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Cognition 70 (1999) 211–240

COGNITION

Acquired ‘theory of mind’ impairments following stroke

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Received 16 September 1998; accepted 15 January 1999

Abstract

The ability to attribute thoughts and feelings to self and others (‘theory of mind’) has been hypothesised to have an innate neural basis and a dedicated cognitive mechanism. Evidence in favour of this proposal has come from autism; a brain-based developmental disorder which appears to be characterised by impaired theory of mind, despite sometimes good general reasoning skills/IQ. To date no case of specific *acquired* theory of mind impairment has been reported. The present study examined theory of mind in adults who had suffered right hemisphere stroke, a group known to show pragmatic and social difficulties. In one study using story materials and two using cartoons, patients’ understanding of materials requiring attribution of mental states (e.g. ignorance, false belief) was significantly worse than their understanding of non-mental control materials. Data from healthy elderly subjects, and a small group of left hemisphere patients (who received the tasks in modified form), suggest that this impairment on mental state tasks is not a function of task difficulty. The findings support the notion of a dedicated cognitive system for theory of mind, and suggest a role for the healthy right hemisphere in the attribution of mental states. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Theory of mind; Autism; Right Hemisphere stroke

1. Introduction

Interest in the brain basis of social understanding has increased in recent years,

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PII: S0010-0277(99)00005-0

with the convergence of evolutionary theories, primate studies, explorations of normal and abnormal development, and brain imaging investigations. Much of this work concerns a specific element of social competence: the ability to attribute mental states (e.g. beliefs and desires) in order to explain and predict people's behaviour. This ability, termed 'theory of mind', normally develops in the pre-school years, although there is some debate concerning the precise age at which a child should be credited with an understanding of others' mental states, according to the type of task or real-life observational measure used (see e.g. Astington et al., 1988; Carruthers and Smith, 1996).

It has been suggested that the child's development of theory of mind rests on an innately predisposed, dedicated cognitive mechanism, perhaps even a module (Fodor, 1992; Leslie and Roth, 1993). Evidence put forward in favour of such a notion includes the finding that young children develop understanding of beliefs, desires and false beliefs in a fairly predictable order, and over a surprisingly uniform time span, and that children from very different cultures appear to develop understanding of beliefs at similar rates and arrive at a similar belief-desire psychology (Avis and Harris, 1991). Functional brain imaging studies have shown frontal brain regions which are specifically more active during theory of mind tasks than during control tasks - although there is, as yet, no agreement as to the exact regions involved (Baron-Cohen et al., 1994; Fletcher et al., 1995; Goel et al., 1995).

Those in favour of a dedicated cognitive mechanism, or module, underlying theory of mind have pointed, in particular, to evidence of dissociation in developmental disorders. Theory of mind ability appears to be dissociable from cognitive ability in other domains; children with autism may be 'mind-blind' yet intelligent in other respects (Baron-Cohen et al., 1993), and children with William's syndrome, it has been suggested, show intact theory of mind despite delayed theorising in other domains (Karmiloff-Smith et al., 1995). Although the argument from double dissociation to separable cognitive systems is controversial (see, for example, Dunn and Kirsner, 1988; Goldberg, 1995; Plaut, 1995), findings of uneven cognitive profiles may at least provide constraints on proposed models of functional architecture.

The dissolution of cognitive abilities, like the development of those abilities, has the potential to reveal distinct and dedicated modular systems, although in this case dissociation can only suggest differentiation in the mature cognitive architecture (perhaps an emergent property; Karmiloff-Smith, 1993), and is silent on the question of intrinsic or innate modularity (Goldberg, 1995). Can theory of mind be specifically 'knocked out' in a previously normal adult, leaving other reasoning intact? This question has not yet been answered, although there is increasing interest in the social and emotional deficits which follow brain injury. What are the candidate groups for acquired theory of mind deficits? One group might be individuals with frontal lobe lesions, who appear to show abnormalities of social and emotional functioning (Damasio et al., 1990; Saver and Damasio, 1991). A second possible group are patients with acquired right hemisphere damage (RHD), and it was this group that formed the focus for the work reported here.

Adults with acquired damage to the right hemisphere are of interest because their

Table 1
Social and communicative functions impaired in RHD and Autism

Impaired function	RHD reference	Autism reference
Indirect requests	Hirst et al., 1984 Foldi, 1987; Stemmer et al., 1994	Paul and Cohen, 1985
Metaphor	Brownell et al., 1984 Van Lancker and Kempler, 1987	Happé, 1993 Ozonoff and Miller, 1996
Irony	Kaplan et al., 1990; Brownell et al., 1992 Winner et al., 1998	Happé, 1993
Humour	Bihle et al., 1986 Dagge and Hartje, 1985	Ozonoff and Miller, 1996
Emotion		
Cross modal matching	Cicone et al., 1980; DeKosky et al., 1980	Hobson et al., 1988; Loveland et al., 1995
Facial affect production	Borod et al., 1985; Borod and Koff, 1990; Martin et al., 1990	Yirmiya et al., 1989; Loveland et al., 1994
Facial affect comprehension	Bowers et al., 1985; Borod, 1993 Adolphs et al., 1996; Mandal et al., 1996	Hobson, 1986a,b
Prosody		
Production	Tucker et al., 1977; Gorelick and Ross, 1987	Baltaxe, 1984; Fine et al., 1991
Comprehension	Weintraub et al., 1981; Heilman et al., 1984	Van Lancker et al., 1989
Cohesive discourse		
Production	Wapner et al., 1981; Joannette et al., 1986 Davis et al., 1997	Baltaxe and D'Angiola, 1992; Baltaxe et al., 1995 Fine et al., 1994; Paul and Cohen, 1985
Judgement	Rehak et al., 1992	Surian et al., 1996
Discourse inference	Brownell et al., 1986, 1992; Delis et al., 1983	Ozonoff and Miller, 1996
Integration of information		
Verbal	Hough, 1990; Benowitz et al., 1990	Happé, 1997
Picture sequences	Huber and Gleber, 1982; Benowitz et al., 1990	Baron-Cohen et al., 1986
Social behaviour	Gardner, 1975; Van Lancker, 1991	Frith, 1989; Borden and Ollendick, 1994
Personal reference	Brownell et al., 1997	Lee et al., 1994

social and communicative impairments appear to resemble those of high-functioning people with autism (see Table 1, which includes representative, though not exhaustive, references)¹. In autism, these deficits have been linked to theory of mind impairment. For example, Happé (1993) found a close relation between ability

¹Of course, the effects of acquired and developmental disorders are dissimilar in many ways, and people with right hemisphere lesions do not resemble people with autism in other important respects.

to process non-literal utterances (metaphor and irony) and theory of mind task performance in people with autism (and normal young children). People with autism have been shown to do poorly on pragmatic and discourse tasks sensitive to right hemisphere brain damage (Ozonoff and Miller, 1996).

While it is clear that similar patterns of deficit at the behavioural level do not necessarily result from similar underlying cognitive impairments, the findings summarised in Table 1 suggest that RHD individuals might be a likely candidate group for acquired theory of mind deficits. A number of authors have discussed the cognitive deficits which follow RHD, many using descriptive terms (e.g. failure to 'assume varied perspectives', problems of 'pragmatics') which fit well with the present hypothesis of impaired theory of mind. In addition, a number of distinct, alternative accounts have been proposed, against which the present hypothesis competes (see McDonald, 1993, for review). Heilman and colleagues (e.g. Heilman et al., 1984) and others (e.g. Ross, 1981) propose primary affective abnormalities following RHD, and suggest that difficulties expressing and recognising emotion are sufficient to account for many of the social and communicative impairments recorded. Alternatively, a generalised 'integration deficit' has been proposed (Benowitz et al., 1990), which might link the communicative problems to the well-documented visuo-spatial construction deficits in RHD, through a failure to integrate information in context.

The present study tested the hypothesis that people with RHD show a deficit in theory of mind in the context of otherwise intact reasoning skills. Such a selective deficit would offer strong support for the notion of a dedicated cognitive mechanism for theory of mind, and suggest a theory of mind account for the social and communicative impairments associated with RHD.

