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Defeasible reasoning in high-functioning adults with autism: Evidence for impaired exception-handling

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ABSTRACT

While autism is one of the most intensively researched psychiatric disorders, little is known about reasoning skills of people with autism. The focus of this study was on defeasible inferences, that is inferences that can be revised in the light of new information. We used a behavioral task to investigate (a) conditional reasoning and (b) the suppression of conditional inferences in high-functioning adults with autism. In the suppression task a possible exception was made salient which could prevent a conclusion from being drawn. We predicted that the autism group would have difficulties dealing with such exceptions because they require mental flexibility to adjust to the context, which is often impaired in autism. The findings confirm our hypothesis that high-functioning adults with autism have a specific difficulty with exception-handling during reasoning. It is suggested that defeasible reasoning is also involved in other cognitive domains. Implications for neural underpinnings of reasoning and autism are discussed.

Autism is a developmental disorder characterized by deficits in social interaction and communication, and by restrictive, stereotyped and repetitive behaviors and narrow interests (DSM-IV, 1994). A hallmark of autism is reduced mental flexibility (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Hill, 2004b; Ozonoff & Jensen, 1999; Ozonoff, Strayer, McMahon, & Filloux, 1994). This term refers to the ability to shift a thought or action when the situation or context changes. Mental flexibility is a broad concept lacking a precise definition. We will investigate the notion of mental flexibility in autism by focusing on a specific, well-defined domain, namely reasoning. As will be shown in the discussion, a particular form of reasoning is a common factor in several tasks that have been shown to be difficult for people with autism.

Although autism is one of the most intensively researched psychiatric disorders, little is known about the reasoning skills of people with autism. Most research has focused on theory-of-mind reasoning, which involves attributing beliefs and intentions to other people to predict and understand behavior (e.g. Baron-Cohen, 1995; Baron-Cohen, Tager-Flusberg, & Cohen, 1993). Only few studies have investigated logical reasoning, and thus far, findings are not very consistent (Leevers & Harris, 2000; Scott & Baron-Cohen, 1996; Scott, Baron-Cohen, & Leslie, 1997). More importantly, these studies have overlooked an essential aspect of reasoning, namely that everyday reasoning requires more than strict rule-following, because almost all rules allow exceptions. Most rules are defeasible and can be revised in the light of new information. For instance, we expect a lamp to light if we switch it on, but we will withdraw this inference if the lamp turns out to be broken. Because one has to adjust one's conclusions when the context changes, mental flexibility is necessary for defeasible reasoning. Because it is mental flexibility, that is often reduced in autism, we expect people with autism to experience difficulties with defeasible reasoning. In fact, as we will discuss below, we expect them to have problems with a specific form of defeasible reasoning. A good tool for investigating defeasible reasoning is the suppression task. Based on a logical analysis of this task by Stenning and Van Lambalgen (2005, 2007, 2008) we are able to formulate

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precise hypotheses. The suppression task will be discussed in detail below.

1. Suppression task

The suppression task is a conditional reasoning task, in which a conditional sentence of the form "If p then q" is always the first premise. There are four forms of conditional inference:

4) *Modus ponens*
If Mary has an exam, she will study in the library.
Mary has an exam.
Mary will study in the library.

5) *Modus tollens*
If Mary has an exam, she will study in the library.
Mary will not study in the library.
Mary does not have an exam.

6) *Affirmation of the consequent*
If Mary has an exam, she will study in the library.
Mary will study in the library.
Mary has an exam.

7) *Denial of the antecedent*
If Mary has an exam, she will study in the library.
Mary does not have an exam.
Mary will not study in the library.

In classical logic, only modus ponens (MP) and modus tollens (MT) are considered valid. On the other hand, neither affirmation of the consequent (AC) nor denial of the antecedent (DA) lead to valid conclusions according to classical logic.

It is now widely accepted that people often do not reason according to the rules of classical logic, and rightly so, because classical logic is not entirely adequate when it comes to reasoning with conditionals. First, a considerable number of people endorse affirmation of the consequent and denial of the antecedent, though these inferences are invalid according to classical logic. For example, a conditional like "If Peter washes my car, I will give him five euros" is often understood as "If and only if Peter washes my car, I will give him five euros". That means, if I give Peter five euros, people tend to infer that Peter washed my car (=affirmation of the consequent). And if Peter did not wash my car, people are likely to conclude that I will not give him five euros (=denial of the antecedent). Both affirmation of the consequent and denial of antecedent are explained as resulting from pragmatic processes and are called invited inferences (Geis & Zwicky, 1971; Horn, 2000). Secondly, modus ponens and modus tollens – which should always be valid according to classical logic – can be suppressed in the light of extra information (Bonnefon & Hilton, 2002; Byrne, 1989; Byrne, Espino, & Santamaria, 1999; Chan & Chua, 1994; Cummins, Lubart, Alksnis, & Rist, 1991; Dieussaert, Schaeken, Schroyens, & d'Ydewalle, 2000; Politzer & Bourmaud, 2002). For example:

8) *Modus ponens with additional premise*
a. If Mary has an exam, she will study in the library
b. If the library is open, Mary will study in the library
c. Mary has an exam
d. Will Mary study in the library?

