

Thought-bubbles help children with autism acquire an alternative to a theory of mind



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ABSTRACT Children with autism have specific difficulties understanding complex mental states like thought, belief, and false belief and their effects on behaviour. Such children benefit from focused teaching, where beliefs are likened to photographs-in-the-head. Here two studies, one with seven participants and one with 10, tested a picture-in-the-head strategy for dealing with thoughts and behaviour by teaching children with autism about cartoon thought-bubbles as a device for representing such mental states. This prosthetic device led children with autism to pass not only false belief tests, but also related theory of mind tests. These results confirm earlier findings of the efficacy of picture-in-the-head teaching about mental states, but go further in showing that thought-bubble training more easily extends to children's understanding of thoughts (not just behaviour) and to enhanced performance on several transfer tasks. Thought-bubbles provide a theoretically interesting as well as an especially easy and effective teaching technique.

KEYWORDS
false belief;
mental states;
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The theory of mind hypothesis for autism proposes that a central cognitive deficit for individuals with autism is an impairment in using mental state concepts (Baron-Cohen, 1995; Baron-Cohen et al., 1985). Mental state

concepts, such as a person's beliefs, knowledge, desires, and intentions, ordinarily allow us to understand our own and others' lives ('She doesn't know the song'), to predict behaviour ('She'll sing the wrong tune'), to interact socially ('To make her happy I'll choose a different song'), and to communicate ('She doesn't know that song, I'd better tell her the words'). Difficulties in understanding and using mental state concepts may therefore underlie the difficulties in social interaction and communication in autism.

A key test of mental state understanding for normally developing children and those with autism concerns understanding false beliefs: when a person holds a false belief (e.g. *thinks* the ball is in the garage when it's really in the car), they will act on the basis of their misrepresentation rather than on the basis of reality. On a 'Sally-Anne' false belief task (e.g. Baron Cohen et al., 1985), for example, a doll character Sally puts her ball in a box. While she is away and can't see, her friend Anne moves the ball from the box to a basket. The child is asked where Sally will look for her ball (or, where will she think her ball is) upon her return. Most children with autism, with verbal and performance competencies greater than 4 years MA, fail such false belief tasks, whereas most normal 4-year-olds, comparison groups of children with Down's syndrome, general developmental delay, or specific language delays, pass them (e.g. Perner et al., 1989). Relatedly, most children with autism with mental ages well beyond 4 years have difficulties with tasks testing understanding of emotions, knowledge and ignorance, deception, and the mental-physical distinction, although these tasks are normally solved by 3- and 4-year-olds (Baron-Cohen, 1989; 1992; Baron-Cohen and Goodhart, 1994; Baron-Cohen et al., 1993). Importantly, the deficits shown by many children with autism on these tasks are not due to impaired understanding and reasoning more generally, but seem specific to understanding mental states. Consider the understanding of photographs and pictures by children with autism (Charman and Baron-Cohen, 1992; 1995; Leekam and Perner, 1991; Leslie and Thaiss, 1992). Studies have shown that although they perform badly on tasks requiring judgements of false beliefs (an outdated and hence mistaken belief), they show good performance on closely comparable tasks requiring judgements of 'false' photographs (an outdated and hence now incorrect photograph).

The theory of mind deficit for autism has inspired possible training interventions for children with autism. An initial group of studies essentially gave multiple trials with feedback on a target false belief problem (e.g. Hadwin et al., 1996; Ozonoff and Miller, 1995; Whiten, 1993). For example, Swettenham (1996) presented multiple trials of a computer generated Sally-Anne task, where correct answers received the feedback

that 'Yes, Sally would think her ball was in the blue box' and incorrect answers received the correction that 'Sally thinks the ball is in the blue box, because that is where she left it – try again'. With sufficient sessions children with autism largely learned to solve this computer problem and then correctly solved a parallel task with dolls similarly named Sally and Anne. However, these children then consistently failed several transfer tasks. Swettenham concluded that 'the follow-up results indicated that children with autism had simply rote learned the Sally–Anne task' and that 'one possibility was that children with autism learned a non-mentalist strategy during the instruction period (for example, "I will always look in the container where the ball is not hidden")' (1996, p. 163).

