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Dissociation between 'theory of mind' and executive functions in a patient with early left amygdala damage

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Summary

There have been recent suggestions that the amygdala may be involved in the development or mediation of 'theory of mind'. We report a patient, B.M., with early or congenital left amygdala damage who, by adulthood, had received the psychiatric diagnoses of schizophrenia and Asperger's syndrome. We conducted a series of experimental investigations to determine B.M.'s cognitive functioning. In line with his diagnoses, B.M. was found to be severely impaired in his ability to represent mental states. Following this, we conducted a second series of studies to determine B.M.'s executive functioning. In the literature, there have been frequent claims that theory of mind is mediated by general executive functioning. B.M. showed no indication of executive function impairment, passing 16 tests assessing his ability to inhibit dominant responses, create and maintain goal-related behaviours, and temporally sequence behaviour. The findings are discussed with reference to models regarding the role of the amygdala in the development of theory of mind and the degree of dissociation between theory of mind and executive functioning. We conclude that theory of mind is not simply a function of more general executive functions, and that executive functions can develop and function on-line, independently of theory of mind. Moreover, we conclude that the amygdala may play some role in the development of the circuitry mediating theory of mind.

Keywords: amygdala; theory of mind; executive functions

Abbreviations: fMRI = functional MRI; WAIS-R = Wechsler Adult Intelligence Scale—revised

Introduction

'Theory of mind' refers to the ability to attribute mental states to self and others, and to predict and understand other people's behaviour on the basis of their mental states (Premack and Woodruff, 1978). Operationally, individuals are credited with a theory of mind if they succeed in tasks designed to test their understanding that an individual may hold a false belief. For example, in the classic false belief test (Wimmer and Perner, 1983), the subject is introduced to two dolls, Sally and Ann. Ann moves Sally's marble from the basket, where Sally placed it, to another hiding place while Sally is out of the room. The child is asked where Sally will look for her marble when she returns. Normally developing children aged ~4 years correctly attribute a false belief to Sally, and predict that she will search in the original location, i.e. where Sally thinks her marble is (Wimmer and Perner, 1983). Severe impairments in theory of mind have been reported in individuals with autism, Asperger's syndrome and paranoid delusional schizophrenia (e.g. Frith, 1989; Happé, 1994; Frith and Corcoran, 1996; Corcoran *et al.*, 1997; Baron-Cohen *et al.*, 1999).

The anatomical basis of theory of mind

Several attempts have been made to delineate the brain regions involved in theory of mind. For example, Baron-Cohen has suggested a neural circuit including the amygdala, superior temporal sulcus and orbitofrontal cortex (Baron-Cohen, 1995). In line with this, Baron-Cohen and colleagues used functional MRI (fMRI) to measure brain activity during a task requiring the subject to infer the mental state of an individual from the expression of their eyes. Areas significantly activated by the task included the left amygdala. Interestingly, amygdala activation during this task was not seen in individuals with Asperger's syndrome, who were impaired on this task relative to controls (Baron-Cohen *et al*., 1999). In an earlier study, Baron-Cohen and colleagues found activation in the orbitofrontal cortex in a SPECT (single photon emission computed tomography) study during a task in which subjects had to decide which aurally presented words 'described the mind or things the mind can do' (Baron-Cohen *et al*., 1994).

An alternative view of the neural circuitry for theory of mind has been put forward by Frith and Frith. They have argued that this circuitry comprises the superior temporal sulcus, the inferior frontal regions and the medial prefrontal cortex (Frith and Frith, 1999). In line with this, a number of neuroimaging studies of mental state processing have observed activity in the medial prefrontal cortex and the region of the temporoparietal junction (Fletcher *et al.*, 1995; Goel *et al.*, 1995; Castelli *et al.*, 2000; Gallagher *et al.*, 2000).

Potentially, the study of individuals with autism and Asperger's syndrome can aid in the identification of the neural substrate for theory of mind. Individuals with autism and Asperger's syndrome consistently fail theory of mind tasks (for reviews, see Baron-Cohen, 1995; Happé and Frith, 1996). This suggests that any brain abnormality consistently observed in autistic individuals might be implicated in theory of mind. One of a number of brain regions in which there are consistent reports of abnormality in individuals with autism is the amygdala (Baron-Cohen *et al.*, 2000). Thus, autopsies of autistic individuals point to an abnormal increase in the packing density of grey matter in the amygdala (for a brief review, see Courchesne, 1997). In addition, a structural MRI study revealed increased volume in the left amygdala and surrounding temporal areas in a group of patients with Asperger's syndrome (Abell *et al.*, 1999). Moreover, in a recent proton magnetic resonance spectroscopy study, Otsuka and colleagues found reduced *N*-acetyl aspartate concentrations in the amygdala and hippocampal regions of a group of autistic children (Otsuka *et al.*, 1999). They suggest that this may reflect the presence of neuronal dysfunction or immature neurones.

Thus the amygdala, in particular the left amygdala, may be part of the neural circuitry involved in the processing of mental states (Baron-Cohen *et al.*, 1999). Alternatively, the amygdala and/or its connections to regions such as the superior temporal sulcus and medial prefrontal cortex (Amaral *et al.*, 1992) may be critical for the development of theory of mind. If this is the case, then early damage to the amygdala and/or its connections should result in deficits in the processing of mental states.