This reasoning problem was presented with and without premise 8b. As soon as the extra premise (8b) came in, the number of people concluding that Mary will study in the library, dropped to about 50%, whereas without the extra premise most people endorsed the conclusion (Byrne et al., 1999). The addition of the extra premise (8b) leads to a significant decrease of the rate at which a valid inference is endorsed. This example clearly illustrates that conditional reasoning is nonmonotonic and defeasible, which means that new information can affect an inference. Classical logic, however, is monotonic: extra information can never change a conclusion. This makes classical logic context-insensitive. In contrast, nonmonotonic, defeasible reasoning is context-dependent. It is the context that determines whether inferences are endorsed or not. This form of reasoning makes demands on mental flexibility, because one has to adjust one's conclusion when the context changes. For this reason, we expect that defeasible reasoning might be difficult for people with autism, as they have been shown to be less flexible and less sensitive to context (Happé, 1997; Hill, 2004b; Jolliffe & Baron-Cohen, 2000; Ozonoff & Jensen, 1999; Ozonoff et al., 1994).

Based on a logical analysis of the suppression task by Stenning and Van Lambalgen (2005, 2007, 2008), we can formulate more specific hypotheses with regard to defeasible reasoning in autism. According to Stenning and Van Lambalgen (2005, 2007, 2008) modus ponens and modus tollens both involve a specific form of defeasible reasoning, namely closed-world reasoning with regard to exceptions. That means, exceptions are considered to be not the case, as long as evidence to the contrary is not available. In the suppression task, the conditional (8a) can be interpreted as "If Mary has an exam and nothing abnormal is the case, she will study in the library." If we know that Mary has an exam (8c) and further assume that there no exceptions (by applying closed-world reasoning to exceptions), we can conclude that Mary will study in the library. However, if an additional premise (8b) is added, the closed-world assumption cannot be maintained anymore, because now a possible exception has become salient, namely that the library may be closed. For modus tollens a similar analysis holds: since we do not know whether Mary does not study in the library because she has no exam or because the library is closed, no definite conclusion can be drawn.

The important thing is that closed-world reasoning to exceptions requires disregarding all possible exceptions as long as there is no evidence thereof, but at the same time keeping open the possibility that one has overlooked a relevant exception and adjust when necessary. This implies flexible thinking: one should discern when an abnormality in a particular context is relevant and when to disregard it. We hypothesize that it is such dealing with exceptions (so called exception-handling), that is the difficult part of defeasible reasoning for people with autism, because they have reduced mental flexibility to adjust to the context.

To show that the problems people with autism experience are due to exception-handling and not due to problems with integrating linguistic information or defeasibility in general, we will also consider arguments with alternative premises (9,10).

9) *Affirmation of the consequent with alternative premise*
a. If Mary has an exam, she will study in the library
b. If Mary has an essay to write, she will study in the library
c. Mary will study in the library
d. Does she have an exam?

10) *Modus ponens with alternative premise*
a. If Mary has an exam, she will study in the library
b. If Mary has an essay to write, she will study in the library
c. Mary has an exam
d. Will Mary study in the library?

Alternative premises like (9b) can suppress the invited inferences affirmation of the consequent (9) and denial of the antecedent, but do not suppress the valid inferences modus ponens (10) and modus tollens. The invited inferences affirmation of the consequent and denial of the antecedent do not involve closed-world reasoning to exceptions, but involve a different kind of closed-world reasoning. For denial of the antecedent, one assumes that in the absence of further information, having an exam is the only reason for studying in the library. Therefore, given that Mary does not have an exam, one can conclude that Mary will not study in the library. For affirmation of the consequent, one supposes that only those rules hold that are explicitly given, that is (9a) is the only rule. Other rules that have "Mary will study in the library" as consequent are assumed to be not the case. Alternative premises like (9b) can suppress invited inferences, because an alternative reason for studying in the library is introduced. The effect of alternative premises (9b) on invited inferences was already shown by Rumain, Connell and Braine (1983), who found that both adults and children made fewer invited inferences when alternative antecedents were provided.

