (1988). R = right; L = left.

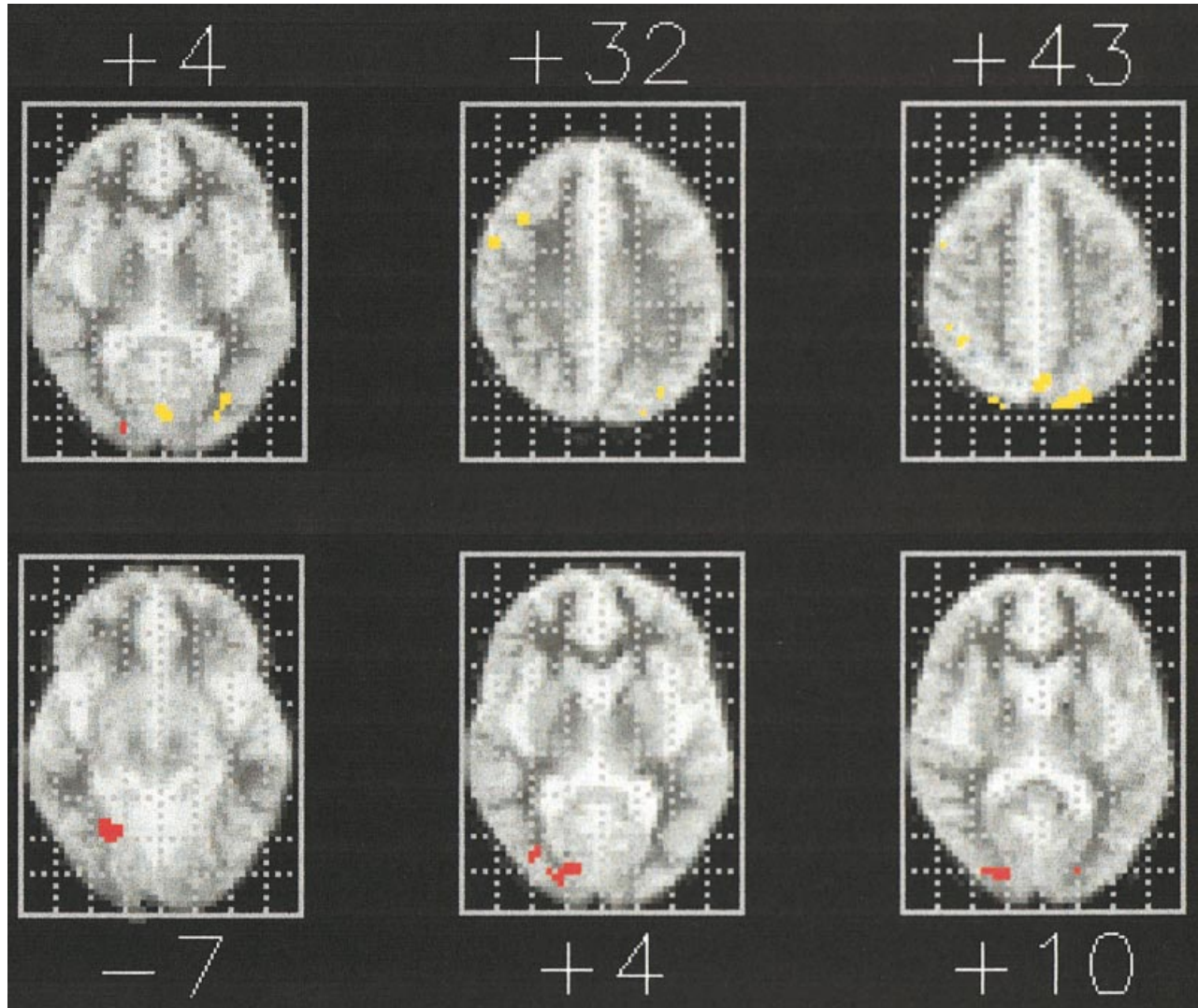
**Table 3** Two-way ANOVA comparing EFT-related activations in control and autism groups

| Cerebral region                      | Brodmann area | P      | Talairach coordinates |     |    |
|--------------------------------------|---------------|--------|-----------------------|-----|----|
|                                      |               |        | x                     | y   | z  |
| Regions more active in autism group  |               |        |                       |     |    |
| R cuneus                             | 17            | 0.004  | 20                    | -83 | 4  |
| R inferior occipital gyrus           | 18            | <0.001 | 35                    | -75 | -2 |
| R middle occipital gyrus             | 19            | <0.001 | 38                    | -72 | -7 |
| Regions more active in control group |               |        |                       |     |    |
| R superior parietal lobule           | 7             | <0.001 | 32                    | -58 | 53 |
| L precuneus                          | 7             | <0.001 | -17                   | -72 | 48 |
| L middle occipital gyrus             | 19            | 0.002  | -26                   | -81 | 4  |
| R cuneus                             | 18            | 0.001  | 0                     | -78 | 4  |
| L cuneus                             | 18            | 0.001  | 0                     | -78 | 4  |
| R inferior frontal gyrus             | 44            | 0.002  | 49                    | 6   | 20 |
| R middle frontal gyrus               | 9             | 0.002  | 40                    | 14  | 31 |
| L superior occipital gyrus           | 19            | 0.003  | -29                   | -67 | 31 |
| R supramarginal gyrus                | 40            | 0.004  | 46                    | -36 | 42 |