To overcome this problem, two recent studies have attempted to teach children with autism a more conceptually intriguing, picture-in-the-head strategy, to aid an understanding of mental states. Swettenham et al. (1996) and McGregor et al. (1998a) both used training sessions where photographs were slotted into a manikin's head or a doll's head and children were told, 'When a person looks at something, they make a sort of picture in their head'. Thoughts, including false thoughts, were thus portrayed as actual pictures inside a head. Swettenham et al. (1996) showed that children with autism could learn to pass a Sally–Anne false belief task via use of a picture-in-the-head strategy and then use it on one other theory of mind task. McGregor et al. (1998a) found similar promising results. But there were also crucial limitations. In the Swettenham et al. (1996) study, the pre- and post-test Sally–Anne tasks asked children only behaviour questions: 'Where will Sally look for the object?' This is typical for false belief tasks, especially those used to test individuals with autism. In the training, however, children were instructed both about behavioural predictions (where will Sally look) and about thought attributions (what will Sally think). All children made progress at behavioural predictions (indeed seven of eight passed the Sally–Anne post-test using 'where will she look' questions). But none made much progress at attributing thoughts (none of eight children were consistently successful in answering the training questions about Sally's thoughts). McGregor et al. (1998a) gave five post-test transfer tasks (tasks with varying degrees of difference from the training task itself) and compared performance for eight children with autism given the picture-in-the-head training versus eight untrained control children. Summed across all five of these tasks, control children gave 4 percent correct answers whereas experimental children gave 22 percent correct answers – a very modest level of post-test performance, but significantly better than controls. However, performance was significantly better on only one of the five individual transfer tasks.

In the present study we extend a general picture-in-the-head approach

using a very different pictorial analogy: thought-bubbles. Thought-bubbles arguably provide a particularly natural or effective way of depicting thoughts pictorially, one that could come to aid autistic individuals' reasoning about people, behaviour, and mental states. In particular, thoughts are representational mental states and thought-bubbles depict a person's thoughts in a straightforward representational fashion, as pictures. The theoretical rationale for using thought-bubbles is the same as that for a picture-in-the-head strategy more generally. The theory of mind hypothesis for autism targets improvements in understanding of mental states, especially representational mental states such as false belief, as especially important *and* especially problematic. Teaching an explicit compensatory strategy could help children with autism bypass their deficit in understanding mental states. Such a strategy should provide a device for thinking about thoughts, and to be most effective should be based on cognitive abilities or skills known to be intact in individuals with autism. Given the good understanding of photographic/pictorial representations that children with autism show, construing thoughts as pictures in the head could potentially provide a device for thinking about mental representation, and thus a compensatory strategy for reasoning more adequately about the role of representation in human action.

This theoretical rationale for exploring a picture-in-the-head strategy receives some indirect, empirical support from a study by Hulburt et al. (1994). They elicited reports of inner experience (sampled during everyday activities) from three individuals with Asperger syndrome. These individuals consistently described only their perceptions and actions, devoid of thoughts, emotions, or inner speech. To the extent that they described inner experiences at all, however, they described them solely in terms of pictures in their head. Typical controls described a complex mixture of inner speech, emotional reactions, mental images, and 'pure thought'. This research suggests that a picture-in-the-head analogy may be one that is arrived at on their own, to their benefit, by some high-functioning individuals with autism, in order to make some sense of mental life (see also Grandin, 1995).

The reasons for using thought-bubbles, as opposed to more literal pictures-slotted-in-head devices, are more pragmatic. Thoughts are *not* literally pictures inside the head, and neither are thought-bubbles shown as literally in the head, although they still pictorially capture something of thought's representational qualities. Thought-bubbles are somewhat naturally occurring in that they, and relatedly speech-bubbles, appear in comics, cartoons, and sometimes in children's books (Dyer et al., 2000). Moreover, 3- and 4-year-old normally developing children easily understand thought-bubbles as depictions of 'what the person is thinking', even

in the case of mistaken thoughts or two people having different thoughts about exactly the same object (Wellman et al., 1996).

Finally, in a recent study Parsons and Mitchell (1999) briefly instructed relatively high-functioning children with autism (mean MA = 5:7 for the 19 children ranging in age from 8:7 to 18:3 in their study 2) that a thought-bubble shows what a pictorialized story character is thinking, and then asked them what various characters were thinking for four further pictures of persons with thought-bubbles. These children were from 79 to 100 percent 'correct' in the sense of reporting the thought-bubble contents on the four test pictures. Then the children received four false belief tasks – two standard tasks and two where the protagonists' false beliefs were displayed in thought-bubbles. The children were 29 percent correct on the standard tasks and 45 percent correct on the thought-bubble tasks, a significant difference. Of course, these children's improved performance when thought-bubbles were present might stem from a lower level strategy of simply answering by 'reading off' the contents of the thought-bubble, as encouraged to do earlier. But, at the least, these data suggest that thought-bubbles provide a context for correct responses, responses that could then be shaped and elaborated in further instruction.

Based on these considerations – the theoretical justification of a picture-in-the-head strategy coupled with the possible effectiveness of thought-bubbles for depicting thoughts pictorially – our hypothesis was that thought-bubbles could be used to help children with autism develop a way to reason more usefully about people's thoughts. In keeping with prior studies we trained children on false belief reasoning, using a version of the Sally–Anne false belief task. We predicted that children with autism could develop correct reasoning on the Sally–Anne task itself as a result of suitable thought-bubble training. A second prediction was that thought-bubble training could aid correct answers about a character's thoughts (what does Sally think) not just her behaviour. A third prediction was that, potentially, a thought-bubble strategy could provide a more generalizable approach to reasoning about behaviour and mental states, as shown on several transfer tasks.