If people with autism have problems with defeasible inferences across the board, and therefore stick to a purely classical logic, then they will show no change in rates at which conclusions are endorsed when additional or alternative premises are provided. This will be reflected in neither suppressing valid inferences with additional premises (modus ponens, modus tollens) nor suppressing invited inferences with alternative premises (affirmation of the consequent, denial of the antecedent). However, if people with autism have specific problems with exception-handling, they will show less suppression of modus ponens and modus tollens with additional premises than matched controls, but equal suppression of invited inferences with alternative premises.

2. Methods

2.1. Participants

Participants in this study included 28 high-functioning adults with autism (autistic disorder (HFA), $n = 11$ and Asperger syndrome, $n = 17$) and 28 matched controls, aged 18–40 years. Both groups consisted of 20 male and 8 female subjects. The groups were matched for handedness, with 24 right-handed en 4 left-handed individuals in each group. Clinical and control participants were individually matched on sex, age and verbal IQ as closely as possible (Table 1). There were no significant differences between the autism group and control group on age, verbal intelligence, performance intelligence, and full scale intelligence ($p > 0.1$ for all variables). IQ was assessed with one of the Wechsler Intelligence scales (WAIS-R, WAIS-III, WISC-R) in participants with autism, and with a short form of the WAIS in controls.

The diagnoses of autistic disorder and Asperger syndrome were established through expert clinical evaluation based on the DSM-IV criteria for these disorders (DSM-IV, 1994). Clinical diagnosis was confirmed by the Autism Diagnostic Interview-Revised (ADI-R), which is a structured developmental diagnostic interview with parents or caregivers (Lord, Rutter, & Le Couteur, 1994) and which is based on behavior of the participant at the age of 4–5 years old. Seven participants did not meet one of the four specified cut-offs of the ADI-R. This was mainly due to the fact that most of our participants received a diagnosis of autism in adulthood and their parents did not recall the relevant data. In the case of two participants it was not possible to do an ADI-R because their parents had passed away. In all these cases, the clinical diagnosis of autism was beyond doubt. People with a PDD-NOS diagnosis were excluded as well as those with severe comorbid axis-I conditions like major depressive disorder, anxiety disorders, or ADHD.

The clinical group was recruited from the referrals to the psychiatric outpatient department of the Radboud University Nijmegen Medical Centre, specialized institutes for diagnosis and treatment of autism spectrum disorders, and via the website of the Dutch Autism Association. Data obtained from the clinical group were compared to a control group of 28 typically developing, healthy people. The control group was screened for any history of psychiatric disorders using the Mini International Neuropsychiatric Interview plus (Sheehan et al., 1998) and was assessed particularly on the presence of symptoms of autism, ADHD and depression by means of three self-report questionnaires: (i) Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), (ii) Inventory of Depressive Symptomatology Self-report (Rush, Gullion, Basco, Jarrett, & Trivedi, 1996) and (iii) ADHD rating scale (Kooij et al., 2005) To ensure that no controls with autistic traits were included, a cutoff score on the Autism Quotient was set at 26 (maximum score is 50). The mean score of the control group on the Autism Quotient was 12 (S.D. = 4, range 3–18), whereas the mean score of the autism group was 34 (S.D. = 9, range 19–47). The mean score on the Inventory of Depressive Symptomatology Self-report indicates no depression for the control group and possibly or slightly depressed in case of the autism group. The mean scores of the ADHD rating scale indicate no ADHD features in both groups. All participants were native speakers of Dutch and had no known history of neurological disorder, head injury or reading problems. All participants had normal or corrected-to-normal vision.

Table 1
Description of the matching variables age, verbal intelligence (VIQ), performance intelligence (PIQ) and full scale intelligence (FIQ) for the autism group and control group.

	Autism ($n = 28$)		Control ($n = 28$)	
	Mean (S.D.)	Range	Mean (S.D.)	Range
Age	26.8 (5.2)	19–40	26.3 (5.2)	19–39
VIQ	117.5 (13.6)	93–144	116.3 (12.9)	94–135
PIQ	115.1 (14.5)	84–144	121.4 (14.1)	94–144
FIQ	117.9 (13.7)	91–140	120.0 (12.2)	96–139

Table 2
Examples of the four inference types used in the simple task and expected answer patterns.

Inference	Example	Conclusion
MP modus ponens	If Mary has an exam, she will study in the library Mary has an exam Will she study in the library?	Yes
MT modus tollens	If Mary has an exam, she will study in the library Mary will not study in the library Does she have an exam?	No
AC affirmation of the consequent	If Mary has an exam, she will study in the library Mary will study in the library Does she have an exam?	Maybe = classical logic Yes = invited inference
DA denial of the antecedent	If Mary has an exam, she will study in the library Mary does not have an exam Will she study in the library?	Maybe = classical logic No = invited inference

All participants gave informed consent to participate in the study and were reimbursed for travel expenses and participation. The study was formally approved by the local medical ethics committee. This experiment was part of a larger study, which also examined scalar implicatures in autism.