2. Study 1: Theory of mind following right hemisphere stroke

2.1. Participants

The right hemisphere damaged (RHD) group was recruited through the Aphasia Research Center of the Department of Neurology, Boston University School of Medicine and Braintree Hospital. Eight participants (five male, three female) had taken part in research at the Aphasia Research Center for a number of years, and were between 7 and 23 years (mean 10 years) post-cerebro-vascular accident (CVA). An additional six participants (all female) had suffered more recent CVAs, between 4 and 9 months prior to testing (mean 5 months). For the total RHD group (five men, nine women) age ranged from 51 to 75 (mean 64 years) and years of education was between 10 and 19 years (mean 13.4). An approximate IQ estimate, using the Quick Test (Ammons and Ammons, 1962), showed the group to range in ability level from 87 to 120 (mean 101).

For all participants, unilateral lesion in the right hemisphere had been confirmed by CT or MRI scan. More precise localisation information was difficult to obtain, however, since scans had in most cases been performed very soon after the CVA (for

clinical purposes, to establish cause), at too early a stage in the illness to reveal the final pattern of tissue loss. Patient notes in nine cases described a CVA in the middle cerebral artery distribution (MCA). Notes in the other cases described a CVA in the parietal, fronto-temporal or temporal regions, or (in one case) in the anterior communicating artery distribution. Lesion details, as available from hospital records, are shown in Appendix A. All participants were right-handed, had English as their first language, and were free of additional diagnoses (past/present psychiatric disorder, developmental/learning disabilities, drug/alcohol abuse). None of the RHD group showed neglect during reading or picture description tasks at time of test.

The control group consisted of 19 healthy elderly individuals (10 women, nine men) recruited from a subject pool maintained by the Aphasia Research Center of the Department of Neurology, Boston University School of Medicine. All were right-handed individuals, aged between 61 and 80 years (mean age 73), and free of past or present psychiatric diagnoses, developmental or learning disabilities, medical illness and drug or alcohol abuse. IQ was not assessed in this group. Years of education ranged from 12 to 18 (mean 14.6 years). For all participants English was the first or joint first language. Comparison of participant characteristics in the RHD and Control groups showed that the RHD participants were significantly younger than the controls ($t = 3.45$, d.f. 31, $P = 0.002$), but did not differ in years of education ($t = 1.59$, d.f. 31, $P = 0.121$). Data from this group are also reported in a study comparing theory of mind in old and young adults (Happé et al., 1998).

2.2. Task 1: Story comprehension

2.2.1. Materials

Sixteen short passages, each followed by a test question, were used. These materials were adapted from a study of theory of mind in autism (Happé, 1994), and subsequently used in two functional imaging studies of this ability (Fletcher et al., 1995; Happé et al., 1996). The story passages were of two types; theory of mind stories and non-mental stories. The theory of mind (ToM) stories concerned double bluff, mistakes, persuasion and white lies (two examples of each of these four story types). These stories were followed by questions requiring an inference about the characters' thoughts and feelings, in most cases an inference about the speaker's/actor's intentions. The non-mental stories also involved people and the subsequent test questions also required inferences to be made, but in this case the mental states of the characters were not relevant and the inference concerned, for example, physical causation. The topics of the eight non-mental stories can be summarised as follows; setting off a burglar alarm, paying for a car by instalment versus lump sum, x-raying an elderly woman following a fall, filing a book in a library, making meringues from egg whites left over after making mayonnaise, the role of weather conditions in determining the outcome of air and land battles, identifying the most likely location for reading glasses to have been mislaid, and buying multi-packs rather than single items while shopping. Examples of the two types of story can be seen in Appendix B.

2.2.2. Procedure

All participants were tested individually following the same procedure. Participants were told that they would be shown a number of short passages and that they were to read each passage silently until they had understood it, at which point they should turn the page for the test question, and tell their answer to the experimenter. Participants were instructed that once they had turned the page for the test question they were not to turn back to the passage, and so they were encouraged to spend as long as necessary studying the passage before turning over. The theory of mind and non-mental stories were blocked and presented in counterbalanced order. Before the first story a practice story was given. Time to read each story (before turning the page) was recorded, and participants' answers to the test questions were noted. These answers were later rated according to a standardised scoring scheme, with good agreement (85%, with disagreements resolved on discussion) from a second rater blind to subject group and hypothesis. Answers were scored 0, 1, or 2, with 2 being credited for a full and explicitly correct answer and one for a partial or implicit answer. Examples of scoring criteria for the stories are given in Appendix B.

2.2.3. Results

Results from the group of elderly Controls have been reported previously with relation to age effects, in comparison with young adults (Happé et al., 1998). The Control and RHD groups' scores on the test questions, and time to read the passages, are shown in Table 2.

A repeated measures ANOVA comparing scores for the two groups by story type, showed a main effect of group ($F(1,31) = 10.4, P = 0.003$) but not of type. There was a significant interaction of group by type ($F(1,31) = 20.7, P = 0.000$).² This was due to RHD participants scoring significantly less well than controls on ToM stories ($t = 4.5, d.f. 15.52, P = 0.000$), but not on non-mental stories ($t = 0.1, d.f. 31, P = 0.92$). In addition, the RHD group scored significantly less well on ToM stories than on non-mental stories ($t = 2.13, d.f. 13, P = 0.053$), while the Control group

Table 2
Results for RHD and control groups by story condition (means \pm SD)

Group		ToM stories	Control stories
Controls ($n = 19$)	Score (max = 16)	14.9 \pm 1.2	12.4 \pm 2.2
	Time (s)	27.2 \pm 5.9	33.9 \pm 8.3
RHD ($n = 14$) ^a	Score (max = 16)	10.6 \pm 3.4	12.5 \pm 2.2
	Time (s)	38.1 \pm 13.1	39.8 \pm 12.0

^aTimes available from 12 subjects only.

²Data were treated as representing interval level measurement in order to facilitate statistical analysis. The critical interaction of group by condition was corroborated using non-parametric analysis of frequencies in the form of 2x2 contingency tables. The groups differed in numbers of subjects who did versus did not get a zero score on the ToM stories ($\chi^2 = 10.78, P < 0.01$), but did not differ in this respect on the non-mental stories ($\chi^2 = 0.004, P > 0.1$).

performed better on ToM than on non-mental stories ($t = 4.97$, d.f. 18, $P = 0.000$). Fig. 1 shows scatterplots giving each individual's explanation score, illustrating the degree of overlap between RHD and Control groups on non-mental stories and lack of overlap on ToM stories (see Appendix C for individual data).

Time data from two RHD participants were missing, due to mechanical failure. Analysis of time data from the remaining 31 participants showed a main effect of group ($F(1,29) = 6.33$, $P = 0.018$), and of story type ($F(1,29) = 13.68$, $P = 0.001$). Again, a significant interaction between group and story type was found ($F(1,29) = 4.7$, $P = 0.038$). Despite equal times for the non-mental stories, the RHD participants were slower than controls to read the ToM stories ($t = 2.72$, d.f. 13.88, $P = 0.017$). Control subjects were significantly faster to read ToM than non-mental stories ($t = 4.52$, d.f. 18, $P = 0.000$), while the RHD group did not show any such time advantage for ToM stories ($t = 1.06$, d.f. 11, $P = 0.31$).

Previous work (Happé et al., 1998) has shown that healthy elderly adults perform better on ToM stories than do young adults (mean age 22 years). Because the RHD group was significantly younger than the control group, the story scores were re-examined to determine whether the critical interaction of group by story type was

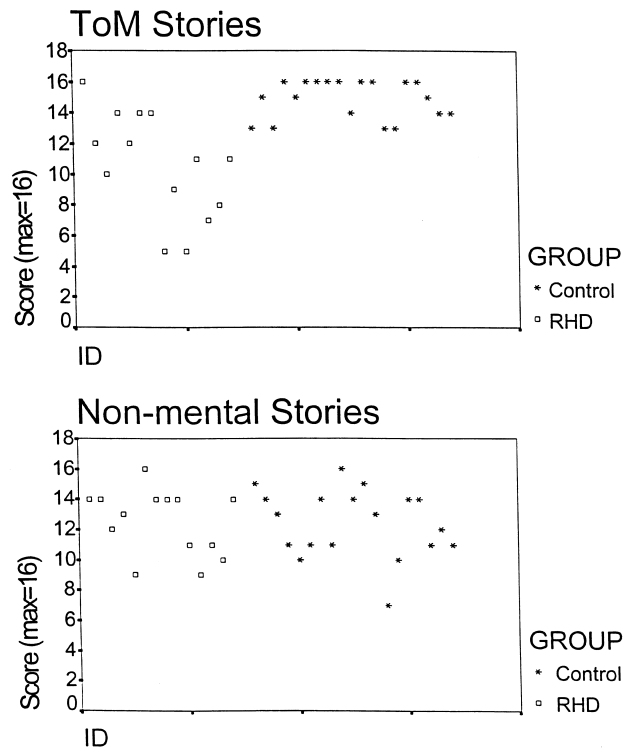


Fig. 1. Scatterplots showing individual explanation scores on ToM and non-mental stories by group.

