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Ambiguous figure perception and theory of mind understanding in children with autistic spectrum disorders

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Researchers in early social-cognition have found that the ability to reverse an ambiguous figure is correlated with success on theory of mind tasks (e.g. Gopnik & Rosati, 2001). The present experiment examined children with autistic spectrum disorders (ASD) without mental delay to see whether a similar relationship existed. Ropar, Mitchell, and Ackroyd (2003) demonstrated that children with ASD with mental delay were impaired on theory of mind tasks, but were as likely as mentally delayed controls to generate both interpretations of an ambiguous figure when informed of its ambiguity. The present study replicated this finding on children with ASD without mental delay. However, overall perception of ambiguous figures was different. These children were less likely to spontaneously generate both interpretations of the figure, and more likely to perseverate on a single interpretation than the comparison children. Like Ropar *et al.*, we found no correlation between theory of mind and informed reversals, but spontaneous reversals were correlated with performance on an advanced theory of mind task. These data suggest that reversals of ambiguous figures are linked to higher-level representational abilities, which might also be involved in social functioning, and impaired in children with ASD.

Recent research suggests that most typically developing 5-year-olds recognize that others have internal mental states such as beliefs, desires, intentions, and emotions (Wellman, Cross, & Watson, 2001). Children with autistic spectrum disorders (henceforth ASD) often perform poorly on tasks in which they have to judge what another person is thinking (Baron-Cohen, Leslie, & Frith, 1985). Further, these children have difficulty with tasks that require knowledge of other mental states, such as tasks involving deception (Sodian & Frith, 1992), tasks involving understanding other emotions (Capps, Yirmiya, & Sigman, 1992), and tasks that measure the spontaneous production of mental and emotional state terms in narrative (Tager-Flusberg, 1993). As a result, children with ASD are often characterized as being impaired in such aspects of social functioning (see, e.g. Baron-Cohen, 1995; Leslie & Roth, 1993).

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Is this social functioning deficit exclusively social, or is it indicative of a broader representational deficit? Several researchers have examined children with ASD's representational abilities in non-social domains. For example, Reed and Peterson (1990) found no difference between a group of children with ASD and a typically developing group on Level 1 and Level 2 visual perspective taking tasks (Flavell, Everett, Croft, & Flavell, 1981). However, Reed and Peterson did find that their target sample had difficulty with conceptual perspective-taking tasks, such as a simple unexpected transfer task (Baron-Cohen *et al.*, 1985). This suggests that children with ASD specifically have exclusive difficulty with social functioning.

Other researchers have found impaired performance on children with ASD's representational abilities in other, non-social domains. Baron-Cohen (1989) demonstrated that children with ASD have difficulty on tasks that require an understanding of the mind, but not necessarily social functioning. Following Wellman and Estes (1986), he demonstrated that these children claimed that a character who was thinking about a biscuit, but did not actually have one, could both touch and eat his thought about the biscuit. These children also had difficulty with appearance-reality tasks (e.g. Flavell, Green, & Flavell, 1986). This suggests that children with ASD have difficulty understanding cases in which they have to keep track of multiple representations, regardless of whether those representations are about others' social cognition.

To explore this question further, we examined how children with ASD without mental delay perceived ambiguous figures, such as Fig. 1. In order to recognize that an ambiguous figure has two interpretations, a perceiver must discern two different representations of the same object. Further, in order to reverse an ambiguous figure, a perceiver must be able to shift between those two representations. Since ambiguous figures are novel non-social stimuli, it is likely that their perception taps how children with autism process stimuli that can give rise to multiple representations.

Perception of ambiguous figures has been found to correlate with typically developing children's performance on theory of mind tasks (Gopnik & Rosati, 2001; Rock, Gopnik, & Hall, 1994). When shown ambiguous figures, 3- and 4-year-olds never generated both interpretations spontaneously. However, some children claimed that they could perceive both interpretations after being informed of the figure's ambiguity and the second interpretation. Importantly, children who passed a standard 'deceptive container' theory of mind task (Gopnik & Astington, 1988) were more likely to be able to make a reversal than children who did not. Mitroff (Mitroff, 1998; cited in Gopnik, Capps, & Meltzoff, 2000) found that 5- to 9-year-olds would spontaneously generate both

Figure 1. The duck–rabbit ambiguous figure used in experiment.

interpretations of ambiguous figures, and those that did were more likely to pass a higher-order theory of mind task (e.g. Perner & Wimmer, 1985).