Theory of mind and executive functioning

The finding that theory of mind is relatively selectively impaired in autistic individuals has led some to suggest that theory of mind ability is domain-specific, with a dedicated neural system (e.g. Frith *et al.*, 1991; Leslie and Roth, 1993; Baron-Cohen, 1995; Frith and Frith, 1999). In contrast, others have argued that mental state information is processed by domain-general cognitive functions, namely executive functions (e.g. Frye *et al.*, 1995, 1996). Executive functions refer to the processes that underlie flexible goal-directed behaviour, e.g. inhibiting dominant responses, creating and maintaining goal-related behaviours and temporally sequencing behaviour (Burgess *et al.*, 1998). Impairment of executive functions is associated with damage to prefrontal areas (e.g. Luria, 1966; Fuster, 1980; Duncan, 1986; Shallice, 1988). Evidence from neuropsychological, functional imaging and animal lesion studies suggests that different aspects of executive functions are dissociable and are mediated by distinct neural systems subserved by different regions of the prefrontal cortex (e.g. Luria, 1966; Fuster, 1980; Robbins, 1996; Shallice and Burgess, 1996; Damasio, 1998).

There are three positions regarding the relationship between theory of mind and executive functions. First, it has been argued that the development of executive functions allows the child's theory of mind to develop, or show its full potential, on theory of mind tasks (e.g. Ozonoff *et al.*, 1991; Russell, 1995; 1996, 1997; Ozonoff, 1997). Secondly, it has been argued that there are no specific systems for processing mental states and that performance on theory of mind tasks can be reduced to executive function ability. For example, Frye and colleagues have suggested that theory of mind is merely one facet of the ability to act according to embedded rules (Frye *et al.*, 1995, 1996). Embedded rules are of the form 'if X, if Y, then Z'. They argue that many executive function tasks can be understood in terms of such rules. A third position is that the capacity to represent mental states is necessary for the development of executive functioning (e.g. Carruthers, 1996; Perner, 1998; Perner and Lang, 2000). Thus, Perner argues that planning skills require one to represent one's own intentions, and that other executive functions, such as inhibitory control and set-shifting, require a representation of one's knowledge that the habitual act is maladaptive (Perner, 1998).

Two lines of evidence have been used to suggest that executive functions mediate theory of mind performance. First, recent studies have found that theory of mind and executive function abilities are correlated in pre-school children (Frye *et al.*, 1995; Hughes, 1998*a*). Moreover, executive function performance predicts theory of mind performance, but not vice versa (Hughes, 1998*b*). Recent research has begun to relate success and failure on particular executive function tasks to performance on theory of mind tests in normal children. In normally developing pre-school children, correlations have been found between tests of inhibitory control and attentional flexibility, and a test of deceit (Hughes, 1998*a*). Secondly, individuals with autism have been found to perform poorly on tests of executive functioning as well as tests of theory of mind (Ozonoff *et al.*, 1991; Hughes *et al.*, 1994). Ozonoff and colleagues found a correlation between performance on executive function and theory of mind tasks in individuals with autism, but not in control subjects (Ozonoff *et al.*, 1991). Thus, it has been suggested that the difficulty that autistic individuals have on theory of mind tests is at least in part attributable to their lack of executive control (e.g. Russell, 1995, 1996, 1997). Consistent with this, children with autism appear to have particular difficulty with inhibitory control and attentional flexibility (e.g. Hughes and Russell, 1993; Hughes *et al.*, 1994; Ozonoff, 1997). These are the two components of executive functioning that have been shown to predict theory of mind performance in normal children (Hughes, 1998*a*).

While the above data are interesting, such studies are not suitable for distinguishing between the different accounts of the developmental interaction between theory of mind and executive functioning for two main reasons. First, in the way that most executive function tasks assess the functioning of more than one executive function, theory of mind tasks may not be 'pure' tests of theory of mind but may also involve an executive function component (e.g. Leslie and Thaiss, 1992). Thus, it is to be expected that there will be correlations, or at least a lack of dissociation, between tests of executive function and theory of mind performance in populations who do not perform at ceiling on executive function tests, such as individuals with autism and pre-school children. However, it should be noted that Perner and Lang, in their review of the literature, consider that the association between theory f mind and executive function performance is found even when theory of mind explanation tasks that putatively have a low executive function component are used (Perner and Lang, 2000). Secondly, it may be that the regions of the brain that mediate theory of mind and executive functions are anatomically proximal. If this were the case, even if they are cognitively separable processes, we would still expect to see the observed association of impairment in individuals with autism, at least at the group level. Given the importance of prefrontal circuits in executive functions (e.g. Shallice and Burgess, 1996) and the proposed role of medial frontal areas in theory of mind processing (e.g. Fletcher *et al.*, 1995), this account of the data is not implausible.

In this paper, we report a forensic patient, B.M., who had a congenital or early lesion of the left amygdala. The first aim was to investigate to what extent B.M. showed impairment in theory of mind. The second aim was to determine the degree to which any theory of mind impairment was independent of executive functioning.