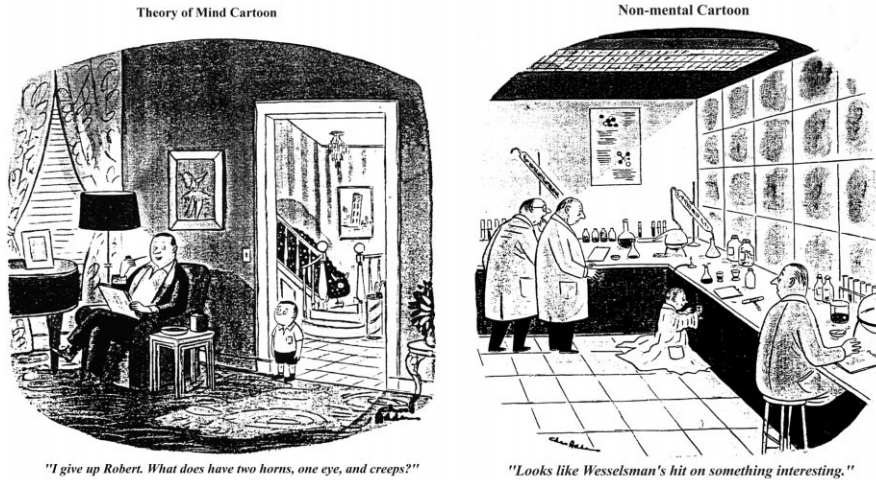


Fig. 2. Examples of theory of mind and non-mental cartoons used in Task 2.

due to age effects. A difference score, the difference between each participant's performance on the ToM stories and on the non-mental stories, formed the dependent variable in a simultaneous model multiple regression analysis. (A reliable group effect for the ToM–non-mental difference score is analogous to an interaction in ANOVA.) With both age and group included as predictor variables, the group variable was statistically significant ($Beta = 0.68$, $t(30) = 4.1$, $P = 0.000$), confirming that the patients' disproportionate difficulty with ToM stories was significant over and above any effect due to age differences across the two groups. The Beta (0.09) for the age variable was not reliably different from zero ($t(30) = 0.57$, $P = 0.57$).

2.3. Task 2: Single cartoons

2.3.1. Materials

The second task used 12 single-frame cartoons taken from popular magazines (e.g. *New Yorker*). The cartoons formed two conditions: theory of mind (ToM) cartoons, in which the humour depended upon what a character mistakenly thought or did not know, and non-mental cartoons in which the humour did not involve a character's false belief or ignorance but instead involved a physical anomaly or violation of a social norm. Examples of each type of material are shown in Fig. 2: the ToM cartoon shown requires an inference about the father's ignorance concerning the monster on the stairs, and consequent mistaken belief (that the boy is just telling a joke or riddle); while the non-mental cartoon requires an inference about prior physical events (that the small boy in the lab was an adult scientist who discovered the elixir of youth). Four cartoons in the ToM set and four in the non-

mental set showed facial expressions. Six cartoons (three ToM, three non-mental) included captions read aloud to participants.³

2.3.2. Procedure

Participants were shown the cartoons in random order, one at a time, with the instruction to tell the experimenter why each was funny. Answer given, and time taken before answering, were recorded. Answers were scored according to a standard scoring scheme in which 3 was given for a full and explicit explanation, 2 for a partial/implicit explanation, and 1 for reference to relevant parts of the cartoon without further explanation. Irrelevant, incorrect or ‘don’t know’ answers were scored 0. Good inter-rater agreement was achieved (87%) and disagreements were resolved upon discussion. Examples of answers and their scoring are given in Appendix B.

2.3.3. Results

The groups’ scores for cartoon explanation, and time to answer can be seen in Table 3. A repeated measures ANOVA comparing scores for the two groups by cartoon type showed a main effect of group ($F(1,31) = 38.5, P = 0.000$) but not of type. There was a significant interaction of group by type ($F(1,31) = 48.3, P = 0.000$).⁴ This was due to RHD participants scoring much less well than controls on ToM cartoons ($t = 9.38, d.f. 31, P = 0.000$), but only marginally less well on non-mental cartoons ($t = 1.98, d.f. 31, P = 0.06$). Fig. 3 illustrates these group differences with scatterplots showing each individual’s explanation score (see also Appendix C). In addition, the RHD group scored significantly less well on ToM cartoons than on non-mental cartoons ($t = 4.5, d.f. 13, P = 0.001$), while the control group performed better on ToM than on non-mental cartoons ($t = 5.3, d.f. 18, P = 0.000$).

Table 3
Results from Single Cartoons task: mean \pm SD score for explanations and time per item

Group		ToM Cartoons	Non-mental Cartoons
Controls ($n = 19$)	Score (max = 18)	15.3 \pm 1.9	12.7 \pm 2.9
	Time (s)	12.2 \pm 5.1	13.3 \pm 4.7
RHD ($n = 14$) ^a	Mean (max = 18)	7.1 \pm 3.1	10.7 \pm 2.7
	Time (s)	17.9 \pm 7.3	15.5 \pm 4.7

³One of the 6 ToM cartoons contained crucial information on the far left side of the drawing, but this did not differ from the other cartoons in scores obtained by the RHD group - supporting the impression that no participant was suffering from neglect at time of test.

⁴The critical interaction of group by condition was corroborated using non-parametric analysis of frequencies in the form of 2x2 contingency tables. When participants were classified by group (Control, RHD) there was a significant effect for ToM cartoons ($\chi^2 = 19.77, P < 0.001$) but not for non-mental cartoons ($\chi^2 = 0.74, P > 0.1$), with relation to numbers of participants who did or did not receive more than one zero score.

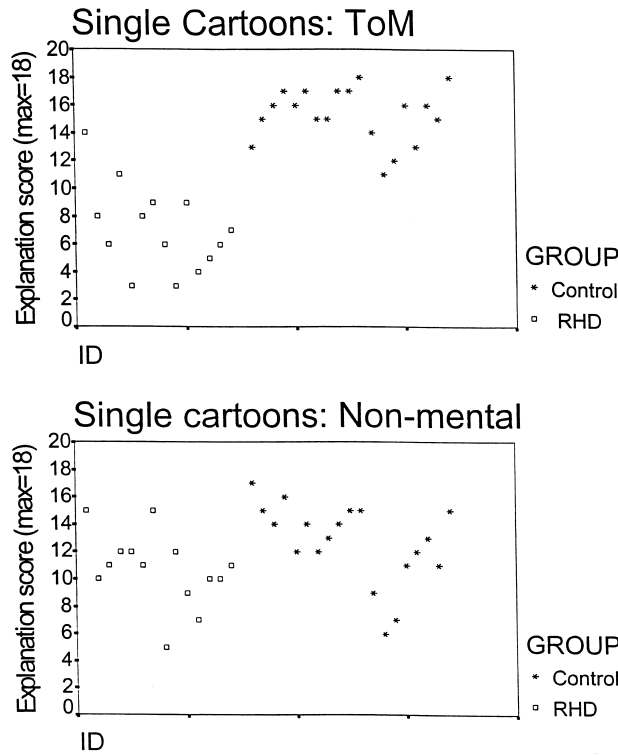


Fig. 3. Scatterplots showing individual explanation scores on ToM and non-mental cartoons by group.

Time data from one RHD participant for the non-mental cartoons were missing, due to mechanical failure. Analysis of time data from the remaining 32 participants showed a main effect of group ($F(1,30) = 4.59, P = 0.040$), but not of cartoon type. Again, a significant interaction between group and cartoon type was found ($F(1,30) = 8.37, P = 0.007$). Despite equal times for the non-mental cartoons, the RHD participants were slower than controls on the ToM cartoons ($t = 2.65, d.f. 30, P = 0.013$).