The correlation between ambiguous figure perception and theory of mind success might seem odd at first, since theory of mind typically involves inferences about the mental states of others, whereas reversing an ambiguous figure involves only a particular awareness of first-person phenomenology. There are, however, other examples in the literature of these relations. For example, success on false belief tasks is correlated to success on a representational change task, which involves reporting one's own immediate past beliefs (Gopnik & Slaughter, 1991). Understanding that one's beliefs can change does not seem to be a matter of inference. Rather, it seems just as immediate as our experience of changing perceptions, much as in the case of perceiving both interpretations of an ambiguous figure. This suggests that there might be a relation between the ability to infer the mental states of others and the ability to have certain kinds of related first-person phenomenological experiences, such as the experience of reversal (see Gopnik, 1993, for further discussion).

There is one study of ambiguous figure perception by children with ASD. Ropar, Mitchell, and Ackroyd (2003) presented ambiguous figures to a sample of children with ASD with mental delay. They suggested that the correlation between ambiguous figure perception and theory of mind found in previous research was spurious. Using Gopnik and Rosati's (2001) interview, they found that these children could produce both interpretations of an ambiguous figure when prompted, which was no different from a MLD comparison sample. Children with ASD were impaired in their performance on a theory of mind task, unlike the MLD comparison group.

The present data attempt to expand on the Ropar *et al.* (2003) findings in two ways. First, Ropar *et al.* examined a relatively low-functioning sample (Mean CA = 12;7, Mean VMA = 7;8). It is possible that these children simply lacked appropriate verbal abilities to succeed on standard theory of mind tasks. Several researchers have pointed out that high-function children with ASD do succeed on first-order, and even higher-order, theory of mind measures (e.g. Bowler, 1992; Happe, 1994). If a deficit in understanding the representational nature of the world is a characteristic of ASD, then these children might appreciate others' false beliefs through a different process than typically developing children. Frith and Happe (1994, 1999) have suggested that instead of being able to comprehend mental experience as it unfolds, these individuals perform a more effortful *post hoc* analysis. While some children with ASD without mental delay are successful on standard theory of mind tasks, their success might be indicative of effortful inferences about learned associations, rather than natural, automatic processing of others' mental states. Examining their perception of ambiguous figures allows us to directly measure their on-line mental experience. If children with ASD have a difficulty introspecting on their own mental states, one might expect their ability to perceive and reverse these figures to differ from that of comparison children.

That difference might come from an investigation of children with ASD's spontaneous reversals of ambiguous figures. Following Gopnik and Rosati's (2001) investigation of 3- to 4-year-olds, Ropar *et al.* (2003) only investigated children's informed reversal. In fact, the one target child who seemed to generate a spontaneous reversal was excluded from the analysis. The second way in which the present data sought to expand on Ropar *et al.*'s findings was to examine children's spontaneous reversals, and the relationship between those reversals and higher-order theory of mind measures. This is especially important when examining an older group of children, as in the present sample. It may be that there are no group differences regarding the more simple abilities, such as informed reversals and performance on first-order theory of mind tasks, but that correlations would appear in the more conceptually advanced tasks.

EXPERIMENT

Children with ASD without mental delay and age- and verbal-IQ-matched comparison children were presented with an ambiguous figure interview similar to that used by Gopnik and Rosati (2001). In addition, children were presented with the Perner and Wimmer (1985) 'ice cream task' as a measure of their second-order theory of mind abilities, and, if successful on this task, Happe's (1994) 'strange stories'. This measure considered children's understanding of various forms of non-literal communication, such as jokes, lies, irony, and sarcasm, and their understanding of the motivations behind such practices.

The present experiment examined whether children with ASD and a comparison sample matched on age and verbal IQ would reverse ambiguous figures, with and without being informed of the figures' ambiguity. Further, would their perception of ambiguous figures relate to performance on theory of mind tasks and, if so, would the strength of the correlations be similar to those found in the comparison children?

