Logical, analogical, and psychological reasoning in autism: A test of the Cosmides theory

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Abstract
An important regulatory process in the development of behavior is cognition. However, cognition as a blanket term is far too broad to be useful. Rather, specific types of cognition need to be examined separately. One proposal is that one type of human reasoning evolved in a social context, to solve social problems. Here, we report two experiments that use autism to test a prediction from that theory: that social intelligence should be independent of nonsocial intelligence. Autism was chosen because deficits in social reasoning ("theory of mind") are well known. The question we tested was whether their theory of mind deficit was dissociable from abstract and relational reasoning ability. In particular, we expected that the abnormalities in the behavioral development of children with autism would be regulated by abnormalities in theory of mind reasoning rather than other forms of reasoning. Children with autism and matched controls were given tests of abstracting reasoning, which did not involve mental state understanding. Results showed that children with autism performed comparably to the control groups, both on a test of transitive inferential reasoning and on a test of analogical reasoning. These results lend support to the specificity of the theory of mind hypothesis for autism and to Cosmides' theory of the evolution of social intelligence. They also show that cognition as a regulatory process in development needs to be examined in highly specific ways.

Cognition as a Regulatory Process of Behavior
The idea that behavioral development is regulated by a variety of processes (both external and internal) is not new. Some of these regulatory processes are explored in this special issue of Development and Psychopathology. In this article we focus on the idea of cognition being one major (internal) regulatory process and address the question of whether highly specific forms of cognitive deficit might regulate the development of specific forms of psychopathology. We contrast social versus nonsocial intelligence, and examine where the childhood psychiatric disorder of autism is more closely associated with disturbances in social cognition or with cognition more broadly. We begin by introducing the notion of social intelligence.

Social intelligence
In 1989, Cosmides put forward a bold theory, that human intelligence had evolved primarily to solve social problems arising in a social context. She reported data showing that when normal adult participants are given tests of logical reasoning, using the classic Wason 4 card problems, performance is massively facilitated when the problems are set in a social context of ex-
change and deception. The Wason Task gives the subject four cards. Each card has a p or a p' on one side, and a q or a q' on the other. The participant is given the four cards showing: p, p', q, and q' and is asked which cards s/he needs to turn over to identify violations to the rule "If p, then q." Normal participants perform rather poorly, turning over cards that are not relevant to the rule. That is, they turn over p and q', even though these are not relevant to the task. However, when given social rules of the same logical complexity, such as "If a person buys alcohol, then s/he must be over 18 years of age," normal participants are very good at checking for violations to the rule in a logical manner. They turn over a card of a person aged less than 18, to see if they are drinking alcohol, or a card showing a glass of alcohol to see if they are under 18. They never turn over a glass of Coke®, or a card showing someone over 18, because these have no social consequences.

The idea that social intelligence may have evolved independently from nonsocial intelligence is not entirely new. Jolly (1966) made a similar claim, as did Humphrey (1976). Indeed, Humphrey called our species "Homo psychologicus" to emphasize this point. More recently, Byrne and Whiten (1988) coined the phrase "Machiavellian Intelligence" to refer to the primate capacity to outwit conspecifics and predators, highlighting the social-cognitive factors that appear to regulate much primate behaviour. (This history is reviewed in Baron-Cohen, 1995.)

In this article, we report two experiments that test Cosmides' general thesis further. We use autism as a test case of whether social and nonsocial intelligence may be independent of one another. Autism is a severe childhood psychiatry disorder arising from some form of brain abnormality, itself probably a result of genetic factors (Folstein & Rutter, 1988). Autism is chosen on the grounds that a large body of experimental work has shown that autistic individuals are impaired in the development and employment of a theory of mind. Here, the term "theory of mind" is defined as the ability to attribute the range of intentional states (beliefs, intentions, desires, etc.) to agents, by way of explaining and predicting an agent's actions (Dennett, 1978; Premack & Woodruff, 1978). The majority of children with autism fail classic theory of mind tasks, despite having chronological and verbal mental ages well above the normal requirement for success (Baron-Cohen, Leslie, & Frith, 1985; Leslie & Thaiss, 1992; see Baron-Cohen, Tager-Flusberg, & Cohen, 1993 for a review). Because much of normal social and communicative functioning requires a theory of mind (Baron-Cohen, 1988), this finding has led researchers to state that social and communicative problems characteristic of autism may be due to the inability to understand that mental states underlie and drive behavior.