Study I

In an initial study we focused on developing a thought-bubble training regimen that might help children with autism reason about false beliefs, and on assessing its efficacy in a preliminary fashion on two transfer tasks. False belief tasks come in at least two different forms. One, as in the Sally–Anne task, focuses on false beliefs created by a change of location. A second, captured in classic Smarties® tasks (Perner et al., 1987), concerns

beliefs about unexpected contents (a Smarties® candy box that is opened to reveal pencils, not candy, in it). One post-test was thus a change-of-location false belief task, but using very different characters and materials from the Sally–Anne task used in training. The other post-test was a Smarties® false belief task.

Method

Participants

Seven male children with autism between the ages of 8 and 18 (mean age 11:2) participated; all met standard diagnostic criteria for autism (DSM-III-R, DSM-IV; American Psychiatric Association, 1987; 1994; Rutter, 1978) and all had been diagnosed in recognized hospitals or clinics by experienced clinicians. The children attended a school in Merseyside, England. Verbal mental age was assessed using the Test of Reception of Grammar (TROG; Bishop, 1983). All the participants involved in the study had mental ages above 4 years (range from 4:0 to 6:6 years, $M = 5:6$).

Materials and procedure

The materials and procedures for training were similar to those used in study 2, where they will be described in detail. Essentially, each child was trained with cardboard Sally–Anne figures (plus cardboard cutout objects and thought-bubbles) through a progression of five teaching stages, plus a sixth stage presenting children with Sally–Anne tasks using the same materials as in teaching but without any thought-bubbles:

- Stage 1: introducing thought-bubbles.
- Stage 2: thoughts about objects out of sight that remain as they are.
- Stage 3: thoughts about objects out of sight that are changed.
- Stage 4: thoughts about hidden objects that remain unmoved.
- Stage 5: false beliefs – thoughts about hidden objects that are moved.
- Stage 6: Sally–Anne tasks without thought-bubbles.

Children had to pass an earlier stage, according to various criteria, in order to advance to the next stage.

Teaching and testing were conducted individually, in a quiet room. Teaching required up to five sessions (depending on the child's rate of progress) of approximately 30 minutes per day. Sessions were always separated by at least a day (and sometimes two or three days if an activity or weekend intervened). More than one teaching stage might be covered in sequence in one day's session, or several sessions might be required for one stage (again, depending on the child's rate of progress). Training ended

after the fifth session, or earlier if the child reached stage 5 in fewer sessions. Most children (five of seven) were instructed for three or four sessions.

All children received the Sally–Anne test with cardboard figures without thought-bubbles and a Smarties® false belief task as a pre-test. They received two post-tests in their last session regardless of which stage they finished in their training: the Bears test (described below) and a Smarties® test.

Pre-tests and post-tests

The Sally–Anne task was modelled closely on that in Baron-Cohen et al. (1985) and described earlier. The Bears post-test was also a change-of-location false belief task, where one bear (George) hides a marble in a bag, and goes away while a second bear (Bertie) moves the marble to a box. Then George returns. Three questions were asked in these change of location tasks: (1) ‘Where does Sally/George think the object is?’ (thought question), (2) ‘Where will Sally/George look for the object?’ (behaviour question), and (3) ‘Where is the object?’ (reality control question). In the Smarties® task (Perner et al., 1987), the child sees a Smarties® tube and is asked what is inside. The child responds ‘Smarties’ or ‘candy’ and then is shown that in fact there is a paper clip inside. The child is then asked to name a friend (X) who has never seen this Smarties® tube before. The child is asked: ‘If we show this to X, what will X think is in here?’

The Bears task was designed as a ‘near’ transfer test and Smarties® as ‘further’ in format, questions and materials. The Bears task is different from the Sally–Anne task used in training (which made use of cutout cardboard pictorial people and objects to allow easy use of the thought-bubbles) in that none of the materials for the Bears task were pictorial: George and Bertie were stuffed teddy bears, who interacted with real bags, boxes, and marbles. The Smarties® task is an unexpected contents task and used only real objects and asked about the beliefs of real persons.

Results

Table 1 summarizes the data from the various phases of the study.

Performance during teaching

At the start of the teaching sessions each child was shown a picture of a person with a thought-bubble. At this point, several children said that the bubble showed talking; no child offered that the bubble was about thinking, dreaming, remembering or the like. During stage 1 all children easily came to understand the bubbles as thought-bubbles in the sense of saying that they showed what the person was thinking and using them to correctly answer the question, ‘What is Sally thinking about?’