Because the RHD and control groups differed in mean age, the explanation scores were re-examined to determine whether the critical interaction of group by cartoon type was due to age effects. A difference score, the difference between each participant's performance on the ToM cartoons and on the non-mental cartoons, formed the dependent variable in a simultaneous model multiple regression analysis. With both age and group included as predictor variables, the group variable was statistically significant ($Beta = 0.8, t(30) = 5.9, P = 0.000$), confirming that the patients' difficulty with ToM cartoons was significant over and above any effect due to age differences across the two groups. The Beta (0.04) for the age variable was not reliably different from zero ($t(30) = 0.33, P = 0.74$). A similar multiple regression analysis was performed for time data, using the difference

between times for ToM and times for non-mental cartoons as the dependent measure. As above, group was a significant predictor of time difference (Beta = 0.56, $t(29) = 2.95$, $P = 0.006$), and the effect of age was not significant (Beta = 0.18, $t(29) = 0.93$, $P = 0.36$).

2.4. Task 3: Cartoon pairs

2.4.1. Materials

A second set of cartoons was selected from the same sources as those used in Task 2, and fell into the same two categories: ToM and non-mental cartoons. Five ToM

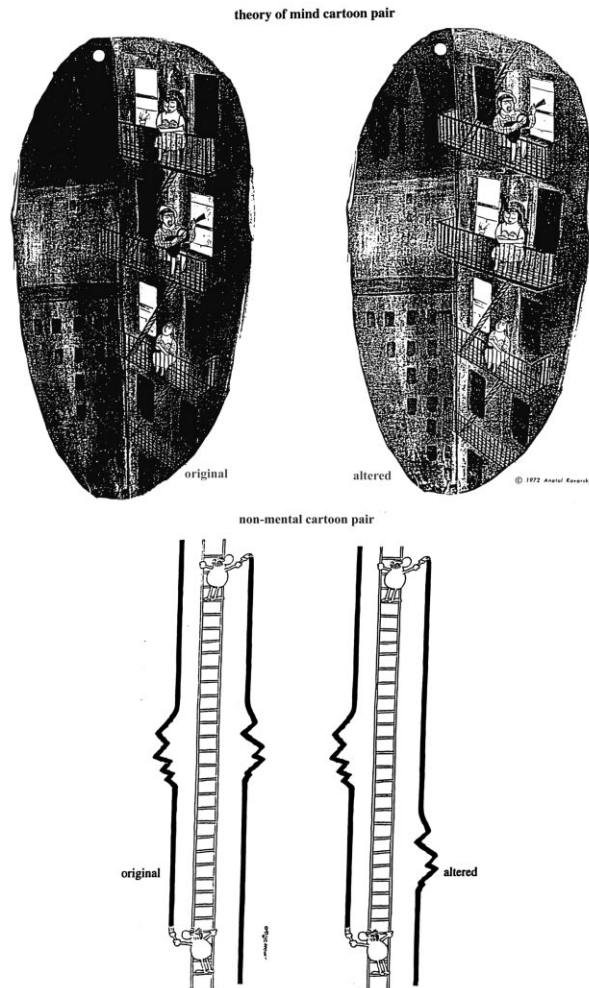


Fig. 4. Examples of theory of mind and non-mental cartoon pairs used in Task 3. Reproduced by kind permission of the artists.

and five non-mental cartoons, all non-verbal (without captions or speech), were used for this study. Three cartoons in the ToM set and three in the non-mental set showed facial expressions. For each cartoon, a matching stimulus was created by making a copy of the cartoon with the key humorous element replaced. Fig. 4 shows an example of the ToM and non-mental cartoon pairs. In each case the element was replaced (not simply omitted), so that the altered versions of ToM cartoons no longer supported an inference of false belief/ignorance, and the altered versions of non-mental cartoons no longer supported an inference of physical impossibility/convention-violation.

2.4.2. Procedure

Cartoon pairs (original and altered) were presented side by side (left-right order counterbalanced). Participants were told that only one cartoon in each pair was funny, and were asked to point to the funny one. Choice was recorded as correct, incorrect or 'don't know'. Time to point was recorded. Participants were then asked to explain why the cartoon was funny. When a participant refused to pick one cartoon from the pair, the correct (unaltered) cartoon was indicated while the explanation question was asked. Answers were recorded and scored according to the same scheme used in Study 1 (see Appendix B for examples).

2.4.3. Results

The results are shown in Table 3. As can be seen, the RHD group again performed less well than the Control group on ToM cartoons. A repeated measures ANOVA for number of correct cartoon choices showed a significant main effect of group ($F(1,31) = 11.18, P = 0.000$) but not of cartoon type, and a significant interaction of group by type ($F(1,31) = 8.6, P = 0.006$). This interaction was due to Controls selecting a greater number of correct cartoons than did the RHD participants, when presented with ToM pairs ($t = 6.43, \text{d.f. } 31, P = 0.000$) but not when choosing from non-mental cartoon pairs ($t = 1.38, \text{d.f. } 31, P = 0.18$). For control participants, choosing the correct cartoon from ToM pairs was easier than choosing from non-mental pairs ($t = 3.31, \text{d.f. } 18, P = 0.004$), while in the RHD group performance across the two types did not differ significantly ($t = 1.0, \text{d.f. } 13, P = 0.34$). Because the data contained ceiling effects that might affect the interpretability of ANOVA,

Table 4

Results from Cartoon Pairs task; mean \pm SD correct choices, explanation scores, and times per cartoon pair

Group		ToM Cartoons	Non-mental Cartoons
Controls ($n = 19$)	No. correct choices (max = 5)	4.7 \pm 0.5	4.0 \pm 0.8
	Score (max = 15)	12.7 \pm 1.5	10.3 \pm 2.3
	Time (s)	17.9 \pm 6.4	24.7 \pm 9.2
RHD ($n = 14$)	No. correct choices (max = 5)	3.4 \pm 0.6	3.6 \pm 0.9
	Score (max = 15)	7.4 \pm 2.4	9.5 \pm 2.7
	Time (s)	23.2 \pm 9.3	21.8 \pm 8.7

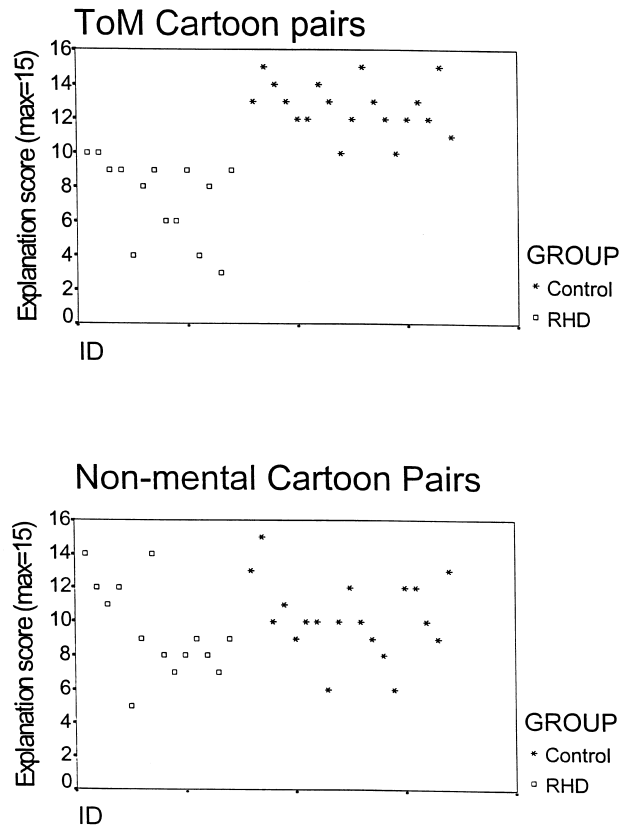


Fig. 5. Scatterplots showing individual explanation scores on ToM and non-mental cartoon pairs by group.

the critical group by task interaction was examined using non-parametric tests. Analysis of frequencies in the form of 2x2 contingency tables confirmed the interaction of group by cartoon type. The numbers of subjects who ever (versus never) chose the wrong cartoon differed between groups for the ToM pairs ($\chi^2 = 15.8$, $P < 0.001$) but did not differ for the non-mental pairs ($\chi^2 = 1.3$, $P > 0.1$) (see Table 4).