Method

Participants

The sample included 25 children diagnosed with ASD, but without mental delay (henceforth target children), and 22 typically developing children (henceforth comparison children). Target children were recruited through non-affiliated clinicians at hospitals in two urban areas. Diagnoses were confirmed using the Autism Diagnostic Interview – Revised (ADI-R; Le Couteur *et al.*, 1989), which generates diagnoses based on DSM-IV criteria. Nine target children met diagnostic criteria for autism, and each had received a prior diagnosis of autism. Sixteen children reportedly suffered early and ongoing social and communicative deficits and the restricted/repetitive behaviours that characterize autism, but did not unequivocally manifest language delays; therefore, they met criteria for Asperger's syndrome.[1]

Comparison children were recruited from local schools and recreation programmes in the same urban area. Table 1 shows ages and WISC-III scores (Wechsler, 1974) for both groups. We only included children with verbal IQ and full – scale IQ scores higher than 80 in the study. This cut-off ensured that no child had a mental delay. None of the comparison children had a prior psychiatric history, and none were being treated for a psychological difficulty of any kind. In addition, the presence of a pervasive developmental disorder was ruled out using a parent-report questionnaire, the Pervasive Developmental Disorder Screening Test (Siegel, 1996). All participants received $10 per hour for their participation.

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[1] *High-functioning autism and Asperger's disorder are distinguished in DSM-IV based on the presence of delayed communication, including some combination of the following: delayed language, stereotyped language use, inability to carry on a conversation in the presence of adequate speech, and lack of imaginative play. Children with Asperger's disorder do not manifest delayed language despite the presence of idiosyncratic language use. As with typically developing children, children with Asperger's disorder use single words communicatively by age 2 and phrases by age 3 (American Psychiatric Association, 1994).*

Table 1. Summary data for participants

Group	Age	FSIQ	VIQ	PIQ
Comparison ($N = 22$)	10.39[a] (1.15)	108.68[b] (7.75)	108.00[a] (9.81)	106.73[b] (8.44)
Target ($N = 25$)	10.74 (2.44)	101.76 (13.54)	104.64 (15.75)	98.12 (13.03)

Notes. Standard deviations given in parentheses.
[a] Comparison group not significantly different from target group, $p > .10$.
[b] Comparison group significantly different from target group, $p < .01$.

The comparison children were recruited to be group-matched on chronological age, gender, and verbal IQ scores. We felt justified matching children on verbal IQ scores only because VIQ is the best predictor of children with autism's success on theory of mind tasks (Happe, 1998), and relations between these two domains (language and theory of mind) have been found in both the social-cognition literature and the language development literature (see Ozonoff, Pennington, & Rogers, 1991, for a discussion of age and verbal IQ matching in studies of high-functioning autism). Table 1, however, indicates that the target children's mean FSIQ and PIQ were below the comparison group. As a result, in the subsequent analyses, we will covary out these factors.

Materials

Children were presented with three ambiguous figures (an example is shown in Fig. 1), each on a standard 20 × 28 cm sheet of white paper. Some children were also shown a subset of six unambiguous figures (see Fig. 2). There were two unambiguous figures per page, one for each interpretation of the ambiguous figure. The ambiguous figures used were the duck – rabbit (shown in Fig. 1), the man – mouse, and the vase – two faces.

The theory of mind task was based upon Perner and Wimmer's 'ice cream task' (1985). In this task, a model village was erected on a wooden board approximately 30 × 53 cm. The park was located in one corner. The church was located on the opposite side of the board. Mary's house was located in the middle. The park consisted of an area painted green covered with five small wooden trees. 'John' and 'Mary' were represented by wooden dolls approximately 4 cm tall. A 4 × 2 cm ice cream truck was also used.

The 'strange stories' were each presented on a standard 20 × 28 cm piece of white paper in a three – ring binder.

Procedure

Each child was interviewed in a private room at the laboratory or tested in a private area in their home. The testing was administered over two sessions. In the first session, children received the ambiguous figure interview and the ice cream task. After this, they were also tested on the WISC-III to evaluate their IQ scores. In the second session, they were tested on the strange stories, along with several other unrelated experiments. The procedures for each individual task are described below.

Ambiguous figures

Children received an interview similar to that of Gopnik and Rosati (2001). Children were shown the figures one at a time. The experimenter told the child to look at the