R = right; L = left.

while controlling for differences in global power of response, we also fitted a two-way analysis of covariance (ANCOVA) model including overall mean FPQ as a covariate. This analysis confirmed significantly greater power of response by the control group in bilateral parietal cortex and the right

dorsolateral prefrontal cortex, but additionally highlighted areas of more powerful response by the autistic group in the right occipital cortex (BA 18, 19) extending inferiorly and anteriorly to the inferior temporal gyrus (BA 37) (Table 4 and Fig. 2).



**Fig. 2** Brain regions differentially activated by the Embedded Figures Task in the control and autistic groups. *Top row*: voxels demonstrating a significantly greater power of response by the control group (yellow) in the bilateral parietal cortex, right prefrontal cortex and occipital cortex, identified by two-way ANOVA. *Bottom row*: voxels demonstrating a significantly greater power of response by the group with autism (red) in the right occipital cortex, identified by two-way ANCOVA. All maps are orientated with the right side of the brain shown on the left side of the map. The spatial location of each map is shown relative to the intercommissural line in Talairach and Tournoux space (1988). Voxel-wise probability of false positive error  $P < 0.01$  for both maps.

## Discussion

In this study we have used functional brain imaging to demonstrate for the first time that an islet of preserved performance on the EFT by people with autism may be subserved by neural systems qualitatively different from those activated in normal control subjects.

Considering first the patterns of activation observed independently in the two groups, both groups similarly activated regions within the occipital, inferior temporal and more inferior parietal areas (Table 2). These sites have previously been implicated in object and spatial visual processing (Ungerleider *et al.*, 1998), and both object and spatial memory (Smith and Jonides, 1995). BA 7 and 40 have previously been reported to be involved in tasks requiring complex processing of visual stimuli and in the

application of visual attention. In an fMRI study of a task explicitly demanding mental rotation and matching of perspective line drawings of three-dimensional shapes, Cohen and colleagues (Cohen *et al.*, 1996) concluded that the activity in these areas was likely to be related to the encoding of spatial relations and the allocation of visual attention. In a PET study (Fink *et al.*, 1997) using simple line and square stimuli to explore similarities and differences between two tasks, one requiring attention to the position of one object relative to another in the visual field and the other requiring analysis of parts of an object as they contribute to the object as a whole, it was found that both tasks involved activity in a number of brain regions including the left and right superior parietal regions (BA 7) and the left inferior parietal lobule (BA 40), which was also activated in the current study. Fink

**Table 4** Two-way ANCOVA comparing group EFT-related activations in control and autism groups with global mean FPQ as a covariate

| Cerebral region                      | Brodmann area | P      | Talairach coordinates |     |    |
|--------------------------------------|---------------|--------|-----------------------|-----|----|
|                                      |               |        | x                     | y   | z  |
| Regions more active in autism group  |               |        |                       |     |    |
| R lingual gyrus                      | 18, 19        | 0.002  | 26                    | -61 | -2 |
| R fusiform gyrus                     | 19            | 0.003  | 26                    | -56 | -7 |
| R lingual gyrus                      | 18            | 0.004  | 12                    | -78 | 4  |
| R cuneus                             | 17            | 0.005  | 17                    | -81 | 9  |
| R middle temporal gyrus              | 37            | 0.003  | 32                    | -69 | 4  |
| R middle occipital gyrus             | 19            | 0.005  | 29                    | -81 | 9  |
| Regions more active in control group |               |        |                       |     |    |
| R middle frontal gyrus               | 9             | 0.005  | 52                    | 6   | 42 |
| R inferior frontal gyrus             | 44            | 0.004  | 52                    | 3   | 31 |
| R superior parietal lobule           | 7             | 0.005  | 29                    | -56 | 48 |
| R superior parietal lobule           | 7             | 0.002  | 32                    | -58 | 53 |
| L precuneus                          | 7             | <0.001 | -12                   | -72 | 48 |

R = right; L = left.

and colleagues (Fink *et al.*, 1997) suggest that the superior parietal regions are involved in visual attention, applied regardless of the precise nature of the task, whilst the activity in BA 40 may relate to the process of locating an object in space and/or making judgements about object-related properties. We did not observe any activation in the regions reported by Fink and colleagues (Fink *et al.*, 1997) when subjects were distinguishing between object- and space-based processes. This may be because the experimental task in our study involved both these processes in both study groups. Overall, however, it is noted that these two studies, one (Cohen *et al.*, 1996) involving operations analogous in complexity to the EFT and the other (Fink *et al.*, 1997) seemingly more simple, both demonstrated a role for parietal regions in visual attention and in object and spatial processing. Hence it is likely that in our study the control and the autism group share these processes in EFT performance.