However, a common factor in many theory of mind tasks is that they require the participant to employ complex reasoning. The participant has to work out a logical relation between the events that s/he perceives, and then draw a conclusion based on that relation. Take, for example, the classic False Belief Task (Baron-Cohen et al., 1985; Wimmer & Perner, 1983). In this task, Sally puts her marble in the red box, but while she is out, Anne moves it to the blue box. When Sally returns, the participant is asked "Where does Sally think her marble is?" The subject has to reason that Sally didn't see her marble being moved, therefore she won't know its new location: the blue box. In principle, then, a participant could fail theory of mind tasks because of being unable to reason about relations. On the other hand, if the theory of mind impairment in autism is specific, then children with autism should have no problems on abstract logical reasoning tasks that do not require reference to mental states. This is another way of approaching the question about which aspects of cognition are regulating the development of autism: social or nonsocial aspects?

This study explored reasoning ability in children with autism, and matched controls, in two different domains: logical and ana-
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logical reasoning. The first task (logical reasoning) tested transitive inference, and was based on the seminal study by Bryant and Trabasso (1971). The second task (analogical reasoning) was based on the method pioneered by Goswami and Brown (1989). These tasks were chosen because both require reasoning of an abstract nature (i.e., reasoning about relations) yet do not involve mental state attribution. Also, both tasks have been demonstrated to be within the ability of normally developing children around 4 years of age, the age at which children demonstrate success with traditional theory of mind tasks. Thus, these reasoning tasks do not require the subjects to perform above the developmental level tapped by tests of theory of mind. A final reason for selecting these tasks derives from their structure. In the transitive inference tasks, participants have to reason logically about relations between items (A > B, B > C, C > D, D > E; therefore B > D). In the analogical reasoning tasks, participants have to reason logically about higher order relations between items (A is to B as C is to D—or, in the standard notion A:B:: C:D). Given that the theory of mind tasks require reasoning about psychological relations (between people), this study allowed us to test if the difficulty for children with autism on theory of mind tasks was due to relational reasoning per se.

In summary, the experiments reported here were designed to further our understanding of two important areas: the nature of intelligence, and the nature of autism. Regarding the first of these, we predicted that if social intelligence has evolved independently of nonsocial intelligence, then children with autism may be relatively unimpaired on pure tests of abstract and relational reasoning. Regarding the second of these, we tested two hypotheses about the nature of autism: The relational reasoning hypothesis predicted that children with autism would show deficits in performance on all three tasks (relative to controls) if their theory of mind deficit was a consequence of a more general underlying deficit in abstract reasoning. In contrast, the theory of mind hypothesis predicted that reasoning about mental states would be selectively impaired in autism, while "non-mentalistic" relational reasoning would be largely intact.

Method

Participants

Three groups of children took part in the study. The first was a group of 17 children with autism, all of whom met the established criteria for autism (American Psychiatric Association, 1987; Rutter, 1978). These subjects were all attending special schools for autism in the London area. The second group comprised 15 children with moderate mental handicap, attending special schools for mental handicap in Norfolk. The third was a group of 17 normally developing children, all attending a primary school in Norfolk.

The two clinical groups were matched on verbal mental age (VMA), calculated using the Test of Reception of Grammar (TROG; Bishop, 1983), which is held to give a clearer estimate of language comprehension than a simple vocabulary test. They were also as closely matched as possible for chronological age (CA). Their details are summarized in Table 1.