2.2. Materials

The experiment consisted of two tasks. The first task was a simple conditional reasoning task, containing two premises and a question. For example:

11)
If Mary has an exam, she will study in the library.
Mary has an exam.
Will she study in the library?

Four different inference patterns were examined: modus ponens, modus tollens, denial of the antecedent, and affirmation of the consequent (Table 2). Ten different conditional premises were constructed, which were used in each inference pattern to keep word frequency and sentence length constant across conditions. In total there were 40 reasoning problems. It should be noted that response patterns indicate how participants reason: endorsement of AC ('yes' response) and DA ('no' response) are indicative of invited inferences, whereas inconclusive responses are indicative of reasoning according to classical logic.

The second task – the suppression task – comprised the same materials as the simple task except that an extra premise had been added. The extra premise was an additional or an alternative premise (Table 3). Thus each reasoning problem of the simple task occurred with an additional and with an alternative premise, so in total there were 80 reasoning problems in the suppression task. The types of interpretations that participants assigned to the conditional can be inferred from their response patterns: taking into account exceptions will result in 'maybe' responses for MP and MT with an additional premise (i.e. suppression of MP and MT), whereas taking into account alternatives will result in 'maybe' responses for AC and DA with an alternative premise (i.e. suppression of invited inferences). Participants always performed the simple task first. Within tasks, items were varied pseudo-randomly in five different orders. The same conditional premises never occurred consecutively and there were at most two identical inference patterns in succession.

2.3. Procedures

The experiment was run on a laptop using the Presentation software package. Instructions and some practice trials preceded the tasks. Participants were instructed that they would be presented with two statements (and three for the suppression task), which they had to read carefully and to assume that they were true. They were instructed that after the statements a question about the statements would follow that had to be answered by pressing the buttons 'yes', 'no' or 'maybe'. They had to read the premises first and subsequently – after a button press – the question appeared below the premises. They were told that the computer recorded their responses and the time they needed to respond. To ensure that participants read the sentences properly before pressing the button for the question, dummies were

Table 3
Examples of additional (=add) and alternative (=alt) premises in the suppression task and expected answer patterns for suppression and no suppression. n.a. = not applicable.

Inference	Example	Suppression	No suppression
Modus ponens add	If Mary has an exam, she will study in the library. If the library is open, Mary will study in the library. Mary has an exam. Will she study in the library?	Maybe	Yes
Modus ponens alt	If Mary has an exam, she will study in the library. If Mary has an essay to write, she will study in the library Mary has an exam. Will she study in the library?	n.a.	n.a.
Modus tollens add	If Mary has an exam, she will study in the library. If the library is open, Mary will study in the library. Mary will not study in the library. Does she have an exam?	Maybe	No
Modus tollens alt	If Mary has an exam, she will study in the library. If Mary has an essay to write, she will study in the library Mary will not study in the library. Does she have an exam?	n.a.	n.a.
Affirmation of the consequent add	If Mary has an exam, she will study in the library. If the library is open, Mary will study in the library. Mary will study in the library. Does she have an exam?	n.a.	n.a.
Affirmation of the consequent alt	If Mary has an exam, she will study in the library. If Mary has an essay to write, she will study in the library. Mary will study in the library. Does she have an exam?	Maybe	Yes
Denial of the antecedent add	If Mary has an exam, she will study in the library. If the library is open, Mary will study in the library. Mary does not have an exam. Will she study in the library?	n.a.	n.a.
Denial of the antecedent alt	If Mary has an exam, she will study in the library. If Mary has an essay to write, she will study in the library. Mary does not have an exam. Will she study in the library?	Maybe	No

included in which the premises disappeared when the question appeared on the screen. These dummies had 1% error responses, which indicate that the sentences were read properly. After pressing the button for the answer, the next reasoning problem appeared on the screen. Participants had to press the left or right button to give their yes/no response, and the space bar for 'maybe'. The buttons were marked with overlays. To avoid a reaction time bias due to hand preference, the assignment of the right and left button for 'yes' responses was counterbalanced across participants. For each participant, response type and reading times were recorded. Reading times were determined by measuring the time from appearance of the question until the moment that the participants gave their response. There were optional rest breaks between the tasks and half way through the tasks.