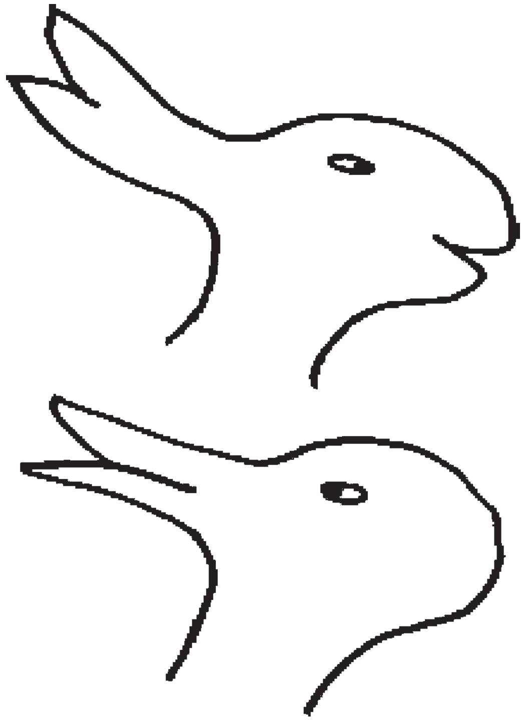

Figure 2. Unambiguous interpretations of the duck–rabbit ambiguous figure used in the experiment.

picture and asked the child, 'What is this a picture of?' After the child responded, s/he was encouraged to continue to look at the image for 10 seconds. After 10 seconds, the child again was asked, 'What do you see?'.

If the child generated both interpretations of the figure, s/he was asked to point to specific parts of each interpretation (e.g. the rabbit's ears, or the duck's bill). If the child did not generate both interpretations of the figure, the experimenter then asked the child if there was anything else the figure could be a picture of. If the child still did not generate both interpretations of the figure, the experimenter suggested the other interpretation and showed the child the two unambiguous pictures. The child was then asked if the ambiguous figure could be like the interpretation they did not generate, as in the unambiguous picture. If the child assented, the experimenter asked the child to point to the various parts of the two alternate interpretations on the ambiguous figure. If the child did not, the experimenter suggested that the ambiguous figure actually could be the second interpretation. Importantly, no child generated an interpretation of the ambiguous figures that was not a synonym of one of the interpretations (e.g. 'rat' for the man–mouse), a member of the same basic-level category (e.g. 'goose' for the duck/rabbit), or an unambiguous basic level category (e.g. 'bird' for the duck–rabbit).

Finally, each child was again shown the ambiguous figure (without the unambiguous versions visible). The experimenter suggested the reversibility by saying, 'It's funny. When I look at this picture, sometimes it flips back and forth from a [duck] to a [rabbit] and from a [rabbit] to a [duck]. Can you look at the picture and tell me if that happens for you?' Children were given a brief delay to respond (up to 10 seconds).

Children received the interview for all three ambiguous figures, always in the order: duck/rabbit, man/mouse, vase/faces.

Ice cream task

The script for the ice cream task (shown in Appendix) was taken directly from Perner and Wimmer (1985). Children were shown two characters, John and Mary, and in order to succeed, they had to make a prediction based on what John was thinking about what Mary was thinking. During the course of the story, children were asked control questions to see if they followed the story. Feedback for these questions was given. Feedback was not given for the test question, or the two control questions at the end.

Strange stories

Children were told that the experimenter was going to read them some stories. These stories were taken directly from Happe (1994). They were each about a character engaged in a particular social activity that had a literal or non-literal interpretation. For example, in one story, a character was said to have a frog in his throat. Other stories were about characters engaging in pretence or a white lie, thinking or speaking metaphorically, dressing up in costumes, and double bluffing. Following Happe, at the end of the story, the child was asked two or three questions. The first question was always of the form, 'Was it true, what [the character] said?'. The second was 'Why did [the character] say that?'. Positive comments were made throughout the testing, but no feedback as to the validity of the answers was given. Children were read 12 stories. Only children who passed the ice cream task were given the strange story task.

Coding

On each ambiguous figure, if children reported seeing both interpretations of the picture before being shown the unambiguous pictures, they were coded as spontaneously reversing the figure. If children only reported reversals after they were informed about the ambiguity and shown the unambiguous pictures, they were coded as making an informed reversal. Finally, children who did not report that the ambiguous figure could be both interpretations were coded as making a single interpretation. Further, to be coded as making a spontaneous or an informed reversal, the child had to agree that the interpretation of the figure could flip from one to the other.