A repeated measures ANOVA for explanation scores showed a significant main effect of group ($F(1,31) = 19.94$, $P = 0.000$) but not of type. In addition, there was a significant group by cartoon type interaction ($F(1,31) = 33.3$, $P = 0.000$)⁵. The groups did not differ in their scores for the non-mental cartoon pairs, but the

⁵The critical interaction of group by condition was corroborated using non-parametric analysis of frequencies in the form of 2x2 contingency tables. The groups differed significantly in the number of participants who did versus did not get zero scores on the ToM cartoons ($\chi^2 = 18.9$, $P < 0.001$), but on the non-mental cartoon pairs there was no significant difference ($\chi^2 = 0.02$, $P > 0.1$).

RHD group was significantly worse than the Control group on the ToM cartoon pairs ($t = 7.8$, d.f. 31, $P = 0.000$). Fig. 5 illustrates this group difference with scatterplots showing each individual's explanation score (see also Appendix C). Controls were significantly better at explaining the ToM cartoons than the non-mental cartoons ($t = 4.38$, d.f. 18, $P = 0.000$). By contrast, the RHD group scored significantly worse on ToM than on non-mental cartoons ($t = 4.08$, d.f. 13, $P = 0.001$).

Although it was possible to give a high scoring explanation following an incorrect cartoon choice, these two measures are clearly not independent. Number of correct cartoon choices correlated with score for explanations in both groups (r values from 0.57 to 0.74, $P < 0.05$). To examine whether the RHD group's poor performance on ToM cartoon explanation was the result of incorrect cartoon choice alone, a mean explanation score was calculated for just those cartoon pairs where the correct cartoon was selected as the funny one. The same group by task interaction was found ($F(1,31) = 8.42$, $P = 0.007$), with RHD patients having lower mean explanation scores than Controls for ToM ($t = 4.79$, d.f. 31, $P = 0.000$) but not for non-mental cartoons ($t = 1.30$, d.f. 31, $P = 0.202$). Thus, even with accuracy of choice taken into account, RHD patients gave significantly poorer explanations of ToM cartoons.

As in Tasks 1 and 2, a simultaneous model multiple regression analysis, in which age and group were entered as predictor variables and the difference between ToM and non-mental scores formed the dependent variable, confirmed that age differences did not account for the worse performance of the RHD group on ToM cartoons. With both age and group included as predictor variables, the group variable was statistically significant (Beta = 0.8, $t(30) = 5.2$, $P = 0.000$), confirming that the patients' disproportionate difficulty with ToM cartoons was significant over and above any effect due to age differences across the two groups. The Beta (0.1) for the age variable was not reliably different from zero ($t(30) = 0.66$, $P = 0.51$).

Analysis of time data showed no significant main effect of group or cartoon type, but a significant interaction of group by type ($F(1,31) = 8.4$, $P = 0.007$). The groups did not differ in their times for non-mental cartoon pairs ($t = 0.92$, d.f. 31, $P = 0.36$), but there was a trend for the RHD group to perform more slowly than the Control group on ToM cartoon pairs ($t = 1.93$, d.f. 31, $P = 0.06$). In addition, Controls were significantly faster at explaining ToM cartoons compared to non-mental cartoons ($t = 3.45$, d.f. 18, $P = 0.003$), while the RHD group did not differ in times for the two conditions ($t = 0.72$, d.f. 13, $P = 0.48$). Again, a multiple regression analysis, using difference between times in the two conditions, showed that group (Beta = 0.5, $t(30) = 2.4$, $P = 0.023$) accounted for these differences over and above age, which was not a significant predictor (Beta = 0.005, $t(30) = 0.03$, $P = 0.98$).

2.4.4. Discussion

The results of the three tasks in Study 1 suggest that people with RHD show specific impairments in understanding stories and cartoons that require mental state attribution. This difficulty does not appear to be the result of greater general task difficulty, since the Control group found the theory of mind materials easier than the non-mental materials in all three tasks. This latter finding fits a previous report of

superior theory of mind in old versus young people (Happé et al., 1998). Although the RHD group was somewhat younger than the Control group, age differences did not account for the present pattern of results.

It would be difficult to explain the present findings in terms of alternative theories of cognitive deficits following RHD. Inference beyond the information given was a key requirement in both the ToM and non-mental stories and cartoons. Demand for recognition of emotional expression and processing of facial information were balanced across the ToM and non-mental cartoon materials. Integration of visual information was required to understand both cartoon types. As reported in previous studies (e.g. Gillikin and Derks, 1991) the RHD patients occasionally gave answers that focused on details or reflected a misperception of some aspect of the visual stimuli (30 of the total 308 responses in tasks 2 and 3). However, these abnormalities were noted in answers for both types of cartoon (17 of 154 responses to ToM cartoons, 13 of 154 responses to non-mental cartoons). The relatively good performance of the RHD group on the non-mental cartoons and stories, then, rules out a number of alternative explanations for their failure on the ToM tasks.

The possible role of gender, age at stroke, and time elapsed since stroke, in explaining the range of performance seen (as illustrated in Figs. 1, 3, and 5) could not be explored here due to small numbers. By chance, the individuals in the group who had suffered recent CVAs happened to be female, and so gender and time elapsed since stroke were confounded. Understanding individual differences in the sequelae of brain damage, in relation to lesion sites, is clearly an important aim for future research.

3. Study 2: Theory of mind following left hemisphere stroke

Study 1 compared the performance of RHD patients with that of healthy elderly people. Is it possible that ToM impairments are not specific to RHD, but that ToM tasks are simply especially sensitive to the cognitive deficits that follow any type of brain damage? Study 2 attempted to address this question by examining ToM in a small group of patients with left hemisphere damage.

3.1. Participants

Five participants (four men and one woman) who had suffered left CVA took part in Study 2. All had unilateral left hemisphere lesions confirmed on CT or MRI scan, and had been assessed at the Aphasia Research Center. All had received the diagnosis of Broca's aphasia, had lesion sites consistent with this characterisation, and currently had good comprehension skills. Patient notes described lesions involving, in addition to Broca's area, the left dorso-lateral prefrontal cortex, frontal horn, frontal operculum, and MCA distribution. They ranged in age from 54 to 80 (mean 67 years), and had between 8 and 16 years of education (mean 12.6). Participants ranged from 12 months to 21 years post-CVA (mean 9 years). Participant details are shown in Appendix A.

3.2. *Materials*

The story and cartoon materials devised for Tasks 1, 2 and 3 were used. Since the LHD participants all had expressive aphasia, and proved unable to answer open-ended questions, a forced-choice answer format was used for the explanation questions. The three explanations offered (in counterbalanced order) were (1) the correct inference, (2) an incorrect/inappropriate inference, (3) verbatim information from the story/reference to a physical aspect of the cartoon. These answers were based on correct and incorrect explanations offered by Control and RHD participants in Study 1. Examples are shown in Appendix B.

3.3. *Task 1: Story comprehension*

3.3.1. *Procedure*

The 16 stories used in Study 1 were shown and read aloud to the LHD patients. Patients signalled when they were ready to proceed to the test question, and the story was read a second time if required. As for the RHD and Control groups, participants were not permitted to return to the story once the page had been turned for the test question. The LHD patients were then read the test question, and offered the three forced-choice answers with the instruction to ‘Choose the best answer’. Test question and answers were repeated as necessary. Answer chosen was recorded. Because of the time needed to read aloud the three answer choices, and the occasional need to repeat an answer, time to select an explanation was not considered a meaningful reflection of processing time, and was not recorded.

3.3.2. *Results*

Of a possible total score of 8, the LHD group scored a mean of 6.6 (SD 0.5) for ToM stories and 5.8 (SD 1.7) for non-mental stories. There was no sign of impairment on the ToM stories, and performance on the two story types did not differ significantly ($t = 1.21$, d.f. = 4, $P = 0.29$). Individual data are shown in Appendix C.

3.4. *Task 2: Single cartoons*

3.4.1. *Procedure*

Participants in the LHD group were shown the cartoons as described in Study 1, and were encouraged to say if possible what was funny in each cartoon. Only two participants were able to say single words that conveyed an answer for any of the cartoons. All participants were therefore offered the choice of three possible explanations (order counterbalanced) from which they were asked to ‘choose the explanation that best fits why the cartoon is funny’. Participants’ choice of answer was recorded. One patient was unable to complete this task due to time constraints.