Design and procedure

All children received both tests, in a counterbalanced order. The children were seen individually, in a quiet room of their school. The two tests are described next:

Test 1—Transitive inference. The experimenter first showed the child some drawings of pairs of objects, where one was always longer than the other, and asked the child "Which is the longest x?", (pencil, for example). The questioning was done to ensure that all the children understood the term "longest."

The experimenter then showed the subject the transitive inference equipment (which consisted of an upright, black wooden block containing five rods of the
Table 1. Subject's chronological and verbal mental ages

<table>
<thead>
<tr>
<th>Group</th>
<th>Chronological Age (CA)</th>
<th>Verbal Mental Age (VMA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autism (n = 17)</td>
<td>12:9 ± 2:10</td>
<td>4:6 ± 1:5</td>
</tr>
<tr>
<td>Range</td>
<td>7:9–18:0</td>
<td>4:0–10:0</td>
</tr>
<tr>
<td>Mental handicap (n = 15)</td>
<td>12:2 ± 2:11</td>
<td>4:6 ± 0:5</td>
</tr>
<tr>
<td>Range</td>
<td>8:6–18:2</td>
<td>4:0–5:0</td>
</tr>
<tr>
<td>Normal (n = 17)</td>
<td>4:10 ± 0:0</td>
<td>—</td>
</tr>
<tr>
<td>Range</td>
<td>4:9–4:11</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SD.

told the child which was the longest after the child had made a choice, and the pairings were repeatedly presented until the child could consistently pick the longest rod each time.

In the test phase, the experimenter presented to the child 10 pairings of rods, 6 of which required an inference (AC, AD, AE, BD, DE, CE) and 4 of which only required memory (e.g., AB). During this phase the experimenter did not give any feedback concerning the lengths of the rods. The child was given each test pairing once only, in random order.

Scoring. We set a conservative criterion of passing this test—defined as passing 6 or more pairings out of 10. This number was chosen because it would be significantly better than chance. For any one pair, chance equals \( p = 0.5 \). Thus, passing six trials by chance would have the small probability of \( p = 0.0156 \).

Tests 2—Analogue reasoning. This task had two conditions. Children received one of these in a first session and the other in a second session (approximately 2 days later). The order of presentation was counterbalanced across participants. Before the task started the experimenter told the child that s/he was going to play a game where s/he had to choose the picture to complete the pattern.

Causal reasoning control condition. In this condition, children were shown sets of three pictures of objects, all of which had all been affected in the same way (e.g., pictures of things that had all been cut into

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1. Each subject was actually asked what he/she would call the "rods" used in the Task, so that the Experimenter could then refer to them in a way that the subject would understand. For simplicity, they will be referred to as "rods" here.

same diameter, but which differed in color. All five rods protruded 1" from the block, but were actually all different lengths, thus it was impossible for the children to tell from looking which rods were longer). The experimenter told the subject that s/he was going to play a game where s/he had to try to work out which rod was the longest. The transitive inference equipment was then removed from sight.

The task had two phases. In the training phase, the experimenter showed the child the transitive inference equipment containing two adjacent rods, and asked him/her to point to the one s/he thought was the longest. Participants were not allowed to take the rods out and had no visible way of telling which rod was the longest, because all rods protruded an equal amount from the block. The only visible difference between the rods was that each was a different color. After the child had made a decision, the experimenter said "Well done! Yes, the (color of rod) rod is the longest" or "That's a good try, but the (color of rod) rod is the longest," depending on whether the child chose correctly or not. The transitive inference equipment was then removed from sight, and the pairing of rods was changed to the next pairing before being presented again to the child. During the training phase the child was shown the rods in pairings AB, BC, CD, DE. The experimenter always
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pieces). The experimenter placed these three pictures in front of the child, one at a time, encouraging the child to name each picture as it was placed to ensure that s/he recognized what was depicted. When the pictures had been named, the experimenter reminded the child that they had to choose the picture that would make a pattern with those already laid out.