For the ice cream task, children were scored as passing if they indicated that John would think Mary was at the park, and correctly justified this response using an explanation that appealed to his mental states (what Bowler, 1992, would call a first- or second-order justification).[2]

Performance on each strange story was coded using a slightly different system from Happe (1994). If the child generated the correct answer to the truth question and explained their answer referring to the social process involved, they received full credit and a score of 2. If the child generated the correct answer, but explained their answer by

[2] *We did not code the distinctions between first and second-order justifications according to Bowler's (1992) scheme. Bowler found relatively few differences between children with ASD generating first- and second-order justifications. Since children who succeeded on the ice cream measure were given the strange stories, we felt that breaking up the data further would have added an unnecessary level of complexity to the results.*

referring to incorrect mental or social processes or to the perceptual features of the story, they received partial credit and a score of 1. If the child generated the incorrect answer, explained their correct answer referring to no mental or social process, or said, 'I don't know', they received no credit and a score of 0. Children's scores were summed, yielding a score from 0 to 24. All of the stories were coded by the first author based on transcriptions that did not reveal diagnosis group or performance on the ambiguous figure interview. Eight children in each diagnosis group were also coded by an undergraduate assistant, blind to diagnosis, performance, and the hypotheses of the investigation. Overall, agreement on the two sets of scores for these 192 stories was approximately 95% ($\kappa = .87$). Disagreements were resolved by the first author.

Results

Table 2 shows children's performance on the ambiguous figures interview, ice cream task, and strange stories as a function of their diagnosis group. Comparison children scored higher on all three tasks. Since the target and comparison groups differed in FSIQ and PIQ scores, and since VIQ often predicts success on theory of mind measures, we analysed all the data with hierarchical regressions or partial correlations that first factored out the combined effects of children's VIQ, PIQ, and FSIQ scores.

Table 2. Performance of children on tasks as a function of diagnosis group

Group	Spontaneous[a]	Informed[a]	Single[a]	Ice cream[b]	Strange stories[c]
Comparison	31/66 (47)	35/66 (53)	0 (0)	22/22 (100)	19.50 ($N = 22$; 2.82)
Target	19/75 (25)	50/75 (66)	6/75 (8)	19/25 (76)	15.39 ($N = 18$; 3.96)

[a] Number of responses, percentage in parentheses.
[b] Number of children passing, percentage in parentheses.
[c] Overall score (out of 24), standard deviation in parentheses.

First, we analysed the difference between the groups on the ice cream task. All of the comparison children passed the ice cream task, while only 76% of the target children did so, $\chi^2(1) = 6.05$, $p < .05$. A hierarchical regression indicated that the combined IQ score did not significantly predict the variance, $\Delta R^2_{\mathrm{IQ}} = .09$, $F(3, 43) = 1.40$, *ns*.[3] Diagnostic group did predict a significant amount of the variance when it was next entered into the model: $\Delta R^2_{\mathrm{group}} = .13$, $F(1, 42) = 7.27$, $p = .01$.[4]

Only children who passed the ice cream task were subsequently given the strange story task. However, due to experimental error, one target child was not administered the task. Thus, all 22 of the comparison children and 18 of the target children were given the strange stories task. Comparison children scored higher on the strange story task than did target children, mean score of 19.50 versus 15.39, $t(38) = 3.79$, $p < .005$. The subgroup of target children under consideration did not differ from the comparison

[3] *Throughout the remainder of the paper, we will use the notation R^2_{IQ} to indicate the combined effect of FSIQ, PIQ, and VIQ in the regression analysis.*
[4] *One concern with this analysis is that the independent variable (i.e. success on the ice cream task) is categorical. However, Keppel and Zedeck (1989) suggest this treatment is mathematically equivalent to an analysis of covariance. For consistency, we will present all the remaining analyses in this manner.*

children in age (11.14 vs. 10.39, $t(38) = 1.18$, $p = .245$), verbal IQ (106.22 vs. 108.00, $t(38) = 0.42$, $p = .674$), or full-scale IQ (102.83 vs. 108.68, $t(38) = 1.58$, $p = .122$). Hierarchical regression indicated that the IQ scores did not significantly predict the variance, $\Delta R^2_{IQ} = .05$, $F(3, 36) = 0.70$, *ns*. Diagnostic group did predict a significant amount of the variance when it was next entered into the model, $\Delta R^2_{group} = .29$, $F(1, 35) = 15.32$, $p < .001$.

Responses to the three ambiguous figures were first analysed to examine whether there was a difference in responses among the figures. A χ^2 analysis among the three response type (spontaneous reversal, informed reversal, and single interpretation), and the three figures revealed no significant differences, $\chi^2(4) = 7.75$, *ns*. Target children showed a different overall pattern of responses on the ambiguous figures interview than the comparison children, $\chi^2(2) = 10.10$, $p < .005$. Target children made fewer spontaneous reversals than did the comparison children, 27% compared to 50%, $\chi^2(1) = 7.18$, $p < .01$, and more single interpretations than did comparison children, 7% compared to none, $\chi^2(1) = 5.52$, $p < .05$. Target and comparison groups did not differ with respect to their number of informed reversals, but there was a trend for target children to make more informed reversals than comparison children, 66% compared to 50%, $\chi^2(1) = 2.73$, $p < .10$.