3.4.2. Results

The LHD patients showed no sign of greater difficulty with the ToM cartoons, and indeed performed better on ToM than on non-mental materials (see Appendix C for individual data). The mean number of correct answer choices (maximum 6) was 5 (SD 0.8) for ToM and 3.3 (SD 0.9) for non-mental cartoons, showing a significant advantage on ToM cartoons ($t = 3.66$, d.f. = 3, $P = 0.035$).

3.5. Task 3: Cartoon pairs

3.5.1. Procedure

Participants were shown the cartoon pairs (as described in Study 1 above) and asked to indicate which of each pair was the funny one. Time to choose was recorded. This response measure was exactly as in Study 1. In addition, all participants were asked ‘Why is that one funny?’, and offered the choice of three possible explanations (order counterbalanced), which fell into the same three categories described above (correct inference, incorrect inference, physical reference). Choice of explanation was recorded.

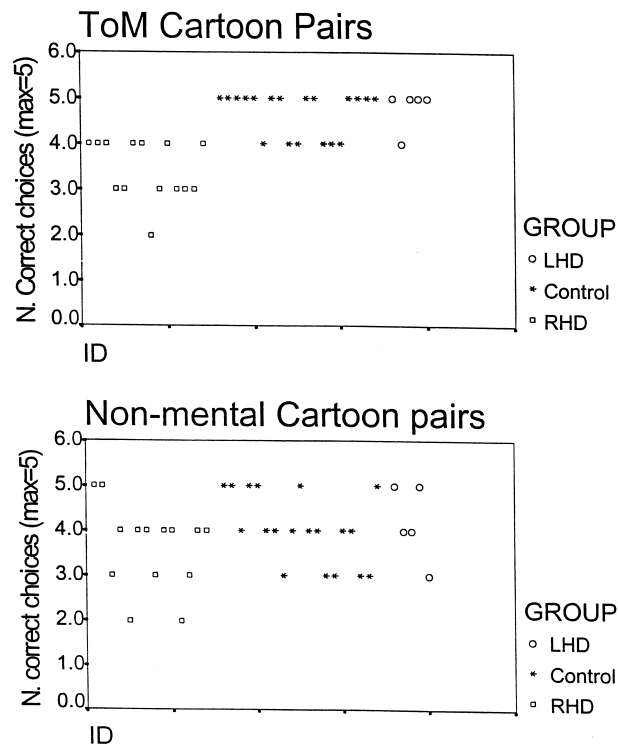


Fig. 6. Scatterplots showing individual cartoon choice scores on ToM and non-mental cartoon pairs by group (RHD, LHD and Control).

3.5.2. Results

The LHD patients performed equally well on the two types of cartoons (see Appendix C for individual data). There was no significant difference in the number of correct cartoon choices (maximum 5); 4.8 (SD 0.5) for ToM pairs and 4.2 (SD 0.8) for non-mental cartoon pairs.

Selection of the funny cartoon from each pair is a task directly comparable across the three groups tested. Comparing the LHD group with the RHD and normal Control groups of Study 1, a repeated measures ANOVA for group (three levels) by condition (two levels) showed a significant main effect of group ($F(2,35) = 9.93$, $P = 0.000$), and of condition type ($F(1,35) = 4.7$, $P = 0.04$) on number of correct cartoon choices. In addition, there was a significant interaction of group by condition ($F(2,35) = 4.55$, $P = 0.02$). One-way ANOVA with post hoc Tukey tests showed that this was due to the RHD group making significantly fewer correct cartoon choices than both Control and LHD groups in the ToM condition only ($F(2,35) = 24.6$, $P = 0.000$; between groups Tukey $P < 0.05$). This group difference is illustrated in Fig. 6 with scatterplots showing individual data for cartoon choice in the RHD, LHD and Control groups. Since ceiling effects threaten the validity of this ANOVA, this interaction was also explored with non-parametric tests. Analysis of frequencies showed that numbers of participants making at least one wrong cartoon choice did not differ in the LHD and Control groups for either condition (Fisher, $P > 0.1$). By contrast, the number of participants making incorrect choices was significantly higher in the RHD group than the LHD in the ToM condition (Fisher, $P < 0.005$), but did not differ in the non-mental condition ($P > 0.1$). Thus the RHD group performed less well on the ToM cartoons (but not on the non-mental cartoons) in comparison to both healthy controls and LHD patients.

Time to pick the funny cartoon from the pairs presented is also a measure of performance directly comparable with Study 1. Time data were available from 4 of the LHD participants, and mean time to choose the cartoon was 13.9 s (SD 1.5 s) for ToM pairs, and 22.5 s (SD 5.7 s) for non-mental cartoons. LHD participants, like the Controls in Study 1, were significantly faster to pick the target cartoon in the ToM condition ($t = 3.23$, d.f. 4, $P = 0.032$). Comparison of the LHD, RHD and Control groups' times to pick cartoons from the ToM and non-mental pairs showed a significant group by task interaction ($F(2,34) = 5.10$, $P = 0.012$). RHD patients took longer than LHD patients to pick the funny cartoon in the ToM condition ($t = 3.57$, d.f. 14.9, $P = 0.003$) but not in the non-mental condition ($t = 0.16$, d.f. 16, $P = 0.88$).

Mean score for explanation (selection from three answers, maximum score 5) was 4.6 (SD 0.6) correct for ToM cartoon pairs and 4.2 (SD 0.8) for non-mental cartoon pairs, with no significant difference between the two conditions ($t = 1.00$, d.f. 4, $P = 0.37$).

3.5.3. Discussion

The LHD patients showed no sign of greater difficulty on the ToM materials, compared with the non-mental tasks. This suggests that acquired damage to the left

hemisphere does not necessarily impair the ability to attribute mental states. The impairment on ToM tasks shown in Study 1 and 2 does seem, then, to be specific to right hemisphere damage. One limitation of the present study is that the RHD participants did not receive the forced-choice explanation task (since they had already been given the cartoon tasks in open question form). It remains possible, then, that the RHD participants would do better on the tasks, and specifically on the ToM tasks, in this forced-choice mode. However, the fact that the foil answers used in the forced-choice format were taken from spontaneous answers given by RHD participants, suggests that such an improvement should not be expected. More importantly, two measures from the cartoon pairs task (choice of cartoon and time to choose cartoon) allow direct comparison between performance in the LHD group and in the RHD and Control groups. Results from these measures mirror those from the forced-choice explanation measures, and show significant group differences, with RHD but not LHD patients performing worse than healthy controls on ToM materials only.

4. General discussion

The present findings suggest that the well-documented social and communication deficits which commonly follow right hemisphere stroke may be due to acquired impairments in theory of mind. Before discussing the possible implications, however, it is necessary to mention the limitations of the present studies. The lack of detailed scan data for the patients, unfortunately prevents an exploration of the relation between specific lesion sites and theory of mind (dis)ability. In addition, it leaves open the possibility that individuals in the RHD group had larger or more serious lesions than those in the LHD group, although the equivalent performance of the groups on the non-mental materials makes this less likely. The ideal comparison group for the RHD patients would be individuals with LH lesions but intact language. However, the rarity of such patients, and the likelihood that such lesions would be small in relation to the RH group's damage, led to the inclusion in the present case of aphasic individuals. This necessitated the modification of some, but not all, of the performance measures. It remains possible, then, that the relative advantage of the LHD group over the RHD group in Tasks 1 and 2 is due to these modifications. However, performance measures (choice of cartoon and time to choose) on Task 3, the cartoon pairs task, were not modified for the LHD group, and still showed significantly better performance in LHD than RHD patients. In sum, our findings do appear to show that ToM can be selectively impaired following stroke, but require replication with a larger group of RHD patients with more clearly mapped lesions, and comparison groups with damage in other brain regions. Future case-studies with detailed lesion information should prove especially informative. With these limitations in mind, we turn to the implications of the present preliminary findings.

The findings suggest a role for the healthy right hemisphere in normal adult theory of mind. This fits with findings by Winner et al. (1998), who found im-

paired discrimination of jokes versus lies in RHD patients, and attributed this to problems in understanding speakers' intentions. Siegal et al. (1996) have also reported failure on (very simple) theory of mind tasks in RHD groups. However, the explanation they offer for this failure, in terms of misinterpretation of experimenter's questions, would not appear to account for the present pattern of data.