The experimenter then laid out five choice pictures one at a time, in a random order, below the first three pictures. Again, the child was encouraged to name the pictures as they were presented. One of these pictures was the correct choice, because it depicted the instrument that caused what was shown in the first three pictures (e.g., a knife, which would be used to cut things up). The other four pictures depicted instruments that were irrelevant to the causal change. There were eight sets of these causal patterns, and were presented to all eight children (see Appendix 1).

Once the children had chosen the picture that they thought would make a pattern, they were then asked to justify their choice. This was to ensure that there was some reasoning behind the choice, rather than mere guessing. It also enabled an analysis of the kind of reasoning that was being used. The experimenter then said, “Well done, that’s the right picture because. . . .” In both instances the experimenter explained why the choice was correct (e.g., “because these pictures show things that have all been cut, and this picture shows a knife which is used to cut things”). An explanation of this kind followed every trial. This condition thus ensured that the children understood the causal relationships depicted.

Analogy condition. In this condition children were again shown sets of pictures and given the same instructions as in the causal reasoning control condition. However, in this condition the first three pictures were not laid out together in a line. Instead, the first two were placed as a pair, with a space before the third picture. These pictures showed an object that was in its normal state, and then the same object after something had happened to it. For example, the first picture might be a Playdough sausage (A), and the second picture the same Playdough sausage but cut into pieces (B). The third picture then showed an apple in its normal state (C), and the fourth slot was left empty for the child to complete the sequence.

Five choice picture cards were presented to the subject, only one of which depicted the analogical solution (e.g., an apple that had been cut into pieces (D)). The other four choice pictures were distractors that were related to (C) in some other way. These were: a correct causal change, but on the wrong object (E), the correct object but with the wrong causal change (F), a perceptually similar object (G), and a semantically related object (H). As in the causal reasoning control condition there were eight trials (see Appendix 2). The five choice cards were presented in random order.

The child was encouraged to name the pictures as the experimenter laid them out, and after selecting a picture to make a pattern the subject was again asked to justify his/her choice. The justifications were recorded and analyzed later. As in the causal reasoning control condition, the experimenter followed each trial with an explanation. All participants received all eight trials.

The distractor choices used in the task were designed to explore what kinds of errors the children were making, and if they consistently made more of certain errors. In other words, would children tend to make perceptually related errors (distractor (G)), or would they tend to choose pictures that depicted the correct object but the wrong causal change (distractor (F)), suggesting that they understood that something had to happen to the object, but could not make the analogical connection, for example.

Finally, the causal reasoning control condition was included to check the children’s causal knowledge and provide some training in this if it was less than perfect.

Scoring. As before, we defined a conservative criterion of passing the analogical reasoning test, defined in terms of passing at
Table 2. Transitive inference test—percentage of subjects passing

<table>
<thead>
<tr>
<th>Subjects</th>
<th>% Pass 6+ Test qs</th>
<th>% Pass Critical BD</th>
<th>% Fail 2+ Memory qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autism</td>
<td>76.5</td>
<td>64.7</td>
<td>17.6*</td>
</tr>
<tr>
<td>Mental handicap</td>
<td>80</td>
<td>66.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Normal</td>
<td>100</td>
<td>88.2</td>
<td>0</td>
</tr>
</tbody>
</table>

*χ², p < 0.05 (Autism × Normal).

least five out of eight trials. This definition ruled out passing by chance alone. The probability of chance performance on any one trial was \( p = 0.2 \). Thus, the probability of passing five trials by chance alone would be \( p = 0.0003 \).