This analysis was supplemented by a hierarchical regression analysis on the number of spontaneous reversals made by each group. On average, comparison children spontaneously reversed 1.41 out of the three ambiguous figures, significantly more than the 0.76 figures spontaneously reversed by the target children, $t(45) = 2.30$, $p < .05$. Hierarchical regression analysis revealed that IQ scores did predict a significant amount of variance in children's spontaneous reversals, $\Delta R^2_{IQ} = .22$, $F(3, 43) = 4.12$, $p < .05$. However, diagnostic group predicted a significant amount of the variance beyond the effect of IQ, $\Delta R^2_{group} = .07$, $F(1, 42) = 4.20$, $p < .05$.

Similarly, target children tended to make more single interpretations (on average 0.24 times out of a possible 3) than the comparison children, who never made a single interpretation, $t(45) = -1.88$, $p < .07$. In particular, four target children generated at least one single interpretation. These four children did not differ in PIQ scores from the other target children (mean of 96.25 vs. 98.48), but did appear to have lower FSIQ and VIQ scores (mean of 95.75 vs. 102.90 for FSIQ, and 96.00 vs. 106.29 for VIQ). Because of the small sample size, these comparisons were not significant. These four children did not come from a particular diagnostic subgroup. Two of them were diagnosed with Asperger's syndrome. The other two received a diagnosis of autism. Regression analysis, however, revealed that the trend between the diagnostic groups was not mediated by IQ scores. IQ did not predict a significant amount of variance, $\Delta R^2_{IQ} = .05$, $F(3, 43) = 0.87$, *ns*. The effect of diagnostic group after the three IQ scores were entered into the model was still a non-significant trend, $\Delta R^2_{group} = .07$, $F(1, 42) = 3.29$, $p < .08$. No difference between the average numbers of informed reversals was found between the two groups.

The relationship between perception of ambiguous figures and theory of mind was then examined. Since all of the comparison children passed the ice cream task, only the target children were considered. No relationship between spontaneous or informed reversals and success on the ice cream task was found. Children who failed the ice cream task, however, did show a different pattern of single interpretations from children who succeeded on the ice cream task, $\chi^2(2) = 7.25$, $p < .05$. In particular, all target children who generated more than one single interpretation failed the ice cream task.

Strange story performance was then examined. Table 3 shows the partial correlations between target children's performance on the strange stories and their perception of ambiguous figures, controlling for verbal, performance, and full-scale IQ scores. Table 3 also shows similar correlations for the comparison children. No relationship between spontaneous reversals and strange stories performance was found for the comparison children. In contrast, spontaneous reversals made by comparison children were more influenced by their IQ scores than by performance on a social functioning measure.[5]

Table 3. Partial correlations between strange story score and ambiguous figure reversals controlling for IQ scores in the target and comparison children

	Number of informed reversals	Number of spontaneous reversals	Number of single interpretations
Target children			
Strange story score	−.633	.527	.468
p value (*df* = 13)	*p* = .011	*p* = .044	*p* = .079
Comparison children			
Strange story score	−.001	−.001	Not computable
p value (*df* = 17)	*p* = .99	*p* = .99	

Notes. Correlation for single interpretations for comparison children was not computable because no comparison child made a single interpretation.

Strange story scores did predict how target children perceived the ambiguous figures. Table 3 shows that higher strange story scores correlated with more spontaneous reversals. A hierarchical regression analysis on the target children revealed that strange story scores did predict a significant amount of the variance in spontaneous reversals after the three IQ scores were partialled out, $\Delta R^2_{IQ} = .32$, $F(3, 14) = 2.18$, *ns*; $\Delta R^2_{ss} = .19$, $F(1, 13) = 4.99$, $p < .05$. Table 3 also shows that higher strange story scores correlated with fewer informed reversals. A hierarchical regression analysis on the target children revealed that strange story scores did predict a significant amount of the variance in informed reversals after the three IQ scores were partialled out, $\Delta R^2_{IQ} = .233$, $F(3, 14) = 1.42$, *ns*; $\Delta R^2_{ss} = .307$, $F(1, 13) = 8.69$, $p < .05$. Table 3 also shows that the correlation between single interpretations and higher strange story scores tended towards significance. However, this trend is slightly misleading, since it is based on only two data points. Two of the children who generated single interpretations failed the ice cream task, and were not included in this analysis. One of the other two, however, did have the highest strange story score among the target children, and this child made two spontaneous reversals and one single interpretation. In general, however, target children showed a relationship between a more advanced theory of mind task and their spontaneous reversals, beyond that of IQ.