Case report

B.M. is a 32-year-old, right-handed man who worked as a caterer. He was arrested in 1994 and subsequently convicted for murder and rape. B.M. was seen in prison for psychiatric assessment before the trial and was diagnosed as suffering from schizophrenia on the basis of formal thought disorder and persecutory and grandiose delusions. Since his admission to the hospital, B.M. has received anti-psychotic medication which, at the time of testing, was flupenthixol depot 400 mg fortnightly and 10 mg procyclidine twice daily.

Hospital file information revealed that B.M. shows profound social isolation, never makes phone calls, and does not write to anyone inside or outside of the hospital. B.M. has no visitors, and has indicated that he does not wish to have any. He spends most of the time in his room. He never attends hospital social functions, and rarely attends sports events. B.M. is always polite but finds it difficult to approach people. He does not have any hobbies or interests. B.M.'s mother reports that as a child he was slow in walking and talking, and was rather clumsy. His language developed normally, but his use of it was 'slow and ponderous'. She recalls that he preferred to be on his own, was isolated from his siblings and other children, and showed little imaginative play. He was also often aggressive without provocation.

A psychiatric opinion based on file information suggested that B.M. suffered from Asperger's syndrome, a schizotypal personality disorder or a schizoaffective disorder. More recently, the diagnosis of Asperger's syndrome has been confirmed by an independent assessment carried out by an experienced psychiatrist. It should be noted that DSM-IV (*Diagnostic and Statistical Manual of Mental Disorders*, 4th edition) stipulates that, if an individual has received a diagnosis of schizophrenia, that individual cannot subsequently receive a diagnosis of Asperger's syndrome (American Psychiatric Association, 1994). This rule has been relaxed by the clinicians involved because, from the clinical records, the patient's Asperger's syndrome preceded his schizophrenia. Moreover, on formal assessment of psychiatric symptomatology he showed little evidence of active schizophrenic illness. On the Brief Psychiatric Rating Scale he scored moderate levels for emotional withdrawal and blunted affect. All other scores were mild or not present. For the Schedule for Assessment of Negative Symptoms, the global rating of affective flattening was mild and physical anergia was moderate, but all others were rated 1 or 2 (questionable or mild). On the Comprehensive Psychiatric Rating Scale, nothing of significance was noted except for a 'severe or incapacitating illness' in the global rating of illness. Additionally, B.M. completed the Personality Disorders Questionnaire (Hyler *et al.*, 1990). The completion of the questionnaire is rated 'too good', which suggests that B.M. may be under-reporting his psychopathology. All other ratings were below threshold for DSM-IV personality disorders.

B.M. gave informed consent to participation in all testing sessions. His co-operation throughout the testing sessions was good. This study was approved by the Broadmoor Hospital ethical committee.

Lesion localization

Figure 1 shows an MRI scan of B.M.'s brain taken in 1996. The scan was performed on a transportable 1 GE Signa MRI scanner (1 T), operated by Alliance Medical Ltd (Upton, Banbury, UK). The scan reveals an abnormal signal return on T_2 and a possible low-intensity lesion in T_1 in the lateral part of the basal nuclei of the left amygdala. There was no generalized atrophy, and the frontal areas gave normal signal

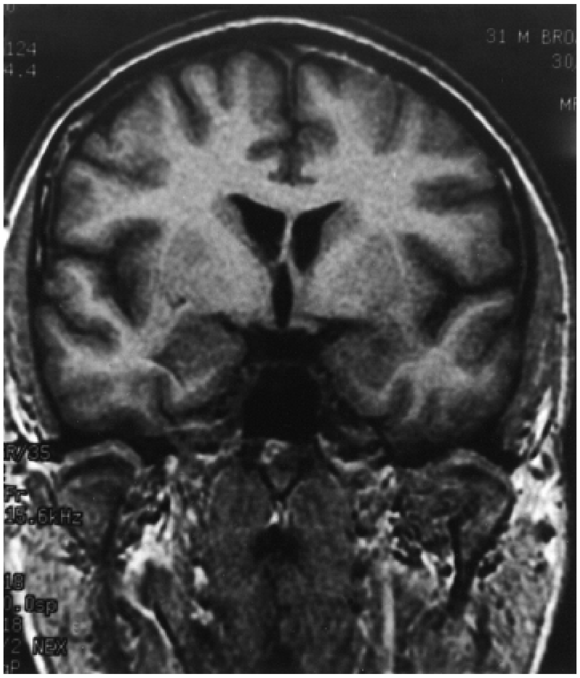

Fig. 1 MRI scan showing abnormal signal return on T_2 and possible low-intensity lesion in T_1 in the lateral part of the basal nuclei of the left amygdala.

return. The scan is consistent with a dysembryonablastic neuroepithelial tumour of long standing or of congenital origin.