2.4. Data analyses

We analyzed both the pattern of responses and reading times. Since each condition consisted of ten items, percentages of 'yes', 'no' and 'maybe' responses were calculated per condition for each participant. As the distribution of these percentages of responses strongly deviated from a normal distribution, nonparametric Mann–Whitney tests (exact, two-tailed) were carried out to investigate response patterns. However, simply comparing the endorsement rates of the inferences in the suppression task is not sufficient, because it would not take into account the baseline endorsement of the reasoning problems in the simple task. Therefore, we also calculated the conditional probability of suppression in the suppression task given endorsement in the simple task for each participant. To illustrate how conditional probabilities were calculated, we will give an example: if someone endorsed 8 MP items out of 10 in the simple task (i.e. 8 'yes' responses), the probability is 0.8. If that participant suppressed 2 MP items out of 10 in the suppression task (i.e. 2 'maybe' responses), but one of these 2 items was not endorsed in the simple task, the probability is 0.1. The conditional probability of suppressed items given endorsed items in the simple task is 0.125, which means that 12.5% of the endorsed items in the simple task were suppressed in the suppression task (in formula: $P(B|A) = P(A\&B)/P(A)$ where A = endorsed items in simple task and B = suppressed items in suppression task. $P(A\&B) = 0.1$ and $P(A)$ is 0.8).

For the reading time data, a log transformation was carried out, because the distribution of reading times was skewed to the right in both groups. Individual cut-off values were calculated for each participant as the mean ± 2 standard deviations over all items. Any value exceeding the cut-off was removed from the data set as were all error trials. Responses were considered as error if they were deviant from

Table 4
Responses that were counted as errors. MP = modus ponens, MT = modus tollens, AC = affirmation of the consequent, DA = denial of the antecedent.

Inference	Error response
MP	No
MT	Yes
AC	No
DA	Yes

classical logic and closed-world reasoning, for example, a 'yes' response for modus tollens (see Table 4 for what was counted as error). Over all participants, 6.3% of the reading time data were removed in the simple task (autism group 5.7%, control group 6.8%), and 5.3% of the reading time data were removed in the suppression task (autism group 5.6%, control group 4.7%). Mean reading times for each condition per participant were entered into repeated-measures ANOVAs with Inference (MP, MT, AC, DA) as a within-subject factor and Group (Autism, Control) as between-subject factor.

3. Results

3.1. Analysis of responses

In the simple task, both groups endorsed MP and MT at equally high rates, and did not differ significantly in the number of 'yes' responses for MP and 'no' responses for MT (see Tables 5 and 6). Endorsement of AC and DA (a 'yes' response for AC and 'no' response for DA) was at a lower rate in both groups. There was a trend for the autism group to endorse AC and DA less often than the control group and to respond 'maybe' more frequently (Tables 5 and 6). Participants with autism also responded 'maybe' more often in case of MP and MT ($U = 292$, $p = 0.029$ for MP and $U = 252$, $p = 0.010$ for MT). This result can be attributed to four participants with

Table 5
Proportion of responses for the simple task and the suppression task. MP = modus ponens, MT = modus tollens, AC = affirmation of the consequent, DA = denial of the antecedent, add = with additional premise and alt = with alternative premise.

% responses	Autism			Control		
	Yes	No	Maybe	Yes	No	Maybe
MP	89.6	0.0	10.4	96.1	2.5	1.4
MP add	71.0	1.1	28.0	51.1	0.7	48.2
MP alt	92.9	0.4	6.8	97.5	0.7	1.8
MT	1.4	79.6	19.0	2.5	92.8	4.7
MT add	0.7	62.1	37.1	0.7	45.0	54.3
MT alt	0.4	90.3	9.3	1.1	95.0	3.9
AC	45.0	1.1	53.9	67.1	2.1	30.7
AC add	28.1	1.1	70.9	35.7	0.0	64.3
AC alt	12.2	2.2	85.7	9.6	0.0	90.4
DA	1.1	48.0	50.9	0.4	69.1	30.6
DA add	2.9	28.9	68.2	2.5	33.6	63.9
DA alt	3.2	15.7	81.1	1.1	10.4	88.5

Table 6
Differences in endorsement rates between the autism group and control group for the simple task and the suppression task (additional premises for MP and MT, alternative premises for AC and DA). MP = modus ponens, MT = modus tollens, AC = affirmation of the consequent, DA = denial of the antecedent.

Autism versus Control	Simple task		Suppression task	
	p-Value	*U*	*p*-Value	*U*
MP ('yes')	0.151	323	0.010	237
MT ('no')	0.092	296	0.066	281
AC ('yes')	0.079	287	0.704	370
DA ('no')	0.054	278	0.396	342

autism who were responsible for the majority of 'maybe' answers for MP and six participants (including the four above) who were responsible for the majority of 'maybe' responses for MT (see Section 4).