[5] *Such a finding is not completely surprising, given the presumption that all typically developing children eventually succeed on theory of mind tasks. Holt and Matson (1974) found that IQ predicted the number of Necker cube reversals in children between the ages of 7 and 10.*

Discussion

Children with ASD without mental delay were as capable as age- and verbal-IQ-matched comparison children at reversing an ambiguous figure when informed about both interpretations. This parallels a previous study on perception of ambiguous figures by children with ASD and mental delay (Ropar *et al.*, 2003). However, in the present study, target children were less likely than the comparison children to reverse these figures spontaneously, and were more likely to fixate on a single interpretation. Since the target and comparison groups were only matched on verbal IQ, and not on performance or full-scale IQ, further correlation analysis revealed that these differences held when controlling for these variables as mediators. Finally, the target children showed a positive correlation between spontaneous reversals and performance on a higher-order social functioning measure (the strange stories task) beyond simple IQ effects, and an inverse correlation between informed reversals and this social functioning measure.

One concern with the observed difference between target and comparison children's spontaneous reversals comes from the overall number of spontaneous reversals made by the comparison children. Comparison children made a spontaneous reversal 47% of the time. Previous research on young children suggested that no 3- to 4-year-olds made such reversals, while previous research on adults suggested that observers would make spontaneous reversals between 25% and 40% of the time (Girgus, Rock, & Egatz, 1977; Rock, Hall, & Davis, 1994; Rock & Mitchener, 1992). Further, Mitroff (Mitroff, 1998; cited in Gopnik *et al.*, 2000) demonstrated that approximately 35% of 5- to 9-year-olds would spontaneously reverse an ambiguous figure. The present data show a slightly higher pattern of performance. This elevated performance level does open up the possibility that they have seen these figures before, especially the popular duck–rabbit and vase–faces figures. However, children did not generate spontaneous reversals on those figures more often than the relatively unpopular man–mouse, so we do not suspect this was the case.

The correlation between ambiguous figure reversals and the social functioning measure suggests a relationship between these two abilities in the target children. What is the nature of that relationship? One possibility is that a single cognitive ability is responsible for spontaneous and informed reversals and theory of mind performance. For example, researchers have suggested links between executive functioning abilities and theory of mind in typically developing preschool-aged children (e.g. Carlson, Moses, & Hix, 1998). Some have suggested that children with ASD's social functioning deficits result from a broader deficit with executive functioning, control, and cognitive flexibility (Courchesne *et al.*, 1994; Hughes, 2001; Ozonoff & McEvoy, 1994; Russell, Saltmarsh, & Hill, 1999). A strong version of this hypothesis, however, seems to incorrectly predict that target children would never spontaneously reverse an ambiguous figure.

A more plausible version of this hypothesis suggests that executive function and theory of mind abilities are correlated and impaired in target children. On this interpretation, children with ASD would make fewer spontaneous reversals and more single interpretations, and individual performance would vary as a function of their social functioning. This is exactly the pattern of data found.

Neuropsychological data are also relevant here. Ricci and Blundo (1990) found that patients with frontal lobe damage had more difficulty perceiving both interpretations of an ambiguous figure (including all three of the figures used in the present experiment) than either patients with posterior brain damage or age- and IQ-matched controls. They also found a significant correlation between the number of prompts necessary to get these patients to reverse the figures and the number of preservation errors these patients made on the Wisconsin card sorting task. Likewise, Meenan and Miller (1994) found that patients with right frontal lesions were significantly impaired in recognizing both interpretations of an ambiguous figure. These studies suggest that the frontal region, which is often impaired in children with ASD (see e.g. Baron-Cohen *et al.*, 1994), plays an important role in visual perspective shifting and executive functioning.

Although the executive functioning hypothesis is consistent with the present data, one extension of it is problematic. In a longitudinal study, Ozonoff and McEvoy (1994) demonstrated that children with ASD do not improve on executive function tasks. Over time, however, their performance on social functioning tasks does improve. If target children's difficulties with theory of mind are rooted in understanding the executive structure of these tasks, then one would expect that performance on theory of mind tasks would not improve as well. This sheds some doubt on the idea that a deficit in executive function ability is the sole cause of target children's difference in perception of ambiguous figures (see also Perner & Lang, 2000).