Neuropsychological assessment

B.M. was assessed on the Wechsler Adult Intelligence Scale—revised (WAIS-R) and obtained a Full Scale IQ in the average range (Table 1). In particular, his performance on the Comprehension subtest was superior. Reading performance on the National Adult Reading Test (Nelson and Willison, 1991) indicated a comparable level of ability. On the Wechsler Memory scale—revised, B.M. was within the normal range for both prose and design recall. His memory for Paired Associates was in the 90th percentile or above. B.M.'s performance on the Recognition Memory Test for faces and words (Warrington, 1984) was at the lower end of the normal range. However, his recognition memory for buildings (Whiteley and Warrington, 1978) was superior, as was his topographical recognition memory (Warrington, 1996). On the Rey Complex Figure Test, he was unimpaired in Copying, but in the low average range for Recall. His performance on all tests in the Adult Memory and Information Processing Battery was in the 50th percentile or above. His naming skills were intact. His performance was within the normal range on the Graded Difficulty Naming Test (McKenna and Warrington, 1980). B.M.'s single-word comprehension was within the average range on a stringent synonym test (Warrington *et al.*, 1998).

Comment

Overall, B.M.'s neuropsychological assessment shows that his IQ and reading ability are all in the average range. In addition, B.M. has no clinically significant intellectual, memory, language or speed of processing difficulties.

Experimental investigation

The following experimental investigation was carried out over a 20-month period. Substantial assessments of B.M.'s mental state processing and executive functioning were conducted. The first aim of this investigation was to determine whether, given the suggestions of a role for the amygdala in theory of mind (e.g. Baron-Cohen *et al.*, 1999, 2000), B.M. had an impairment in mentalizing.

Control subjects

B.M.'s performance was compared with those of 13 healthy males, matched for educational level, with mean age 30 years (SD = 4) and mean WAIS-R subtests scores of 10.7 (SD = 1.3). While not every control subject performed every task, five subjects performed at least two of the theory of mind tasks and seven executive functions tasks, and eight subjects performed at least three theory of mind tasks and two executive functions tasks. On seven of the 16 executive functions tasks, standardized data were used as the comparison. All control subjects gave informed consent.

Theory of mind assessment

Ten theory of mind tasks were administered to B.M. There were five tests assessing understanding of false belief, two tests assessing understanding of the mental states implied in cartoons, and three tests assessing understanding of intended meaning in non-literal utterances. The control subjects were also given these tasks, with the exception of the false belief tasks, as these are passed by normally developing children of 4–8 years.

Tasks 1–5: false belief tests

In false belief tests, the participant must predict a story character's action on the basis of the character's mistaken belief about the situation. These tests can either be first-order ('Anne thinks that . . .') or second-order ('Mary thinks that John thinks that . . .'). Two first-order tests and three second-order tests were given to B.M. Both the first-order tests ['Smarties' (Perner *et al.*, 1989) and 'Sally–Anne' (Baron-Cohen *et al.*, 1985)] and the second-order tests ('Chocolates' (Roth and Leslie, 1991), 'Ice Cream Van' (Perner and Wimmer, 1985) and 'Coat Shopping'; Bowler, 1992)] include control questions that assess story comprehension and memory for what happened in the story. B.M.'s performance on these tasks was exceedingly poor (2 out of 5). He passed

Table 1 *Neuropsychological scores*

Test	Score, percentile
WAIS-R Full Scale IQ	103
Age-related Subtest Scaled Scores (mean = 10)	
Comprehension	14
Digit Span	11
Similarities	9
Block Design	10
Digit Symbol	10
National Adult Reading Test—revised	108
Wechsler Memory Scale—revised	
Prose Recall: immediate	11/22, 31st percentile
Prose Recall: delayed	11/22, 50th percentile
Design Recall: immediate	34/41, 56th percentile
Design Recall: delayed	33/41, 69th percentile
Paired Associates	
T1	23/24, 90th percentile
T2	24/24, >90th percentile
Recognition Memory Test	
Faces	39/50, 25th percentile
Buildings	46/50, high average
Landscapes	27/30, 75th percentile
Words	42/50, 10th–25th percentile
Rey Complex Figure Test	
Copy	36/36, 100th percentile
Recall	18/36, 20th–30th percentile
Adult Memory and Information Processing Battery	
Information Processing, Form 1	
Motor Speed	60/90, 90th percentile
Cognitive Speed A	79/105, 75th–90th percentile
Cognitive Speed B	81/105, 75th–90th percentile
Accuracy A	2, 50th percentile
Accuracy B (all pro-rated from half-administration)	0, >90th percentile
Graded Difficulty Naming Test	21/30, 50th percentile
Concrete Word Synonym Test	22/25, 50th–75th percentile
Abstract Word Synonym Test	21/25, 50th percentile

the two first-order false belief tests, but failed the three false belief tests that required second-order mental state representation (Table 2). In contrast, B.M. answered all of the control questions correctly. His failure on the majority of the tasks is striking given that the tests are usually passed by normally developing children between the ages of 4 and 8 years.