Test 3—False belief task. All children were assessed on a standard false belief task, the Sally–Anne task (Baron-Cohen et al., 1985). In this task, the child watches the experimenter enact a short story using two dolls, Sally and Anne: Sally hides her marble in the red box and then goes out for a walk. Anne moves the marble to the blue box; then Sally re-enters, and the subject is asked “Where does Sally think the marble is?” Control questions for this include a memory question (“Where was the marble in the beginning?”) and a reality question (“Where is the marble really?”). Two trials were administered, varying the hiding locations each time, and a pass was scored if the child passed on both trials, as well as on the control questions.

Results

Transitive inference test

All children across groups passed the control questions concerning the meaning of the term “longest.” Therefore all children were given the transitive inference task. Table 2 illustrates the percentages of children in each group who passed six or more test questions and also the percentage of children in each group who failed two or more memory questions. There was no significant difference between groups for children passing at least 6 out of 10 test questions (Autism × Normal, \( χ² = 2.55, p = 0.11 \); Autism × Mental handicap, \( χ² = 0.04, p = 0.85 \); Mental handicap × Normal, \( χ² = 1.77, p = 0.18 \)). When the critical BD inferential question was examined (this being the one question that Bryant and Trabasso (1971) argue to be truly inferential), again there was no significant difference between groups in their pass rates (Autism × Normal, \( χ² = 1.62, p = 0.1 \); Autism × Mental handicap, \( χ² = 0.06, p = 0.75 \); Mental handicap × Normal, \( χ² = 2.17, p = 0.1 \). Thus, children with autism do not show any deficit in their ability to perform transitive inferential reasoning of this kind.

Table 3. Analogical Reasoning Test: Percentage of subjects passing

<table>
<thead>
<tr>
<th>Subjects</th>
<th>2+</th>
<th>3+</th>
<th>4+</th>
<th>5+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autism</td>
<td>94.1</td>
<td>82.4</td>
<td>76.5</td>
<td>58.8</td>
</tr>
<tr>
<td>MH</td>
<td>100</td>
<td>86.7</td>
<td>86.7</td>
<td>86.7</td>
</tr>
<tr>
<td>Normal</td>
<td>100</td>
<td>100</td>
<td>88.2</td>
<td>82.4</td>
</tr>
</tbody>
</table>

Analogical reasoning test

Children across all three groups performed virtually at ceiling in the causal reasoning control condition of this task (Autism: 94% pass, Mental handicap: 93.3% pass, Normal: 100%), showing that children understood the causal relationships that underlay the analogy trials. In the analogy condition, because the subjects had to choose the correct analogical solution out of a choice of five distractors, the probability of a correct
choice by chance on any one trial was $p = 0.2$. Passing more than two out of the eight trials overall would also be above chance ($p < 0.04$). The percentage of children passing two or more trials (up to those passing all five out of eight trials), is shown in Table 3.

The children with autism performed well above chance on the analogical reasoning, because they showed no significant difference in performance for passing five or more trials compared to controls ($\text{Autism} \times \text{Mental Handicap} = 3.06, p > 0.1$; $\text{Autism} \times \text{Normal}, \chi^2 = 3.78, p > 0.1$). Because they still performed above chance, children with autism apparently are capable of reasoning by analogy.

**False belief task**

Only 4 out of the 17 children with autism (or 23.5%) passed the theory of mind test, compared to 12 out of 15 children with mental handicap (80%) and 14 out of 17 normal children (82.4%). This difference between the autism group and the other two groups is highly significant ($\text{Autism} \times \text{Mental Handicap} \chi^2 = 10.81, df = 1, p = 0.001$; $\text{Autism} \times \text{Normal}, \chi^2 = 12.77, df = 1, p = 0.0004$). In contrast, the two control groups did not differ significantly from each other ($\text{Mental Handicap} \times \text{Normal} \chi^2 = 0.08, df = 1, p = 0.78$). In the group with autism alone, the proportion passing the false belief task was significantly lower than those passing either the transitive inference test ($\text{McNemar} \chi^2 = 11.11, p < 0.001$) or the analogical reasoning test ($\text{McNemar} \chi^2 = 8.17, p < 0.010$). This within-group difference is shown in Figure 1 below.