In case of the additional premise, the autism group showed significantly less suppression of MP ($U = 234$, $p = 0.008$) than the control group and less suppression of MT at marginal significance level ($U = 277$, $p = 0.058$), thus, more endorsement of MP and MT (Table 6 and Fig. 1). There were no significant differences between the groups for additional premises in AC and DA (p's > 0.1).

For the alternative premise, both groups showed equally high rates of 'maybe' responses for AC and DA and high proportions of endorsement of MP and MT (all p's > 0.1). The percentages of errors (see Table 4) were low and the groups showed no significant differences in number of errors (p's > 0.1), except for AC with alternative premise ($U = 336$, $p = 0.040$). However, this effect is negligible, because the number of errors was very low (see Table 5).

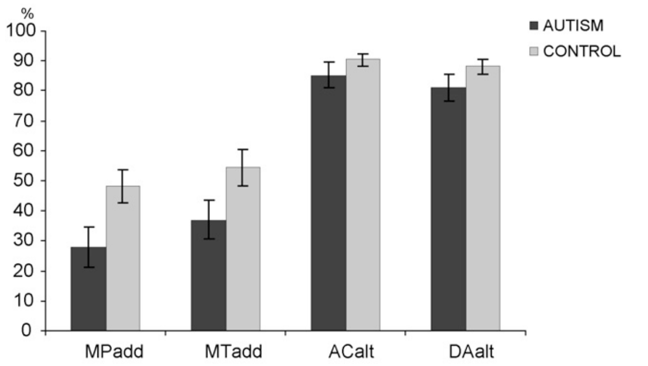

Fig. 1. Suppression of modus tollens (MP) and modus tollens (MT) with additional premise, and suppression of affirmation of the consequent (AC) and denial of the antecedent (DA) with alternative premise (% 'maybe' responses). Error bars represent 1 S.E. of the means.

Table 7
Differences in endorsement rates between the simple task and the suppression task (additional premises for MP and MT, alternative premises for AC and DA) for each group. MP = modus ponens, MT = modus tollens, AC = affirmation of the consequent, DA = denial of the antecedent.

Simple versus suppression task	Autism		Control	
	p-Value	*U*	*p*-Value	*U*
MP ('yes')	0.007	238	<0.001	54
MT ('no')	0.041	270	<0.001	83
AC ('yes')	0.004	225	<0.001	98
DA ('no')	0.001	193	<0.001	113

Furthermore, participants with a diagnosis of autistic disorder (high-functioning autism/HFA) endorsed inferences in the simple task at the same rate as the participants with a diagnosis of Asperger syndrome (p's > 0.1), except for a trend for MT with HFA participants showing more 'maybe' responses ($U = 56$, $p = 0.062$). For the suppression task, there were no significant differences between the HFA group and the Asperger group in suppression of MP and MT and suppression of AC and DA (all p's > 0.1).

Because simply comparing the endorsement rates of the inferences in the suppression task would not take into account the baseline endorsement of the problems in the simple task, we also calculated the conditional probabilities of suppression, which represent the probability of suppressed items given the probability of endorsed items in the simple task. We found significant differences between the autism group and control group for both MP and MT with additional premise ($U = 242$, $p = 0.013$; $U = 258$, $p = 0.027$). The autism group showed significantly less suppression of MP and MT with additional premise than the control group. For AC and DA with alternative premises, conditional probabilities of suppression of invited conclusions were calculated for those participants who showed invited inferences in the simple task. For both AC and DA no significant differences were found between groups in conditional probability of suppression of invited inferences given the probability of endorsed inferences in the simple task (p's > 0.1).

Finally, we examined endorsement rates in the simple and suppression task per group to check for purely classical logical reasoning, which means that endorsement rates do not change when extra information is supplied in the suppression task. As displayed in Table 7, both groups showed significantly less endorsement of MP and MT, and less endorsement of AC and DA in the suppression task compared to the simple task.

3.2. Analysis of reading times

A repeated measures ANOVA on mean reading times of the simple task showed a main effect of Inference ($F(3,162) = 18.3$, $p < 0.001$), no significant effect of Group ($p > 0.1$) and no significant Inference × Group interaction ($p = 0.096$). Post hoc paired *t*-tests revealed that responses to MP were faster than to MT and DA, but not faster than to AC. Responses to MT and DA were equally fast, as well. Finally, responses to AC were faster than to DA.

A repeated measures ANOVA on mean reading times of the suppression task with Inference (MP, MT, AC and DA) and Argument (additional, alternative) as within-subject factors and Group as between-subject factor showed a main effect of Inference ($F(3,162) = 74.7$, $p < 0.001$). Moreover there was a main effect of Argument ($F(1,54) = 45.4$, $p < 0.001$) and an Inference × Argument interaction ($F(3, 162) = 7.78$, $p < 0.001$) indicating that inferences with additional premises took more time to respond than with alternative premises, except for DA. There was no significant effect of Group ($p > 0.1$).