Tasks 6–7: Joke Comprehension Test

B.M. was given 20 cartoons (Joke Comprehension Test Set 1; Corcoran *et al.*, 1997). There were 10 'mental state' cartoons, and 10 'physical state' cartoons. To understand the mental state cartoons required an appreciation of the mental states of the characters. A score of one is given for each cartoon that is appropriately explained using a mental state term. The physical state cartoons could be understood without reference to mental states, by the use of physical and semantic analysis. A score of 1 is given for each cartoon that is appropriately explained by reference to the physical situation. B.M. was at floor for the mental state cartoons (1 out of 10), but in the normal range for the physical state cartoons (9 out of 10). This test was extended and replicated with a second set of mental state and physical state cartoons (Joke Comprehension Test Set 2). Again, B.M.'s performance on the mental state cartoons was below the normal range (6 out of 21), but in the normal range for the physical state cartoons (17 out of 22).

Tasks 8–9: Advanced Theory of Mind Test

The Advanced Theory of Mind Test Set 1 (Happé, 1994) assesses the ability to use mental state understanding to make sense of non-literal utterances (for example, see Appendix I). There are 24 mental state stories and eight physical state control stories. In each of the 24 mental state stories, a protagonist says something that isn't literally true for a variety of different motivations, e.g. tact or sarcasm. The subject must offer an explanation of why the protagonist said what she or he did.

Table 2 *Performance of B.M. and control subjects on theory of mind (TOM) tasks*

	B.M.	Controls		
		Mean	SD	Range
False belief TOM tests* (tasks 1–5)	2/5			
Joke Comprehension Test Set 1 (task 6)				
Mental state jokes	1/10	5.8	1.7	4–8
Physical state jokes	9/10	8.3	1.9	6–10
Joke Comprehension Test Set 2 (task 7)				
Mental state jokes	6/21	10.7	3.1	7–15
Physical state jokes	17/22	18.6	4.7	6–23
Advanced TOM Test Set 1 (task 8)				
Test question score	17/24	22.6	1.7	19–24
Correct mental state use	13/17	17	3.2	15–24
Control physical story comprehension	6/8	6.5	0.9	5–8
Advanced TOM Test Set 2 (task 9)				
Test question score	20/24	23.3	0.8	22–24
Correct mental state use	16/20	21.0	1.7	18–24
Non-literal speech comprehension (task 10)				
Sarcasm	5/24	22.3	2.1	18–24
Metaphor	23/24	23.8	0.4	23–24

*These tasks are passed by normally developing children aged 4–8 years.

Three scores are generated from the subject's performance on the mental state stories. The first, termed 'total score', indicates the subject's ability to comprehend the situation. The other two scores refer to the justifications the subject uses when interpreting the behaviour of the story characters, in particular whether the subject refers to the character's mental states of physical information. An example justification involving mental states for the example story is 'Because Jim knows that Simon always lies and so he should look in the other locations'. An example justification involving physical information for the same story is 'Because it will be in the opposite place to wherever Simon says'. B.M.'s performance was below the range of the comparison group for both total score (17 out of 24) and number of mental state justifications (13 out of 17). For the physical state control stories, only a total score, indicating comprehension of the situation, is given to subjects' responses. B.M. was in the normal range for the control physical state stories (6 out of 8).

The experiment was replicated and extended with a different set of mental state stories that were structurally identical to Set 1 but with superficial details changed (Advanced Theory of Mind Test Set 2). Again, B.M. was below the normal range of the comparison group for both total score (20 out of 24) and the number of mental state justifications (16 out of 20).

Task 10: non-literal speech comprehension

The comprehension of sarcasm requires understanding of mental states. In sarcasm, the thoughts of the speaker must be taken into account in order to reject the incorrect literal interpretation. For example, the listener can only reject the literal interpretation of 'You're looking smart tonight, Frank' if the hearer knows that the speaker thinks that Frank looks scruffy. However, if the listener does not take the speaker's thoughts into account, the literal meaning of the utterance will not be rejected. Individuals with autism have been shown to find sarcasm particularly difficult to understand (Happé, 1993). Metaphor comprehension was also assessed. Metaphor, like sarcasm, involves understanding that the literal meaning is not the intended one, and abstracting implicit meaning.

B.M. was given 24 stories involving a conversation in which both sarcasm and metaphor were used. After each sarcastic and metaphorical utterance, B.M. was asked 'What did so-and-so mean by this?' (for an example, see Appendix I). B.M. was markedly impaired on the comprehension of sarcasm (5 out of 24). For all incorrect answers, B.M. gave the literal meaning as the intended one. In contrast, B.M. was normal on the metaphor task (23 out of 24), demonstrating an intact ability to understand non-literal language and to abstract implicit meanings from utterances. B.M. may have performed normally on the metaphor task because, unlike sarcasm comprehension, the understanding of metaphor does not require the listener to take into account the thoughts of the speaker in order to reject the nonsensical literal meaning. The metaphor itself can suggest what the intended meaning is, e.g. 'You're a little computer' implies skill at maths. Individuals with autism have been found to show impairments in metaphor comprehension (Happé, 1993). However, this may reflect their difficulty in rejecting literal meanings rather than their difficulty in the representation of mental states.

Comment

The above results clearly indicate that B.M. has a significant theory of mind impairment (Table 2). However, his performance on all of the control tasks was normal. Thus, his theory of mind impairment cannot easily be accounted for in terms of difficulty in comprehension, abstraction or memory, as the control tasks also required these abilities. Moreover, since many of the theory of mind tests involved the use of stories, it is worth noting B.M.'s good performance on the WAIS-R Comprehension subtest and the National Adult Reading Test.