**Discussion**

With regard to understanding the nature of autism, this study tested two competing hypotheses: (a) that children with autism demonstrate poor performance on theory of mind tasks because they have a specific deficit in understanding mental states; versus (b) their theory of mind deficit is the result of a more general deficit in abstract relational reasoning. The relational reasoning hypothesis was clearly refuted: children with autism were comparable to match controls on both logical (inferential) and analogical reasoning. The deficit in autism then, appears to be specifically related to psychological reasoning. This is strong support for the "mindblindness" account of autism (Baron-Cohen, 1990, 1995).

Frith (1989, 1994) proposed an alternative account in terms of "weak central coherence." This proposal holds that children with autism may have a deficit in their ability to see information as an integrated whole and instead tend to focus more on the separate parts. They lack the normal drive for Gestalt perception and, instead of seeing "the wood but not the trees" (as a normal individual does), they tend to see "the trees but not the wood." Frith (1989) suggested that this lack of strong central coherence leads to their superior performance on the embedded figures task (Shah & Frith, 1983), and on block design (Shah & Frith, 1993), as well as explaining their difficulties with theory of mind tasks. This account would predict that they should be less able to make relevant connections between pieces of information. However, the results of these studies suggest that children with autism are capable of making relevant connections between several pieces of related information. If there is weak central coherence in autism, it is not pervasive, as it does not prevent logical transitive inference, across relations, nor a degree of analogical reasoning about higher order relations.

We focus next on the structure of the analogical reasoning task, and the implications this has for Leslie's modular theory of mind (ToMM; Leslie, 1987, 1991, 1994). As mentioned earlier, the analogical reasoning test involves reasoning about higher order relations. In looking at picture cards (A), (B), and (C), there are many possible connections. To complete the analogical pattern, the participant must be able to consider the relation between (A) and (B), and understand that that relation must be represented in relation to that between (C)
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Figure 1. Percentage of each group passing each test (Pass AR = 5+; Pass T1 = 6+).

Figure 2. Representation of a higher order relation in analogies.

and (D). Thus, it is not enough to understand the relation between cards (A) and (B) alone, and the relation between (C) and (D) alone. If the participant were unable to represent the higher order relation, then s/he would pair any of the distractors with card (C) randomly, because all five distractor cards are related to card (C) in some way.

Because the children with autism perform well above chance on the analogical reasoning task, this ability to represent higher order relations between stimuli raises questions in relation to Leslie's (1987) and Perner's (1993) theories of the “metarepresentational” deficit in autism. Leslie and Roth (1993) suggested that children with autism are capable of creating primary representations of the world, that is, they can directly represent objects, situations, and real-world scenarios. They also suggested that children with autism are unable to represent an agent’s attitude to a proposition (a so-called M-representation). In contrast, Perner (1993) suggested autistic children are unable to represent representations of representations (or “metarepresentations”). One reading of Perner’s theory would predict that children with autism should be unable to pass the analogical reasoning task, because this involves representing a higher order relation, which in itself is a representation of the two lower order representations (see Figure 2).

Our results show evidence of children with autism reasoning with representations of representations, this evidence suggests that the deficit in autism is unlikely to be a general deficit in metarepresentational ability as Perner maintains. Rather, the results are consistent with Leslie’s modular view that there is a deficit in the representation of mental states alone. Such a conclusion is consistent with a series of independent studies showing that children with autism can represent nonmental representations such as drawings, photographs, models, and maps (Charman & Baron-Cohen, 1992, in press; Leekam & Perner, 1991; Leslie & Thaiss, 1992) while still failing in tasks requiring the representation of mental representations. The results of these experiments take us one step further in suggesting that the cognitive system that is impaired in autism is not involved in logical or analogical reasoning, but appears to be dedicated to psychological reasoning (Baron-Cohen, 1994). This view is consistent with claims by Cosmides (1989) and Brothers...
(1990) that specific brain systems may have evolved to solve specifically social and intentional problems. Children with autism may show us the limitations of a cognitive system capable of nonsocial logical reasoning, but severely impaired in social-psychological reasoning. They also reveal the important regulatory role different aspects of cognition may play in development.