4. Discussion

This study investigated how high-functioning adults with autism deal with extra information during conditional reasoning. We hypothesized that they would have a specific problem with exception-handling due to reduced mental flexibility to adjust to the context. The findings of the simple task showed that high-functioning adults with autism are good at conditional reasoning. The autism group showed equally high proportions of modus ponens and modus tollens inferences and no significant differences in reading times. The suppression task revealed that although participants with autism were good at conditional reasoning, they had difficulties with exceptions. They showed less suppression of modus ponens and modus tollens when an exception was made salient, but equal suppression of affirmation of the consequent and denial of the antecedent when alternative premises were available. Because they were able to suppress invited inferences (AC and DA) when an alternative premise was available, it is not defeasibility as such, that is problematic in autism. Moreover, that the autism group showed equal suppression of invited inferences strongly suggests it is not the integration of linguistic information, that is problematic either, as has been proposed by a number of studies supporting the Weak Central Coherence account (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 2000).

An alternative explanation is that suppression of invited inferences in the suppression task could be explained by that the autism group also showed more inconclusive responses to affirmation of the consequent and denial of the antecedent in the simple task, and thus seemed to reason more according to classical logic than the control group. However, when comparing endorsement rates in the suppression task with those in the simple task, it turned out that the autism group endorsed fewer inferences in the suppression task, as did the control group. In other words, like the control group, participants with autism who endorsed affirmation of the consequent and denial of the antecedent in the simple task were able to suppress the invited inferences when an alternative premise became available. We can therefore conclude that the autism group was capable of integrating the alternative premises. Moreover, when exceptions were supplied, modus ponens and modus tollens were endorsed at a lower rate in both groups, though the autism group took significantly fewer exceptions into account than the control group. To conclude, our findings cannot be attributed to a purely classical logical reasoning style in autism, because in that case no change of endorsement of conditional inferences would have occurred when extra premises were provided.

In the simple task there were four participants with autism who exhibited a deviant pattern for modus ponens and six (including the four above) who exhibited a deviant pattern for modus tollens, indicating some heterogeneity within the autism group. These participants gave substantially more inconclusive answers ('maybe') to modus ponens and modus tollens than the other participants. Presumably these participants did not apply closed-world reasoning at all in order to anticipate any possible exception. Although our findings suggest that these participants took exceptions into account during reasoning, this does not mean that they are good at exception-handling. The pattern that they exhibited might be a strategy and just the other side of the coin: one can refuse to adjust to exceptions, or always anticipate exceptions and endorse no valid inference at all. In both cases, no flexibility is required because one can stick to one's initial conclusion without adjusting if new information becomes available. Finally, we should note that the majority of these participants had a diagnosis of autistic disorder and not Asperger syndrome, which suggest that the severity of autism symptoms may play role.

4.1. Closed-world reasoning in other cognitive domains

So far we have only discussed exception-handling in the suppression task, but closed-world reasoning is presumably involved in other cognitive domains as well. In the following, we will discuss three domains that may be important for autism.

First, Stenning and Van Lambalgen (2007, 2008) argued that closed-world reasoning is involved in false belief tasks, which investigate reasoning about other people's beliefs (Theory of Mind). In the standard design of the task, a child sees a chocolate being moved from a box to a drawer, while a doll called Maxi is taken out of the room (Perner, Leekam, & Wimmer, 1987). To understand that Maxi believes that the chocolate is in the box and not in the drawer, Stenning and Van Lambalgen (2007, 2008) suggest that the child must apply closed-world reasoning combined with a principle of inertia, i.e. things do not change places spontaneously. A child must acknowledge that Maxi's belief that the chocolate is in the box persists, unless an event occurs which causes him to revise his belief. Because no such event has been mentioned, one can apply closed-world reasoning and assume that Maxi still believes that the chocolate in the box. Like others (Grant, Riggs, & Boucher, 2004; Peterson & Bowler, 2000; Riggs, Peterson, Robinson, & Mitchell, 1998), Stenning and Van Lambalgen (2007, 2008) argued that false belief tasks require more than attributing beliefs to others, and that 'logical' reasoning is involved too.