The regions identified as significantly more active in controls, using a two-way ANOVA with sex as the second factor (Table 3), included the right dorsolateral prefrontal and bilateral dorsal parietal regions. In this study there was generally greater activity during task performance in the controls than in the group with autism. This observation is compatible with previous reports that functional imaging in adults with autism reveals widespread reductions in markers of resting state cerebral activity compared with non-autistic control subjects (Sherman *et al.*, 1984; Herold *et al.*, 1988; George *et al.*, 1992). We therefore also compared the groups by two-way ANCOVA with a measure of global functional response as a covariate. This analysis demonstrated that the autism group showed increased activity in the right ventral occipitotemporal regions, which have been implicated in object perception (Ungerleider *et al.*, 1998), as well as confirming the greater involvement of specific dorsolateral prefrontal and parietal regions in the control group. These latter regions have previously been implicated in studies of

working memory for objects and spatial relations in a study using line drawings as stimuli (Smith and Jonides, 1995). These authors found that spatial working memory involved activation of the right ventrolateral prefrontal cortex (BA 47), the right inferior parietal lobule (BA 40) and the right middle frontal gyrus (premotor cortex, BA 6).

In the present study the controls also activated the dorsal parietal regions: bilateral precuneus (BA 7) and the superior parietal lobule (BA 7). These latter sites have been reported to be active in normal subjects during a task involving visual searching of simple targets (dots), in a more complex array, defined by a conjunction of colour and motion (Corbetta *et al.*, 1995). Although this task clearly differs in many ways from the EFT, both involve searching across a more complex scene for a relatively simple target. In addition, in the EFT the subjects had to tackle conjunctions of shape and colour rather than motion and colour. Corbetta and colleagues (Corbetta *et al.*, 1995) concluded, given that superior parietal lobule and precuneus activations in their conjunction task were similar to activations previously associated with shifting spatial attention (Corbetta *et al.*, 1993), that tasks requiring a visual field to be searched normally involve shifts of spatial attention in a successive analysis of each object in the field. Our observation that subjects with autism do not activate areas employed in what appears to be a normal strategy of serial search, involving visual search and working memory components, also supports the proposition that this group are employing a different method of solving the EFT.

Whilst the regions more active during EFT performance in controls may be involved in higher order visual perception and working memory, the primary and association visual areas more active in the subjects with autism may reflect a different approach to task performance. The greater activations in the subjects with autism in BA 17, 18 and 19 correspond to brain regions that have previously been reported to be activated in conditions of visual imagery of objects



(Kosslyn *et al.*, 1995). It is possible that subjects with autism may perform the EFT by using mental imagery to lay either all or part of the target shape over the complex design and then searching for a site where the complex design and the imagined design match. In the group with autism there is also right-sided activation of a region near the junction of the middle occipital and middle temporal regions. This site has been reported in a number of studies to be in the vicinity of the postulated human equivalent of area MT, reported in macaque monkeys to be sensitive to motion (Dubner and Zeki, 1971). The EFT does not involve any overt motion. However, it has also been reported that there is activation of this region in paradigms where there is either the illusion of movement (Tootell *et al.*, 1995; Goebel *et al.*, 1998) or no real or apparent movement, but nevertheless the neural mechanisms that are involved in processing movement may be employed in some processing capacity (Cohen *et al.*, 1996). Hence it may be that part of the strategy employed by the subjects with autism makes use of this, perhaps by using imagery to move the simple shape over the complex design, a strategy not employed by the controls. However, in the current study this possibility must remain speculative. First, in humans the location of area MT may vary by several centimetres from one subject to another, meaning that averaging group data will lead to destructive interference, making accurate identification of this functional region more difficult. Secondly, without including a moving stimulus we cannot confirm this site as area MT in humans.