Table 1 Summary of results by subject for study 1

Subject	Age (years:months)	MA	Pre-tests		Teaching: highest stage reached	Post-tests	
			Sally-Anne (correct/2)	Smarties® (correct/1)		Bears (correct/2)	Smarties® (correct/1)
1	10:2	6.0	0/2	0/1	Stage 6	2/2	0/1
2	8:8	5.5	0/2	0/1	Stage 3	2/2	0/1
3	8:6	4.0	1/2	1/1	Stage 6	2/2	1/1
4	11:10	5.75	0/2	0/1	Stage 3	0/2	0/1
5	13:5	6.0	0/2	0/1	Stage 6	2/2	0/1
6	13:3	5.0	0/2	0/1	Stage 6	2/2	0/1
7	18:8	6.5	1/2	1/1	Stage 6	2/2	1/1

The seven children advanced through the teaching stages at different rates and with different levels of success. All seven children proceeded at least as far as stage 3 which demonstrated and asked questions about Sally's thoughts and thought-bubbles of an object, when Sally could not see that the object was changed. Children required from one to three teaching sessions to get to these stage 3 concepts. Children received multiple stage 3 target questions about Sally's thoughts during their stage 3 question and feedback phases (as detailed below in study 2); they averaged 68 percent correct on these target questions (range 48 to 100%). They averaged 87 percent correct on their last three stage 3 trials (range 50 to 100%).

Five children advanced as far as stage 6, which presented multiple trials of the Sally–Anne false belief task, with no thought-bubbles. Each child was asked a thought and a behaviour question about Sally for each of these stage 6 trials. On average these children answered 94 percent of these thought and behaviour stage 6 questions correctly (range 74 to 100%). On their last three presentations of these questions in stage 6 they were 100 percent correct on the thought questions and 100 percent correct on the behaviour questions (as well as 100% correct on the reality control questions). These last three stage 6 trials can be compared to the pre-test Sally–Anne questions, since the children received the exact same test at both points. Average correct at pre-test was 14 percent; at stage 6 it was 100 percent ($t(4) = 6.53, p < 0.005$).

Pre-test and post-test results

At post-test, six of seven children passed the Bears test, by correctly answering both the thought and the behaviour questions (every child was correct on the reality control question). If the Sally–Anne pre-test is used for comparison, then there is a significant change from the average of 14 percent correct answers for the pre-test to the 86 percent correct answers for the parallel post-test Bears false belief questions ($t(6) = 4.80, p < 0.005$).

Two children correctly answered the Smarties® task false belief question. The same two children passed Smarties® at pre-test, however, so this represents no change.

Discussion

These data provide initial evidence for the efficacy of the method. In particular, they show that these children with autism could easily understand the basic concept of a thought-bubble, at least at some minimal level. All seven children consistently answered correctly to the questions about 'what is Sally thinking' when viewing thought-bubbles in stage 1, requiring at most one brief training session to do so. In this respect, our results complement and extend those from Parsons and Mitchell (1999). Similar

to their results, children were quickly able to use thought-bubbles to correctly answer questions about what a character was thinking. Again, such responses (in their study and in stage 1 here) could result from a low level strategy of simply reading off the contents of the bubbles themselves. However, in the present study children with autism were able to become even more competent at using thought-bubbles in stages 2 through 5. Indeed, these children with autism significantly improved on false belief reasoning on tasks that did not include thought-bubbles.

Study 2

The preliminary results required replication. In addition, over the course of the initial study we gained insight into how to better conduct such training. Finally, to assess the effects of training we considered it would be better to pre-test children on all post-test tasks and use a wider variety of pre-test and post-test tasks.

Method

Participants

Ten children with autism (nine male, one female) between the ages of 5 and 17 (mean = 11:2) participated, all of whom met standard diagnostic criteria in the same ways as did children in the preliminary study. Verbal mental age was again assessed using the TROG (Bishop, 1983). Verbal mental ages ranged from 4:0 to 8:0 years ($M = 4:11$). Eight children came from a school in Middlesex, England; two came from a summer program in Michigan, USA.

Materials

Materials for the Sally–Anne tests and the teaching stages used cardboard cutout Sally and Anne ‘dolls’, cardboard cutout objects (ball, boot, teddy bear, apple, hat, cake, bucket, tea cup), a ‘story board’ with a room and a flap door (so that if Sally was on the other side of the door, she couldn’t see the room), and a picture of a cardboard box and of a basket, both with a slot and a flap so that the cutout objects could be hidden inside. In addition, the training stages used cutout thought-bubbles showing pictures of the objects, or showing the box and the basket either empty or with an object inside.

The Bears task was essentially identical to that in the preliminary study and used two small stuffed teddy bears, a marble, a small box and a draw-string bag. Materials for the Smarties® false belief task used a Smarties® tube containing a large paper clip, or a Band-Aid® box containing a crayon.

The Seeing-Knowing task used two dolls of adult figures, one male, one female, and a small box.