In the literature, there have been frequent claims that theory of mind is mediated by general executive functioning (e.g. Frye *et al*., 1996; Russell, 1997). We therefore wished to determine whether B.M.'s impairment in mentalizing could be accounted for in terms of a deficit in executive functioning.

Executive functions assessment

These tests were grouped into three categories: Inhibition (the ability to suppress a habitual response); Intentionality

Table 3 *Performance of B.M. and control subjects on executive functions tasks*

	B.M.	Controls		
		Mean	SD	Range
Inhibition tests (tasks 11–16)				
Trail-making Part B* (seconds to complete)	>75th percentile			
Stroop*	100th percentile			
Hayling Sentence Completion (scaled score)	19	16.2	2.5	12–18
Verbal Fluency	36	48.6	25.8	16–81
Cognitive Estimates (errors)	0	4.8	4.2	0–11
Temporal Judgements*	3/4	2.2	0.9	
Intentionality tests (tasks 17–21)				
Modified Six Elements Task	4/4	3.6	0.5	3–4
Zoo Map*	3/4	2.4	2.0	
Key Search*	4/4	2.6	1.3	
Action Program*	4/4	3.8	0.5	
Tower of London (score system 1)	25	26.6	4.0	21–31
Executive Memory tests (tasks 22–26)				
Rule Shift	3/4	3.4	0.9	2–4
Modified Wisconsin Card Sorting Task				
Shifts	7	4.6	2.5	1–7
Perseverative errors	0	2.8	4.8	0–11
Intra-dimensional/Extra-dimensional Shift				
Intra-dimensional errors	1	1.1	2.0	0–4
Extra-dimensional errors	4	23.1	22.1	1–59
Reversal errors	4	6.3	1.8	4–9
Brixton Spatial Anticipation* (errors)	14	16.0	5.7	
Non-spatial Conditional Learning	16	21.0	12.0	7–34

*Standardized data used as comparison.

(the creation and maintenance of goal-related behaviours); and Executive Memory (temporal sequencing). This grouping was based on the results of a factor analysis in which these categories emerged as the three cognitive components of executive function (Burgess *et al.*, 1998). Where possible, tests were grouped according to how strongly they loaded onto the three factors in the factor analysis. Tests that were not used in the factor analysis study were grouped according to their similarity to the tests that were used. It should be noted that many of the tasks have been conceptualized in a variety of ways (e.g. trail-making has been conceptualized as reflecting set-shifting in addition to inhibition). Indeed, many of the tests are likely to index multiple executive functions. However, in the absence of detailed information regarding the functions that each of the tasks index, we chose an approach that has been validated empirically (Burgess *et al.*, 1998).

Tasks 11–16: inhibition tests

B.M. was given six standardized executive function tests of inhibition. Although the superficial features of the tasks are very different, each is thought to require the participant to inhibit a prepotent response. The tests were: Trail-making Part B (Army Individual Test Battery, 1944); Stroop (Stroop, 1935); Hayling Sentence Completion (Burgess and Shallice, 1996*a*); Verbal Fluency (e.g. Miller, 1984); Cognitive Estimates (Shallice and Evans, 1978); and Temporal Judgements (Wilson *et al.*, 1996). B.M. performed in the normal range or above on all six tests of inhibition (Table 3).

Tasks 17–21: intentionality tests

It has been argued that intentionality, the ability to create and monitor goal-related behaviour, is a necessary precursor of self-awareness and the development of concepts of mental states (Russell, 1996). An impairment in this executive capacity might therefore be predicted in B.M. Intentionality tests require the subject to create and maintain a plan in order to achieve a goal in the absence of any external stimuli cueing the appropriate responses. Such tasks also involve the use of embedded rules, which Frye and colleagues have argued encompasses theory of mind (Frye *et al.*, 1995). B.M. was given five standardized tests assessing this ability: Modified Six Elements Task; Zoo Map; Key Search; Action Program (Wilson *et al.*, 1996); and Tower of London (Shallice, 1982). B.M. performed in the normal range or above on all five tests of intentionality (Table 3).

Tasks 22–26: executive memory

Tests of executive memory require the participant to shift attention away from a given cue, to transfer attention to another cue, or to do both. As noted in the Introduction, individuals with autism have been shown to be impaired on such tasks (Hughes and Russell, 1993; Hughes *et al.*, 1994). B.M. was given five tests that reflect executive memory processes. In all tests but the last, the participant must shift set from a dominant response according to an arbitrary rule. The tests were: Rule Shift (Wilson *et al.*, 1996); Modified Wisconsin Card Sorting Task (Nelson,1976); Intra-dimensional/Extra-dimensional Shift (Hughes *et al.*, 1994); Brixton Spatial Anticipation (Burgess and Shallice, 1996*b*); and Non-spatial Conditional Learning (Petrides, 1990). B.M. performed in the normal range or above on all five tests of executive memory (Table 3).