The present findings implicating right hemisphere processes in theory of mind are consistent with some of the data emerging from functional brain imaging studies of ToM. Baron-Cohen et al. (1994) found increased activation in right orbito-frontal regions when participants were asked to identify words that had to do with the mind (e.g. think, dream, plan). Two other functional imaging studies, however, reported greater activation (during ToM versus non-mental tasks) in frontal regions of the left hemisphere (Fletcher et al., 1995; Goel et al., 1995). In the present study, LHD patients showed no evidence of ToM impairments; however, none of these patients had lesions to the key frontal areas implicated in functional imaging studies of ToM. The relationship between imaging findings and neurological deficits is an interesting one; while left frontal regions may play key roles in the neural circuits underlying ToM, there is no reason to think that the same circuit could not be disrupted by damage to other sites. Which specific brain regions or pathways are important for ToM could not be ascertained in the present study due to insufficient lesion data, but will be an interesting issue for future research.

The findings suggest that it may be fruitful to think of acquired RHD as (in some cases) a syndrome of impaired theory of mind. Impaired ability to attribute mental states to others has implications for therapy, and relevance for relatives and caregivers. Problems representing mental states may also relate to some of the other puzzling features of RHD. For example, RHD appears to be a risk factor for psychotic, atypical schizophreni-form symptoms following stroke (Rabins et al., 1991). Frith (1992) has suggested that such symptoms may be the result of abnormal mental state attribution; an anomaly in ToM leading to misattribution and misidentification of own and other's thoughts and intentions. Indeed, individuals with schizophrenia also show problems understanding cartoon humour based on characters' mental states (Corcoran et al., 1997). Impaired access to one's own mental states might be important in a number of intriguing clinical deficits which commonly follow right (but not left) hemisphere damage. Hence anosognosia (lack of concern for handicap such as hemiplegia) has been hypothesised to result from a breakdown in monitoring of one's own action intentions (Gold et al., 1994; Heilman, 1991). Could this be part of a more general failure of mental state representation? It remains to be seen, however, whether difficulties in reading other minds extend to reading own mind.

Do the present findings suggest that the right hemisphere is implicated in autism? It appears that people with RHD and people with autism have difficulty with social and communicative tasks for similar reasons - problems representing the mental states of others. The present data suggest that areas in the right hemisphere are necessary *on-line* for the operation of normal adult theory of mind. However, this

does not allow us to conclude that right hemisphere structures are necessary in the *development* of theory of mind, nor that damage elsewhere in the brain cannot disrupt theory of mind on-line or developmentally. There are, however, some intriguing hints that right hemisphere functions may be relevant to understanding autism. For example, people with autism show detail-focused processing of visuo-spatial information and relative inability to process configural/global information (Happé, 1996; Shah and Frith, 1983, 1993), configural processing being linked to the right hemisphere (Robertson and Lamb, 1991). Autism is also characterised by repetitive, stereotyped movements and activities (DSM-IV; APA, 1994), suppression of which is believed to be the responsibility of control centres in the right hemisphere (Brugger et al., 1996). At least one brain imaging study to date has found right hemisphere abnormalities in three individuals with a high-functioning form of autism, Asperger Syndrome (McKelvey et al., 1995). In addition, there are strong behavioural similarities between autism and so-called ‘right hemisphere learning disability’, in at least some cases of which there is known right hemisphere pathology (Gross-Tsur et al., 1995; Manoach et al., 1995). However, it is important to bear in mind the complexity introduced by developmental plasticity: in some cases, early left hemisphere pathology may result in a pattern of impaired right hemisphere skills, due to cortical reorganisation (Ogden, 1989; Polster and Rapcsak, 1994).

The findings suggest that theory of mind may have a separable brain basis, and a dedicated cognitive mechanism. The brain damage suffered by the participants in the present studies presumably affected fully developed cognitive mechanisms for theory of mind. In adulthood, then, the ability to attribute mental states can be selectively impaired, suggesting that our normal adult ‘mind-reading’ abilities are not simply the product of general-purpose reasoning mechanisms. It remains to be seen how the developmental picture might differ from that found here in adults; the present findings are mute with regard to the issue of dedicated mechanisms for theory of mind acquisition, and it is possible that a process of modularisation or cognitive specialisation could result in dedicated brain mechanisms for theory of mind later in life (Karmiloff-Smith, 1993). It is clearly an important task for the future to explore the effects of brain damage at different points in the development of theory of mind.

Acknowledgements

This work was undertaken while the first author held a Human Frontiers Science Program long-term travel fellowship at Boston College. Parts of this work were also supported by grants 2R01-NS27849 and DC00081 and by a Research Grant from Boston College. We are grateful to Jennifer Balogh, Lorrie Kirchner, and the staff of Braintree Hospital for help with recruitment and testing. This paper has benefited greatly from the comments of a number of colleagues, especially Uta Frith and Chris Frith, who had the original idea to use cartoons to explore theory of mind.

Appendix A. Patient information

Right hemisphere-damaged patients						
ID	CVA description	Sex	Age	Time post onset	Education (years)	Quick test IQ estimate
CB	Middle cerebral artery distribution	M	63	10 years	16	108
VF	Parietal regions	F	54	8 years	11	92
SB	Frontal region extending to mid parietal	M	75	10 years	11	96
MC	Midbrain	F	51	7 years	16	98
KE	Middle cerebral artery distribution	M	65	9 years	19	102
JM	Middle cerebral artery, parietal regions	F	53	7 years	12	108
AM	Middle cerebral artery distribution	M	63	23 years	16	108
SO	Middle cerebral artery distribution	M	74	10 years	14	108
JD	Middle cerebral artery distribution	F	70	5 months	12	100
VA	Posterior frontal	F	58	6 months	10	92
DS	Frontal temporal-parietal	F	74	6 months	14	90
JH	Middle cerebral artery distribution	F	55	3 months	13	120
JF	Middle cerebral artery, temporal and parietal	F	74	4 months	12	87
CL	Middle cerebral and anterior communicating artery	F	71	4 months	12	100
Left hemisphere-damaged patients						
ID	CVA Description	Sex	Age	Time post onset	Education (years)	
WF	Broca's area, lateral frontal, frontal operculum, putamen	M	60	2 years	9	
FC	Middle cerebral artery, Broca's area, dorso-lateral prefrontal	M	63	21 years	16	
RD	Broca's area, insula, frontal horn, temporal lobe	M	80	10 years	14	
JC	Middle cerebral artery, Broca's, frontal-parietal	F	54	1 year	16	
EM	Middle cerebral artery, Broca's, parietal, posterior frontal	M	78	10 years	8	

Appendix B. Examples of theory of mind stories and non-mental stories*Example Theory of Mind Story*

A burglar who has just robbed a shop is making his getaway. As he is running home, a policeman on his beat sees him drop his glove. He doesn't know the man is a burglar, he just wants to tell him he dropped his glove. But when the policeman shouts out to the burglar, 'Hey, you! Stop!', the burglar turns round, sees the policeman and gives himself up. He puts his hands up and admits that he did the break-in at the local shop.

Q: Why did the burglar do that?

Example responses scored:

2: 'Because he thought the policeman knew he had robbed the shop'

1: 'Because he thought he was caught'

Example Non-mental Story

A burglar is about to break into a jewellers' shop. He skilfully picks the lock on the shop door. Carefully he crawls under the electronic detector beam. If he breaks this beam it will set off the alarm. Quietly he opens the door of the store-room and sees the gems glittering. As he reaches out, however, he steps on something soft. He hears a screech and something small and furry runs out past him, towards the shop door. Immediately the alarm sounds.

Q: Why did the alarm go off?

Example responses scored:

2: 'Because the burglar disturbed a cat, which ran through the detector beam'

1: 'Because something broke the beam'

Example answers and scoring for Single Cartoons task (see Fig. 2)

ToM Cartoon

3: 'He thinks the kid's just asking him a riddle - doesn't realise there really is a monster there!'

2: 'He hasn't seen the thing on the stairs!'

1: 'There really is something there with two horns and one eye'

Non-mental Cartoon

3: 'The scientist has discovered a potion to make him a kid again!'

2: 'The scientist has made something which has made him shrink!'

1: 'He must have shrunk!'