Procedure

Teaching and testing were conducted individually, in a quiet room. All children received four pre-tests: (1) the Sally-Anne test with cardboard figures (without thought-bubbles), (2) a change-of-location false belief task using two stuffed bears, (3) a Smarties® false belief task, and (4) a Seeing-Knowing task (Baron-Cohen and Goodhart, 1994). They received the same four tasks as post-tests in a final session, regardless of which stage they finished in their training.

Pre-tests and post-tests

The Sally-Anne change-of-location false belief task using cardboard figures was conducted. Three questions were always asked: (1) 'Where does Sally think the object is?' (thought question), (2) 'Where will Sally look for the object?' (behaviour question), and (3) 'Where is the object?' (reality control question). In the Bears task, one bear (Jill) hides a marble in a bag and goes away, and while she is away a second bear (Bobby) moves the marble to a box. The same three questions were asked as in the Sally-Anne task. Because the Bears task was also a change-of-location false belief task, albeit with quite different materials, we considered it a 'near' transfer task.

The Smarties® task came in two varieties. For subjects in England a Smarties® tube with a paper clip inside was used. For subjects in the US a Band-Aid® box with a crayon inside was used. Otherwise procedures and questions were as in the preliminary study. Because training was exclusively in terms of change-of-location situations, this task represents a 'further' transfer task to a very different sort of false belief situation.

In the Seeing-Knowing task (Baron-Cohen and Goodhart, 1994) one doll looks into a box while a second doll does not look but touches the box. The child is then asked, 'Which one knows what is in the box?' Although the task concerns judgements about a person's mental states, the key issue is knowledge and ignorance, not false belief, and the terms 'think' or 'thought' are not used in the task descriptions or questions. Thus, Seeing-Knowing also represents a 'further' transfer test.

Teaching sessions

As in study 1, teaching itself took place for up to five sessions of approximately 30 minutes per day, depending on the child's rate of progress. Most children (eight of 10) were instructed for at least four sessions. Two children were available for a longer period and these two received eight sessions of teaching. Study 2 used more comprehensive and detailed

versions of essentially the same five teaching stages followed by a sixth stage with no thought-bubbles as used in study 1 (and as described below).

Teaching proceeded in order through the five teaching stages. Each stage consisted of demonstrations and then questions to check and practise the principles involved. A child was considered to have passed or understood a stage when he or she correctly answered that stage's target questions on three trials in a row or, for later stages, on at least three trials within a block of five presentations. At that point he or she was advanced to instruction at the next stage. Within this general procedure, several changes were made from study 1 to clarify the training topics. One change was that in study 2 if a child failed the test questions for a stage, we developed several alternative demonstrations to try to better convey the critical concepts. In study 1, children were simply given the same demonstration used initially. Additionally, we took care to more systematically tailor the contents and methods to each child's interests. For example, for one hyperlexic child we provided printed scripts for all the stage demonstrations so the child could read along. For another, who was greatly interested in trains, the focal objects became train carriages and thought-bubbles of trains.

Most children received information and questions from several successive stages in some session or another. Because our procedures were partly child-controlled, in the sense that children advanced to later stages only upon demonstrating mastery at the prior stage, children's progression through training was variable. Nonetheless, a typical progression of teaching for a child was as follows: stages 1 and 2 in session 1; stage 3 in session 2; stages 4 and 5 in session 3; stage 5 in session 4 (over sessions 3 and 4 the child failed to advance to stage 6 for three separate passes through stage 5, so teaching was ended). This progression was followed exactly by three children. Two others made similar progress but attained stage 6. Three children never got as far as stage 5. Finally, as noted earlier, because they were available, two children were engaged in teaching for eight sessions. One of these children had reached stage 4 by his fifth session and one had reached stage 5 by his fifth session. Both were taught on stage 5 concepts for sessions 6, 7 and 8; one never achieved full mastery of stage 5 and so did not advance to stage 6; one advanced to stage 6 late in his eighth session, but did not master it.

Stage 1: introducing thought-bubbles

Demonstration phase The adult demonstrated that people can get something like thought-bubbles in their heads when they look at things. For example: "This is Sally. Sally is LOOKING at a ball. So Sally gets a think-bubble with a ball in it [add appropriate thought-bubble]. That means Sally is

THINKING about the ball. When people LOOK at things, they THINK about them.' This demonstration was repeated at least three times.

Question and feedback phase On each of five trials with Sally looking at five different objects, the child was asked, 'What is Sally looking at?' and 'What is in Sally's think-bubble?' The correct thought-bubble was then shown, and the child was asked, 'What is Sally thinking about?' When the children correctly answered all questions for three objects in a row, they were advanced to stage 2. If they did not pass three in a row after five objects, they repeated the stage 1 demonstration phase, with further clarifications, before receiving the question and feedback phase again.