Comment

B.M. clearly showed normal performance on all aspects of executive functioning. The 16 tests he was given included those that have been frequently associated with poor performance on theory of mind tasks, i.e. those involving inhibition, the use of embedded rules and the execution of an arbitrary response in competition with a dominant response. Thus B.M.'s poor theory of mind performance cannot be accounted for in terms of executive dysfunction. Moreover, it is interesting to note that one of the control individuals had impaired performance on the Hayling Sentence Completion, Verbal Fluency, Cognitive Estimates, Rule Shift and the Modified Wisconsin Card Sorting tasks. However, this subject showed no impairment on any of the theory of mind tasks.

Discussion

B.M., who had a unilateral left amygdala lesion of longstanding or congenital origin, showed profound difficulty in representing the mental states of others. B.M. performed consistently poorly on 10 mental state processing tasks, assessing false belief understanding (tasks 1–5), mental state understanding in the comprehension of cartoons (tasks 6 and 7) and the understanding of intended meaning in non-literal utterances (tasks 8–10). We investigated the degree to which his theory of mind impairment was independent of executive functioning. B.M. was given 16 executive function tests assessing his ability to inhibit dominant responses, to create and maintain goal-related behaviours, and to sequence behaviour temporally (tasks 11–26). The battery included executive function tests that previous research has associated with the development of theory of mind. B.M. performed in the normal range or above on all the executive function tests. These findings show that the neurocognitive system mediating theory of mind is developmentally separable from the neurocognitive systems mediating executive functions, and that executive functions can develop and function on-line, independently of theory of mind.

Implications for the anatomy of theory of mind

There have been recent claims that the amygdala may be involved in the mediation of theory of mind (Baron-Cohen, 1995; Baron-Cohen *et al.*, 1999, 2000). However, as far as we are aware, there have been no investigations of theory of mind performance in individuals with amygdala lesions. B.M. presented with a lesion in the basal nuclei of the left amygdala that was consistent with a dysembryonablastic neuroepithelial tumour of long standing or congenital origin. In line with suggestions that the amygdala may be one of the brain regions involved in the mediation or development of theory of mind, B.M. presented with profound impairment in mentalizing ability.

Several hypotheses can be developed concerning the role of the amygdala in theory of mind functioning. These could be tested in future neuropsychological case studies. First, as suggested by Baron-Cohen and colleagues (Baron-Cohen, 1995; Baron-Cohen *et al.*, 1999, 2000), the amygdala may mediate theory of mind functioning. In line with this position, Baron-Cohen and colleagues, using fMRI, reported left amygdala activation during a task requiring the subject to infer the mental state of an individual from the expression of their eyes (Baron-Cohen *et al.*, 1999). Moreover, individuals with autism and Asperger's syndrome, who show profound theory of mind impairment, present with structural abnormalities involving the amygdala, particularly the left amygdala (Courchesne, 1997; Abell *et al.*, 1999; Otsuka *et al.*, 1999). In addition, individuals with paranoid delusional schizophrenia, who also show theory of mind impairment, also present with structural abnormalities involving the amygdala (for a review, see Lawrie and Abukmeil, 1998). This position predicts that other patients with amygdala lesions, whether these occur early in development or in adulthood, should present with theory of mind impairment. Secondly, appropriate amygdala functioning may be a prerequisite for the development of theory of mind even if it is not itself involved in mediating the representation of mental states. The amygdala certainly has extensive interconnections with regions of the medial prefrontal cortex and the superior temporal sulcus (e.g. Amaral *et al.*, 1992). Both these areas have been implicated in the circuitry that mediates theory of mind (Fletcher *et al.*, 1995; Goel *et al.*, 1995; Gallagher *et al.*, 2000). This position predicts that patients whose amygdala lesions were acquired very early in life should show impairment in theory of mind but patients whose lesions were acquired in adulthood should not. Thirdly, it is possible that B.M.'s amygdala lesion plays no role in his theory of mind impairment. For example, B.M.'s impairment could be due to undetected damage elsewhere in the system. Fourthly, B.M.'s early social isolation may have caused his theory of mind impairment (anonymous reviewer's suggestion).

Implications for the relationship between theory of mind and executive functioning

There has been considerable debate concerning the association between theory of mind and executive functioning. Indeed, many have argued that there is no specific neurocognitive system that mediates theory of mind, but rather that performance on theory of mind tasks is mediated, at least in part, by executive functioning (e.g. Ozonoff *et al.*, 1991; Frye *et al.*, 1995, 1996; Ozonoff, 1997; Russell, 1995, 1996, 1997). There are two main forms of this argument. First, it has been argued that the development of executive functions allows the child's theory of mind to develop or show its full potential (e.g. Ozonoff *et al.*, 1991; Russell, 1995, 1996, 1997; Ozonoff, 1997). Secondly, it has been argued that there are no specific systems for processing mental states and that performance on theory of mind tasks can be reduced to executive function ability (e.g. Frye *et al.*, 1996).