**Implications for the role of cognition as a developmental regulatory process**

In closing, we bring out the relevance of the above findings for the topic of this Special Issue. It is often thought that the major regulators of development are either environmental (such as poverty, understimulation, parental neglect, etc.), or genetic (e.g., Fragile-X or Down's syndrome). However, using the approach of developmental cognitive neuropsychology, it can be shown that highly specific cognitive mechanisms also play a key role in development. If a child with autism possesses much of what we have called nonsocial intelligence, but lacks aspects of what we have called social intelligence, this pattern could be expected to lead him or her down a very different developmental trajectory to a child (without autism) who shows the opposite pattern. Karmiloff-Smith, Grant, Bellugi, and Baron-Cohen (1995) argued that, in some respects, children with Williams syndrome show this opposite pattern: despite deficits in nonsocial intelligence, their social intelligence is relatively spared. Of course, we do not wish to suggest that cognitive, genetic, or environmental regulators are mutually exclusive of one another, because in the case of autism, it is highly likely that a genetic abnormality causes the cognitive defect in theory of mind. This in turn will determine which aspects of the environment the child focuses on or is confused by. Further environmental regulators are likely to act in a secondary fashion, in the case of autism, as parents, peers, and others unwittingly exclude the child with autism from the normal range of opportunities for social interaction. In other developmental disabilities, comparable interactions between genes, cognition, and the environment might also occur. (Pinker, 1994, makes the case for Specific Language Impairment fitting this model.) Equally, we should expect yet other disabilities in which just one of these regulators acts alone, but we hope that studies of the kind reported here will serve to ensure specific cognitive processes are not ignored as important developmental regulators.

**References**


Appendix 1

Causal reasoning control sequences and distractors

The subject is shown the first three pictures, and has to select the correct causal instrument, here listed fourth.

Causal term

Cut: Cut playdough:cut apple:cut bread:knife
hand dropping something:rain wetting:ball:banana

Break: Broken egg:broken lamp:broken plate:hand dropping something
plug going in socket;muddy field;sled

Wet: Wet car:wet hair:wet umbrella:rain wetting
matches:knife:fringing:beard

Burn: Burning candle:burning newspaper:burning
pan:matches:sun:hand opening something:plastic
bag:book

Open: Open box:open bottle:open drawer:hand opening something:hand dropping something:plug in socket:vaseline:can of Pepsi

Melt: Melted chocolate:melted snowman:melted crayon:sun
knife:muddy field:scarecrow:sledge

Dirty: Dirty dog:dirty shorts:dirty boots:rain wetting
matches:toy dog:pig

Appendix 2

Analogy sequences and distractors

All sequences have the general form a:b::c:d, with d hidden among four distractors.

Cut: Playdough(a):cut playdough(b)::

apple(c):cut apple(d)
cut bread(e);bruised apple(f);
ball(g);banana(h)

Break: Egg:broken egg::lamp:broken lamp

broken plate;lamp switched on;
bottle;torch

Wet: Car:wet car::hair:wet hair

wet umbrella;cut hair;fringing;
beard

Burn: Candle:burning candle::newspaper:burning newspaper

Open: box:open box::bottle:open bottle

open drawer;broken bottle;vase;
can of Pepsi

Melt: Chocolate:melted chocolate::

snowman:melted snowman
melted crayon;dirty snowman;
scarecrow;slide

Dirty: Dog:dirty dog::shorts:dirty shorts

dirty boots;wet dog;toy dog;pig

Switch on: TV:TV on::hairdryer:hairdryer on

radio on;hairdryer burning;food-
mixer;curling tongs