Stage 2: thinking about objects out of sight that remain as they are

Demonstration phase The adult showed that people can think about something which at the moment they cannot see. Three examples were shown of Sally looking at an object and getting a thought-bubble of it. The child was asked, 'What is Sally looking at?' and then 'What is in Sally's think-bubble?' Then Sally, with her thought-bubble, was moved out of the room, behind the door. 'Look, Sally's gone out of the room. And look, her think-bubble has gone with her. She can't SEE what's on this side of the door. But she can THINK about it with her think-bubble.'

Question and feedback phase Sally was shown looking at five different objects, and the child was asked: 'Can Sally see the object?', 'What is Sally thinking about?', 'What does Sally think is on the other side of the door?' The same procedures for advancing or repeating were used in this (and subsequent) stage(s) as in stage 1.

Stage 3: thinking about objects out of sight that are changed

Demonstration phase The adult introduced the idea that people's thoughts about the world depend on what they have seen, so if the world changes but a person does not see it change, their thought about the world stays the same. In these demonstrations, when Sally left the room (as in stage 2), the child was first asked: 'What does Sally think is on this side of the door?', 'Is she right?' (yes), 'But can Sally see what is on this side of the door?' (no). Then, as the adult changed the object in the room, the child was told: 'So if we take away X and put Y there instead, Sally can't see what we've done. Her think-bubble still has an X!', 'When Sally comes back into the room, she sees that her think-bubble is wrong. THEN she gets a new think-bubble of a Y [the thought-bubbles are changed over].'

Question and feedback phase Five trials of a changed object situation were used and the following questions were asked: 'What does Sally think is on the other side of the door?' (object 1), 'Can Sally see it?' (no), 'Is she right, will she see object 1?' (no, she's wrong, she'll see object 2).

Stage 4: predicting location of hidden objects that remain unmoved

Demonstration phase The adult illustrated the use of thinking to predict where an object will be in the future. Now, instead of a single object, there was a cutout box and a basket, which could contain the cutout object. The child was told thought-bubbles can aid behaviour: 'People can use think-bubbles when they want to find something. Look, Sally is putting her ball in the box. So she gets a think-bubble of the ball in the box [Sally goes out of the door, with think-bubble]. 'Sally can't SEE where her ball is. But she can THINK about it with her think-bubble. So when she goes back into the room, she knows where to LOOK for the ball.' Successful looking with thought-bubbles was demonstrated three different times with different objects.

Question and feedback phase Sally is shown outside the room, with a thought-bubble of an object in a container, on five different trials. Child is asked: 'Where does Sally think the object is?', 'Where will Sally look for the object?'

Stage 5: predicting location of hidden objects that are moved

Demonstration phase Thought-bubbles were used to show that if a person does not see the location of an object change they will think it is still in the last place they saw it, and so will be mistaken about the object's actual location. Thus, the situation in stage 4 was extended to include a new character, Anne, who moves the object from the box to the basket. Sally places her favourite toy in the box and the child chooses a thought-bubble that shows her current thought about where the toy is. Sally leaves and the child is asked: 'Can Sally see where the toy is?' (no). 'Where does Sally think the toy is?' (in the box). 'Where is it really?' (in the box). Then Anne moves the toy: 'Did Sally see what Anne did?' (no). 'So Sally's think-bubble still says the toy is in the box. But really it's in the basket! Sally will look for the toy in the place where she THINKS it is. She'll look in the box. But she's wrong, because the toy is really in the basket! Ha ha! Wasn't that a funny joke Anne played?'

Question and feedback phase Five similar situations, where the child is asked: 'Where is the ball?', 'Where does Sally think the ball is?', 'Where will Sally look for the ball?'

Stage 6: the Sally–Anne task without thought-bubbles

The Sally–Anne test was presented without thought-bubbles, as in the original pre-test. At the start the adult says the child is going to play the same game, 'but without pictures of the think-bubbles to help, since think-bubbles are really inside people's heads and cannot be seen'. Then the child received up to five Sally–Anne trials, with the same three target questions as in the pre-test: 'Where is the X?' (reality control), 'Where does Sally think the X is?' (thought question), 'Where will Sally look for the X?' (behaviour question).

Results

Table 2 summarizes the data for the several phases of this study. On the basis of their pre-test performances children formed two groups of five participants each. One group of five consistently failed the pre-test tasks (performing correctly on at most one of six target questions about mental states: mean correct = 10%), although performing correctly on all the associated control tasks. These subjects represent the strongest test of our teaching procedures and are presented in the top panel of Table 2. For the other group of five, performance was somewhat better on the pre-test, as shown in the bottom panel of Table 2. Each of these children, however, failed at least half of the six focal pre-test questions (mean correct = 28%). We included children who passed some pre-tests in case the teaching strategy's effectiveness was limited to individuals with some, as opposed to no, advance understanding of mental states.