B.M. presented with a profound impairment in theory of mind in the complete absence of any impairment in executive functioning. This clearly indicates, contrary to some suggestions, that performance on theory of mind tasks cannot be reduced to executive function ability. Indeed, it is important to note that B.M. showed no impairment on the executive function tasks that are typically found to be impaired in individuals with autism, e.g. the Wisconsin Card Sorting Task and the Tower of London (Pennington and Ozonoff, 1996). Moreover, it is important to note that B.M. showed no impairment on the executive function tasks that neuroimaging and lesion work has indicated recruit areas of the medial frontal cortex. These tasks include the Stroop task and Conditional Learning (e.g. Petrides, 1990; Bench *et al.*, 1993; Carter *et al.*, 1997). Very proximal areas of the medial frontal cortex have been shown to be recruited during theory of mind processing (Fletcher *et al.*, 1995; Goel *et al.*, 1995; Gallagher *et al.*, 2000). Thus, it is clear that an impairment other than in executive functioning caused B.M.'s impairment on the theory of mind tasks. Given the considerable variety of tasks used, addressing different modalities and with a range of task demands, the most parsimonious explanation is that his impairment was due to an impairment in the ability to represent mental states.

While B.M.'s difficulty on theory of mind tasks was clearly due to a specific problem with the representation of mental states, this may not be typically the case in autism, in which executive dysfunction has been reported widely (Ozonoff *et al.*, 1991). Indeed, it could still be argued that executive functions are necessary (if not sufficient) for successful performance on theory of mind tasks (Russell, 1995; Ozonoff, 1997). This position has to predict that individuals with executive function impairment should fail on theory of mind tasks. However, with regard to the executive functions of inhibitory control and attentional set-shifting, this prediction does not appear to hold. Recently, a patient, J.S., was reported with 'acquired sociopathy' following frontal lobe damage. J.S. failed two of four tests of inhibitory control and one of two tests of attentional set-shifting. However, he performed normally on the Advanced Theory of Mind Test (Blair and Cipolotti, 2000). The frequent occurrence of executive dysfunction in individuals with autism or Asperger's syndrome may be because many patients with these disorders have suffered damage to many neurocognitive systems that rely on the prefrontal cortex. Similarly, the findings of correlations in normally developing children between theory of mind and executive functioning (e.g. Hughes, 1998*a*, *b*) may either reflect proximal systems or similarity in the developmental time course between theory of mind and specific executive functions.

An alternative position on the relationship between theory of mind and executive functioning has been developed by Carruthers (Carruthers, 1996) and, more formally, by Perner and colleagues (Perner, 1998; Perner *et al.*, 1999; Perner and Lang, 2000). These authors suggest that the capacity to represent mental states is necessary in order to develop executive functions. Indeed, Perner has argued that, 'Since executive functions are characterised by formulation of higher-order intentions and representations, they need the conceptual repertoire for expressing these higher-order states, i.e. a theory of mind. So one would expect people with a deficient theory of mind to have executive function problems.' (Perner, 1998: 277–8).

More specifically, Perner argues that meta-representational abilities are essential in order to overcome dominant responses or old strategies, as in tests of inhibition and attentional set-shifting (Perner, 1998; Perner and Lang, 2000) B.M. passed only two out of five simple false belief tests. From this, Perner's position would predict impairment in the inhibitory and attentional set-shifting components of executive functions. However B.M.'s performance on all executive functions was normal. This suggests that executive functions do not require the same representational abilities as those involved in mental state processing.

The performance of B.M. thus clearly supports the position that theory of mind ability is domain-specific, with a dedicated neural system (e.g. Frith *et al.*, 1991; Leslie and Roth, 1993; Baron-Cohen, 1995; Frith and Frith, 1999). B.M. presented with a very severe impairment in theory of mind but no impairment in executive functioning.

Conclusions

This study has demonstrated a dissociation between theory of mind and executive functions in an individual with a congenital or very early lesion of the left amygdala. This finding suggests a possible role for the left amygdala and/or its connections in the development of understanding of mental states. In addition, the findings clearly suggest that theory of mind is neither mediated by nor necessary for executive functioning. Rather, the present findings suggest that theory of mind is mediated by a domain-specific, dedicated neural system.

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Appendix I

Tasks 8 and 9: example of an advanced theory of mind story

Simon is a big liar. Simon's brother Jim knows this, he knows that Simon never tells the truth! Now yesterday Simon stole Jim's ping-pong bat, and Jim knows Simon has hidden it somewhere, though he can't find it. He's very cross. So he finds Simon and he says 'Where is my ping-pong bat? You must have hidden it either in the cupboard or under your bed, because I've looked everywhere else. Where is it, in the cupboard or under your bed?' Simon tells him the bat is under the bed.

The participant is asked:

Q1: 'Was it true, what Simon told Jim?'

Q2: 'Where will Jim look for his ping-pong bat?'

Q3: 'Why will Jim look there for his bat?'

Task 10: example of a non-literal speech comprehension story

Karen is very thin, but thinks she needs to go on a diet. She tells her friend, Jen, that she is going on a diet. Jen thinks that Karen is too thin and says 'That's good, because you're so enormous, Karen.'

The participant is asked, 'What does Jen mean by this?'

She continues, 'You're a stick.'

The participant is asked, 'What does Jen mean by this?'