An alternative interpretation of the correlation between social functioning and ambiguous figure reversal is that children with ASD have a general representation deficit, which mediates both their on-line perception of their mental states and their ability on social functioning tasks (as suggested by Frith & Happe, 1999, and indirectly by Gopnik *et al.*, 2000). One difficulty in making this conclusion, however, is the growing line of research suggesting that children with ASD's impairments on social functioning tasks are not due to the representational nature of these tasks (see e.g. Baron Cohen, 2000). One example is that children with ASD often show spared performance on the 'false photograph test' (Leekam & Perner, 1991; Leslie & Thaiss, 1992). In this task, a photograph of a scene is taken using a Polaroid camera. While the picture is developing, the experimenter moves an object in the scene, thus rendering the photograph out of date. Children with ASD, however, correctly report that the photograph will not contain the object in its new location, but rather in its former one. These findings suggest that removing the social aspect of the task is critical to children with autism's performance.

However, it is not clear that the representational structure of the false photograph task is equivalent to the false belief tasks. Leekam and Perner (1991) trained children that 'when it (the camera) goes "click", it makes a picture of [the current state of the world – in their case, a doll wearing a dress of a certain colour]' (p. 210). This establishes an association between the camera's activation and a memory of the present state of the world, and short-term memory appears intact in children with ASD. A crucial difference between the false photograph task and a similar false belief task might be the lack of this association where no association is made between an action and the current state of the world during the analogous false belief task. Accurate performance on the false photograph task by children with ASD may be due to the presence of this association, which might enable them to generate an association that would answer the false photograph task more easily (see also Peterson & Siegel, 1998).

This possibility is reflected in intervention studies on individuals with ASD. McGregor, Whiten, and Blackburn (1998) demonstrated that both children and adults with ASD who were trained on various associations concerning false belief stories were slightly more likely to transfer that understanding onto real-world scenarios involving another's false beliefs. Similarly, in an investigation of typically developing 3-year-olds, Mitchell and Lacohee (1991) found that associative information helped children succeed on a standard 'unexpected contents task'. When children were asked to write down their initial belief state, and then post it in the mail, they were more accurate at recalling their original false belief. The association between the original belief state and the act of posting might have assisted children (although see Bowler & Briskman, 2000, for an dissimilar finding). However, more research seems necessary to examine whether such associations benefit individuals with ASD's responses to false belief tasks, and whether individuals with ASD show good performance on false photograph tasks that lack such associative information.

In summary, children with ASD showed a different pattern of perception of ambiguous figures than comparison children. They tended to make fewer spontaneous reversals and more single interpretations. As in previous research, there appears to be a correlation between children's ability to reverse ambiguous figures and their success on theory of mind tasks. While these data are by no means conclusive, they are consistent with the view that children with autism have difficulty understanding their on-line introspective states (Frith & Happe, 1999). However, other hypotheses, specifically ones that consider executive function deficits, are also consistent. More research needs to be done to discriminate among these, and other, possibilities.

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Appendix

Script for the ice cream task (borrowed from Perner & Wimmer, 1985): The experimenter first brought out the model of the town, pointed to two small dolls, and told the child they were John and Mary. The experimenter also pointed out the park, the church, and Mary's house. The child was then asked which doll was John and which was Mary. If the child did not give the correct answer, feedback was given. Children are told:

'John and Mary are at the park. While they are there, the ice cream man comes. Mary wants to buy ice cream, but has no money. The ice cream man tells her that he will be at the park all day, so she goes home to get her money. While she is away, the ice cream man tells John that he will go to the church because there is no one in the park to buy ice cream. The ice cream man leaves and John stays at the park. While the ice cream man is driving to the church, he meets Mary walking back to the park and tells her that he is going to the church to buy ice cream. Mary and the ice cream man go to the church. A little while later, John goes to Mary's house and asks for Mary. Mary's mother tells John that she just left to buy ice cream.'

The child was then asked where John will look for Mary. Children were asked to justify their response and were asked two control questions, 'Where did Mary really go to buy ice cream?' and, 'Where was the ice cream man in the beginning?' During the course of the story, children were asked control questions to see if they followed the story. Feedback for these questions was given, but not for the two control questions at the end.