Performance during teaching

At the start of the teaching sessions each child was shown a picture of a person with a thought-bubble. No child offered that the bubble was about thinking, dreaming, remembering or the like. In stage 1, within the space of one session, all children came to understand the bubbles as thought-bubbles in the sense of saying that they showed what a person was thinking and using them to correctly answer the question, 'What is Sally thinking about?'

As noted earlier, the 10 children advanced through the teaching stages at different rates and with different levels of success. Eight of 10 children proceeded at least as far as stage 3, which demonstrated and asked questions about Sally's thoughts and thought-bubbles of an object, when Sally could not see into the room and then the object in the room was changed. On average these children answered 68 percent of their stage 3 target

Table 2 Summary of results by subject for study 2

Subject	Age (years:months)	MA	Pre-tests				Teaching: highest stage reached	Post-tests			
			Sally-Anne (correct/2)	Bears (correct/2)	Smarties® (correct/1)	Seeing-KKnowing (correct/1)		Sally-Anne (correct/2)	Bears (correct/2)	Smarties® (correct/1)	Seeing-KKnowing (correct/1)
1	11:10	5.0	1/2	0/2	0/1	0/1	Stage 5	2/2	2/2	1/1	1/1
2	13:5	8.0	0/2	0/2	0/1	1/1	Stage 6	2/2	2/2	1/1	1/1
3	14:3	4.25	0/2	0/2	1/1	0/1	Stage 2	1/2	1/2	1/1	1/1
4	12:10	5.75	0/2	0/2	0/1	0/1	Stage 6	2/2	2/2	1/1	0/1
5	5:4	4.0	0/2	0/2	0/1	0/1	Stage 6	2/2	2/2	1/1	0/1
6	16:1	4.25	1/2	1/2	0/1	1/1	Stage 5	1/2	1/2	1/1	1/1
7	17:9	4.5	1/2	1/2	1/1	0/1	Stage 5	2/2	2/2	1/1	1/1
8	12:0	4.5	1/2	1/2	0/1	0/1	Stage 3	1/2	0/2	0/1	1/1
9	14:5	4.25	1/2	1/2	1/1	0/1	Stage 2	1/2	2/2	1/1	0/1
10	5:6	4.5	1/2	1/2	1/1	0/1	Stage 5	2/2	2/2	0/1	0/1

questions correctly (range 0 to 100%). They averaged 71 percent correct on their last three stage 3 trials (0 to 100% correct).

Pre-test versus post-test comparisons

Table 2 shows the results for all 10 children. Our hypothesis as to differences from pre- to post-test is clearly directional: we predicted improved performance due to the teaching sessions. Thus, our statistical comparisons are one-tailed, as appropriate (although almost all comparisons are significant two-tailed as well).

Children clearly improved on the Sally–Anne task itself. Across all 10 subjects, performances changed from 30 percent correct at pre-test to 80 percent correct at post-test ($t(9) = 4.53, p < 0.005$). Considering just those five subjects who were consistently incorrect on the pre-test, judgements went from 10 percent correct at pre-test to 90 percent correct at post-test ($t(4) = 11.50, p < 0.001$).

Across all four post-test tasks, children were asked three questions about the character's thoughts, two about behaviour ('Where will she look for her X?') and one about knowledge. Considering just the three thought questions, across all 10 subjects, judgements went from 37 percent correct at pre-test to 87 percent correct at post-test ($t(9) = 3.50, p < 0.005$). For just the five subjects who were consistently incorrect at pre-test, judgements on these thought questions went from 13 percent correct at pre-test to 93 percent correct at post-test ($t(4) = 6.00, p < 0.001$).

Children were taught with the Sally–Anne materials; excluding Sally–Anne tasks, children were asked four target questions across three transfer tasks. Considering all 10 children, judgements on these questions went from 28 percent correct at pre-test to 75 percent correct at post-test ($t(9) = 4.39, p < 0.005$). Considering just the five children who were consistently incorrect at pre-test, judgements on these questions went from 10 percent correct at pre-test to 85 percent correct at post-test ($t(4) = 4.75, p < 0.005$).

As outlined earlier, the Smarties® and Seeing–Knowing tasks can be considered 'further' transfer tasks in that they are quite different from the Sally–Anne change of location tasks used in training. Considering all 10 children, judgements on these tasks went from 30 percent correct at pre-test to 70 percent correct at post-test ($t(9) = 3.21, p < 0.01$). Considering just the five children who were consistently incorrect at pre-test, judgements went from 20 percent correct at pre-test to 80 percent correct at post-test ($t(4) = 2.71, p < 0.05$).

Finally, consider children's performance on each transfer task separately. Given the reduced data from considering single tasks at a time, we tested these comparisons only for the full sample of 10 children. On the Bears

task, performance went from 25 percent correct at pre-test to 80 percent correct at post-test ($t(9) = 3.50, p < 0.005$). On the Smarties® task performance changed from 40 percent correct at pre-test to 80 percent correct at post-test – an improvement that fell just short of conventional significance (binomial test, $p < 0.062$). On the Seeing-Knowing task, performances went from 20 percent correct at pre-test to 60 percent correct at post-test – an improvement that similarly fell just short of conventional significance (binomial test, $p < 0.062$).