It is also noted that the primary and association visual cortices that are active in the group with autism have previously been implicated in processes that lead to successful separation of figure from ground (Hupe, 1998; Lamme *et al.*, 1998), and our results support the possibility that part of the way in which subjects with autism solve the EFT using a highly localized analysis is by using imagery to move the simple target shape, or one part of it, so that it is superimposed on the complex shape. They then go through a process of forming figures from elements of the complex shape to see if they resemble the overlaid target. Interestingly, Driver and Baylis, in a series of studies examining edge-assignment in a contour-matching task, note that in general their normal subjects were unable to restrict their judgements to just the edges of shapes, and yet when deliberate attention was directed to one region of a display an advantage was conferred (Driver and Bayliss, 1996). This process of figure-ground separation may relate directly to one possible method of disembedding the target from the complex shape in the EFT, and it may be why the natural resistance of the subjects with autism to consider the images as whole structures enables them to perform the task well.

In summary, both the autism and the control group performed the EFT in association with activation of temporal, parietal and occipital structures that have previously been implicated in the processing of complex coloured designs. However, the group with autism may have employed an approach characterized by fewer demands on working

memory but with greater activity in some of the regions involved in object perception.

In the scanner, subjects with autism performed the EFT slightly, but not significantly, better than the normal controls in terms of accuracy, but the time taken by each subject to identify each embedded figure was not recorded. However, the subjects with autism scanned in this study had previously formed part of the group investigated by Jolliffe and Baron-Cohen (Jolliffe and Baron-Cohen, 1997). That group had been observed to perform the EFT significantly more rapidly than normal controls. In the design of the current study each figure was presented for 15 s and subjects were instructed to look for as many representations of the target within the complex figure as they could, although in actuality there was only one such representation present in the complex figure. Thus, even if the subjects with autism performed the task more rapidly, as has previously been shown, given the duration of stimulus presentation most control subjects were likely to find the target shape.

In this study the control task against which cerebral activity on the EFT was compared involved subjects looking at a blank video monitor. The choice of this control may be criticized in that the absence of a more active visual task means that aspects of EFT performance such as looking at shape, line and colour, as well as more complex processes of visual search and comparison, cannot be subtracted from the observed results. In addition, if a series of control tasks had been explored, allowing fractionation of the overall EFT, then a more definitive account may have emerged with respect to distinguishable cognitive processes underlying final task performance. The choice of such a minimal control task arose for several reasons. At the outset we hypothesized differences in the manner of performing the task as a whole between the two groups, but we had no reason to predict that any component tasks would have distinguished contributory processes that were actually employed by our two groups. Secondly, it is not obvious which control tasks would have been optimal. Thus, presegmenting the complex design to reveal the target would give away the solution to the task, whereas presenting the target alone, or the complex figure alone, or other visual stimuli involving colour, brightness, shape, line analysis, etc. would demonstrate various aspects of visual processing but would not tackle the disembedding process itself. Therefore we reasoned that if in the first instance there was a difference in neural processing between the two groups, a comparison of the whole task with a pure rest control would give the best chance of highlighting such differences. Any componential discussion of the functional differences between the groups will need to await future research. Finally, with respect to the sex differences in the groups, the incorporation of sex as a factor in the AN(C)OVA analyses demonstrated that the differences between the groups were not explained by the difference in sex ratio between the groups.

Beyond the very specific demands of the EFT there is further evidence that people with autism employ local

processing of complex stimuli. Frith (1989) has proposed that people with autism have a cognitive processing style characterized by weak 'central coherence', spending more time processing information at the local than at the global level. Four other pieces of experimental evidence support this hypothesis. First, on the block design subtest of the Weschler intelligence scales, whilst normal subjects find that presegmented designs facilitate reconstructing the designs using the blocks, people with autism are equally good at the test regardless of whether or not the design to be copied has been presegmented (Shah and Frith, 1993). Secondly, subjects with autism fail to pronounce homographs according to the wider semantic context of the sentence in which they occur, for example reading 'there was a tear in her dress' and 'there was a tear in her eye' using the same pronunciation of 'tear' in both cases (Happé, 1997). Thirdly, people with autism or Asperger's syndrome have difficulty achieving local coherence in processing text (Jolliffe and Barob-Cohen, 1999). Finally, people with autism appear to be relatively immune to the effects of visual illusions (Happé, 1996), presumably because they are focusing more on the constituent parts of the visual scene than on the global image.

Hence it is suggested that people with autism employ a more local approach to the processing of complex stimuli, leading to what in the circumstances of the EFT is a more efficient strategy, involving a piecemeal process rather than a less efficient but more 'normal' use of working memory and a global approach. Finally, it may also be that the use of such a piecemeal analysis of social phenomena could underlie some of the difficulties that people with autism have in understanding emotional and the theory of mind interactions.

## Acknowledgements

We wish to thank two anonymous referees for their helpful comments on an earlier version of this paper. This work was funded by a grant to S.B.-C., H.A.R. and S.C.R.W. from the Wellcome Trust and by a grant to S.B.-C. from the Gatsby Foundation. E.T.B. is supported by the Wellcome Trust.

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*Received December 3, 1998. Revised February 15, 1999.*

*Accepted February 19, 1999*