Example answers and scoring for Cartoon Pairs task (see Fig. 4)

ToM Cartoon

3: 'He's got each girl thinking his song is just for her'

2: 'You can't tell which girl he's singing to'

1: 'The guy's singing and they listen'

Non-mental Cartoon

3: 'Their lines went wrong when they had to pass in the middle'

2: 'The ladder wobbled, maybe they had a fight?'

1: 'The painters made a mistake'

Example forced-choice answers offered to Aphasic participants

Stories

(1) Appropriate inference choice,

e.g. 'Because he thinks the policeman knows he robbed the shop'

(2) Inappropriate inference choice,

e.g. 'Because he thinks the policeman wants to give him back his glove'

(3) Verbatim information choice,

Appendix C. Individual participants' performance

ID	Story task				Single cartoons				Cartoon pairs					
	ToM		non-ToM		ToM		non-ToM		ToM			non-ToM		
	Score (max = 16)	Time (s)	Score (max = 16)	Time (s)	Score (max = 18)	Time (s)	Score (max = 18)	Time (s)	Choice (max = 5)	Score (max = 15)	Time (s)	Choice (max = 5)	Score (max = 15)	Time (s)
<i>RHD</i>														
CB	16.00	67.20	14.00	66.60	14.00	10.67	15.00	16.50	4.00	10.00	38.00	5.00	14.00	23.00
VF	12.00	40.60	14.00	45.50	8.00	18.33	10.00	17.83	4.00	10.00	17.80	5.00	12.00	16.40
SB	10.00		12.00		6.00	16.67	11.00	14.67	4.00	9.00	13.80	3.00	11.00	18.80
MC	14.00	38.60	13.00	34.20	11.00	17.33	12.00	10.83	3.00	9.00	22.60	4.00	12.00	20.40
KE	12.00	46.40	9.00	52.90	3.00	30.17	12.00	22.83	3.00	4.00	28.60	2.00	5.00	26.20
JM	14.00	28.00	16.00	39.60	8.00	9.83	11.00	7.67	4.00	8.00	12.40	4.00	9.00	13.40
AM	14.00	21.20	14.00	30.40	9.00	12.50	15.00		4.00	9.00	14.80	4.00	14.00	19.40
SO	5.00	56.00	14.00	52.00	6.00	25.17	5.00	18.17	2.00	6.00	37.00	3.00	8.00	40.80
JD	9.00		14.00		3.00	15.00	12.00	14.17	3.00	6.00	21.60	4.00	7.00	10.80
VA	5.00	34.40	11.00	36.10	9.00	10.17	9.00	10.33	4.00	9.00	9.60	4.00	8.00	18.20
DS	11.00	36.90	9.00	29.60	4.00	17.50	7.00	15.33	3.00	4.00	21.00	2.00	9.00	15.60
JH	7.00	28.60	11.00	27.80	5.00	11.33	10.00	14.67	3.00	8.00	24.80	3.00	8.00	15.20
JF	8.00	31.40	10.00	32.20	6.00	32.00	10.00	24.33	3.00	3.00	36.60	4.00	7.00	31.80
CL	11.00	28.00	14.00	31.20	7.00	18.83	11.00	13.83	4.00	9.00	25.60	4.00	9.00	34.60
<i>Healthy controls</i>														
CS	13.00	23.00	15.00	21.80	13.00	13.00	17.00	9.00	5.00	13.00	15.00	5.00	13.00	17.20
JH	15.00	25.50	14.00	26.90	15.00	17.17	15.00	19.67	5.00	15.00	29.60	5.00	15.00	45.00
BS	13.00	22.20	13.00	31.50	16.00	5.83	14.00	9.50	5.00	14.00	12.40	4.00	10.00	21.80
SS	16.00	30.40	11.00	30.90	17.00	7.83	16.00	12.17	5.00	13.00	13.60	5.00	11.00	17.00
NW	15.00	27.50	10.00	48.80	16.00	7.17	12.00	9.67	5.00	12.00	27.80	5.00	9.00	24.60
OM	16.00	20.50	11.00	24.90	17.00	6.67	14.00	7.67	4.00	12.00	12.40	4.00	10.00	20.80
BR	16.00	25.50	14.00	29.90	15.00	14.17	12.00	12.00	5.00	14.00	10.40	4.00	10.00	16.20
JR	16.00	25.90	11.00	27.50	15.00	14.50	13.00	13.67	5.00	13.00	10.60	3.00	6.00	26.60
MB	16.00	24.10	16.00	33.50	17.00	19.67	14.00	22.00	4.00	10.00	16.40	4.00	10.00	49.60

Story task	Single cartoons										Cartoon pairs						
	ToM					non-ToM					ToM			non-ToM			
	Score (max = 8)	non-ToM	ToM	Score (max = 6)	non-ToM	Time (s)	Score (max = 5)	ToM	Score (max = 5)	non-ToM	Time (s)	Choice (max = 5)	Score (max = 5)	Time (s)	Choice (max = 5)	Score (max = 5)	Time (s)
JA	14.00	21.40	14.00	26.60	17.00	6.50	15.00	6.33	4.00	12.00	10.80	5.00	12.00	10.80	5.00	12.00	12.60
CF	16.00	17.20	15.00	27.10	18.00	7.50	15.00	11.33	5.00	15.00	15.00	4.00	10.00	15.00	4.00	10.00	27.80
SF	16.00	32.50	13.00	48.20	14.00	18.83	9.00	18.67	5.00	13.00	18.20	4.00	9.00	18.20	4.00	9.00	29.40
JH	13.00	26.90	7.00	32.80	11.00	9.17	6.00	9.00	4.00	12.00	24.20	3.00	8.00	24.20	3.00	8.00	21.00
BB	13.00	37.20	10.00	43.00	12.00	14.83	7.00	12.50	4.00	10.00	15.80	3.00	6.00	15.80	3.00	6.00	19.00
GC	16.00	27.90	14.00	32.80	16.00	13.17	11.00	17.33	4.00	12.00	19.40	4.00	12.00	19.40	4.00	12.00	20.00
CW	16.00	30.90	14.00	48.90	13.00	8.50	12.00	12.00	5.00	13.00	14.50	4.00	12.00	14.50	4.00	12.00	22.20
EK	15.00	32.40	11.00	40.60	16.00	11.67	13.00	18.67	5.00	12.00	30.80	3.00	10.00	30.80	3.00	10.00	30.40
MT	14.00	24.50	12.00	30.40	15.00	11.67	11.00	11.83	5.00	15.00	20.60	3.00	9.00	20.60	3.00	9.00	23.80
JS	14.00	41.50	11.00	37.20	18.00	23.33	15.00	20.50	5.00	11.00	22.40	5.00	13.00	22.40	5.00	13.00	24.00

LHD	Single cartoons						Cartoon pairs								
	ToM			non-ToM			ToM			non-ToM					
	Score (max = 8)	non-ToM	ToM	Score (max = 6)	non-ToM	ToM	Choice (max = 5)	Score (max = 5)	Time (s)	Choice (max = 5)	Score (max = 5)	Time (s)	Choice (max = 5)	Score (max = 5)	Time (s)
WF	7.00	8.00	5.00	5.00	4.00	5.00	5.00	5.00	15.60	4.00	3.00	15.00	5.00	3.00	15.00
FC	7.00	6.00	5.00	5.00	4.00	5.00	5.00	5.00	5.00	4.00	5.00	5.00	5.00	5.00	5.00
RD	6.00	3.00	4.00	4.00	4.00	4.00	13.20	4.00	4.00	22.20	4.00	22.20	4.00	22.20	4.00
JC	7.00	6.00	6.00	6.00	3.00	3.00	5.00	5.00	12.20	5.00	5.00	24.20	5.00	5.00	24.20
ER	6.00	6.00	4.00	4.00	2.00	2.00	5.00	4.00	14.60	3.00	4.00	28.60	4.00	4.00	28.60

e.g. 'Because the policeman on his beat sees the burglar drop his glove'.

Cartoons

(1) Appropriate humorous inference choice,

e.g. 'The father hasn't seen the monster - he thinks his son is telling a joke!'

(2) Inappropriate inference choice,

e.g. 'The little boy is telling a joke about a monster with one eye and two horns!'

(3) Reference to a physical detail in the cartoon choice,

e.g. 'The little boy doesn't have a mouth, and the father has a silly face!'

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