In short, children improved with training. This improvement occurred on change-of-location tasks of the sort used during training. Crucially, the improvement also transferred to a battery of three increasingly different transfer tasks. This improvement was significant for all three tasks considered together, was significant for the change-of-location task considered separately, and was substantial for the unexpected contents task and a knowledge-ignorance task, although failing to reach conventional levels of significance in these two latter cases.

Discussion

Our results complement other recent picture-in-the-head training studies. Like the Swettenham et al. (1996) and McGregor et al. (1998a) studies, we found a picture-in-the-head strategy increased false belief understanding in children with autism with mental ages of 4 and older. In comparison to these other studies, however, our results demonstrate better and more generalized post-test performance. In study 2, children were 80 percent correct on the post-test composite of six target questions, a high level of performance as well as a significant improvement over pre-test. In addition, these children improved on each of the three transfer tasks and significantly so in one case. Moreover, in the current thought-bubble research, all children made substantial progress at answering questions about thinking during training. In both studies, all children passed the stage 2 or 3 thought questions at some point. Thus, when thought-bubbles were available these children were often successful at answering questions about Sally's thoughts. Further, on our post-tests children were significantly successful at answering thought questions (as well as behaviour questions) even though thought-bubbles were no longer available. The ability of many of these trained children to answer such thought questions in a variety of post-test contexts, evident in study 2, suggests that they were indeed adopting a more mentalistic strategy, probably the one instructed, which asked them to treat thoughts as thought-bubbles and thus pictures in the head.

We do not want to give the false impression that thought-bubble instruction works effectively or easily with all children with autism, or even all relatively able children with autism of the sort we worked with. Several

of the children we worked with learned very little. For several others, as noted, progress required creative tailoring to the child's skills, preoccupations, and limits (as well as teaching persistence). Instruction was particularly effortful and difficult with the two youngest children in study 2, whose abilities to attend to and benefit from instruction were less well developed than the older children of comparable MA. Moreover, we do not have follow-up data on any of the children from post-tests several weeks or months after training. Finally, our conclusions are limited by the small samples we have worked with. Nonetheless, across our two studies 14 of 17 children clearly improved from pre- to post-tests and some did quite well indeed. We think these methods thus warrant more intensive investigation and development in further research.

For further research, we hypothesize that thought-bubbles may have other advantages, beyond better transfer, over other picture-in-the-head approaches. Specifically, several of us have been involved in both the Swettenham et al. (1996) manikin study and the current research. It is our impression that the thought-bubble materials were easier to devise and use than the manikin materials, and the training seemed to go more quickly and smoothly in the thought-bubble case. Given that individuals with autism seem able to learn to use them, then, thought-bubbles may also be more versatile than the literal use of photographs in heads in the manikin procedure; specifically, thought-bubbles are more naturally occurring in that they, and relatedly speech bubbles, appear in comics, cartoons, and picture books.

This raises the issue of the generalizability of these techniques to real-life situations. It may be argued that a picture-in-the-head analogy, as instantiated in thought-bubbles, can be used to capture certain important aspects of belief and false belief (as demonstrated in our training protocols). It could also be used to capture aspects of seeing and knowing and of thus knowledge and ignorance (e.g. a person who sees and gets a thought-bubble versus one who does not and has a blank bubble), of memory and forgetting (a person who retains their thought-bubble versus a thought-bubble that fades), of mental imagery, and thus of at least one form of imagination (thought-bubbles of fictional, not real happenings). It remains to be seen if a more systematic, broad-ranging training regimen focusing on thought-bubbles could be developed, or if it could be acquired, employed in a variety of situations, and helpfully applied to everyday life by children with autism.

We want to emphasize that in our minds a picture-in-the-head intervention strategy does not attempt to target a normal developmental conception that children of autism fail to develop ('thoughts are pictures in the head'); nor do we claim that this understanding would somehow result in

a normal theory of mind being acquired by individuals with autism. (See McGregor et al., 1998b, however, for a stronger claim that training on a 'pictures-in-the-head' strategy may cause development of a normal theory of mind in people with autism.) Instead, we see this as an artificial prosthetic device that can be used to compensate for the lack of a larger mechanism for understanding in some ways and in some situations. Pictures in the head can serve as an analogy based on phenomena that individuals with autism understand well – physical photographs and pictures – to help reason about phenomena that they understand poorly – mental states and mental representations. Empirically, a picture-in-the-head strategy gives promise of being a useful and trainable reasoning device for children with autism to use in thinking about several aspects of mind and action. A thought-bubble approach to utilizing the general picture-in-the-head strategy seems particularly worthy of further development.

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