Second, closed-world reasoning appears to be important for executive functions, which are known to dysfunction in autism (Hill, 2004a, 2004b; Ozonoff, 1997; Russell, 1997). For example, Hughes and Russell (1993) found that children with autism had great difficulty using the switch-route in their box task. In this task they had to retrieve a marble lying on a platform inside a box, but first had to turn a switch before reaching inside the box, otherwise an invisible trap-door mechanism was activated, which made the marble drop out of reach. However, the same children had no problems to obtain the marble when they had to push a knob, which caused the marble to be caught by a chute. These findings can be explained by a difficulty with taking exceptions into account. In the knob-route, the initial rule ("If I put my hand through the opening, I can obtain the marble") simply has to be replaced by another one ("If I push the knob, I can obtain the marble"). However, in the switch-route it is not just a matter of replacing one rule by another one, but a precondition must be incorporated into the initial rule ("If the switch is in the correct position and I put my hand through the opening, I can obtain the marble"). Here the child has to take into account the possible exception that the switch may not be in the correct position.

Finally, exception-handling appears to be involved in planning, which has also been reported to be difficult for people with autism (Ozonoff, 1997; Ozonoff & Jensen, 1999). Planning requires setting and maintaining a goal. Because it is impossible to anticipate all events that might obstruct the achievement of a goal, the best thing to do is assume that there are no obstacles as long as none are in evidence, in other words, to apply closed-world reasoning to exceptions. However, one must keep open the possibility that one has overlooked a possible obstacle, and hence adjust one's plan if an obstacle does arise. For example, if I plan a train journey, I will assume there is no train strike, power failure, accident and so forth, as long as I have no information to the contrary. We suggest that it might be the flexible application of closed-world reasoning to exceptions, that is difficult for people with autism. Since flexible handling of exceptions is required in many situations, it is not surprising that people with autism often have problems with planning and organizing everyday life, and cling to fixed routines and rigid schedules.

4.2. Closed-world reasoning and the brain

A final issue is what implications our findings might have for the neural underpinnings of autism. As mentioned before, little is as yet known about logical reasoning skills in autism. Therefore, one starting point was to investigate how high-functioning adults with autism deal with defeasible inferences at a behavioral level. Conditional reasoning is a higher-order cognitive process in which several cognitive components are involved such as linguistic processing, recruitment of information from long-term memory, maintaining and manipulating verbal information in working memory, attention and inhibition of responses. Several of these components belong to the so-called 'executive functions', which have been shown to be an area of dysfunction in autism (Hill, 2004a, 2004b; Ozonoff, 1997; Russell, 1997). Executive functions are thought to be regulated by the frontal lobes, though evidence is inconsistent (see for a review, Alvarez & Emory, 2006). Studies that have investigated the neural basis of reasoning found frontal-temporal and frontal-parietal networks involved in deductive reasoning (Goel & Dolan, 2004; Knauff, Mulack, Kassubek, Salih, & Greenlee, 2002; Monti, Osherson, Martinez, & Parsons, 2007; Parsons & Osherson, 2001).

It is conceivable that defeasible reasoning requires precise collaboration between different cortical areas, more than strict rule-bound classical reasoning might do. From this perspective, current research on the neural basis of autism has provided evidence of functional underconnectivity between cortical areas in autism (Courchesne & Pierce, 2005; Just, Cherkassky, Keller, Kana, & Minshew, 2007; Just, Cherkassky, Keller, & Minshew, 2004). This in effect has consequences for the integration of information from widespread and diverse regions, and hence presumably for defeasible reasoning in which several pieces information must be integrated to arrive at a conclusion. Further research is needed to address the question how the autistic brain integrates information during the process of reasoning.

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References

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review*, *16*(1), 17–42.

Baron-Cohen, S. (1995). *Mindblindness: An essay on autism and the Theory of Mind*. Cambridge: MIT Press.

Baron-Cohen, S., Tager-Flusberg, H., & Cohen, D. J. (1993). *Understanding other minds: Perspectives from autism*. Oxford: Oxford University Press.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism Spectrum Quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*, 5–17.

Bonnefon, J., & Hilton, D. J. (2002). The suppression of modus ponens as a case of pragmatic preconditional reasoning. *Thinking and Reasoning*, *8*(1), 21–40.

Byrne, R. M. J. (1989). Suppression of valid inferences with conditionals. *Cognition*, *31*, 61–83.

Byrne, R. M. J., Espino, O., & Santamaria, C. (1999). Counterexamples and the suppression of inferences. *Journal of Memory and Language*, *40*, 347–373.

Chan, D., & Chua, F. (1994). Suppression of valid inferences: Syntactic views, mental models, and relative salience. *Cognition*, *53*, 217–238.

Courchesne, E., & Pierce, K. (2005). Why the frontal cortex in autism might be talking only to itself: Local over-connectivity but long-distance disconnection. *Current Opinion in Neurobiology*, *15*(2), 225–230.

Cummins, D. D., Lubart, T., Alksnis, O., & Rist, R. (1991). Conditional reasoning and causation. *Memory and Cognition*, *19*(3), 274–282.

Dieussaert, K., Schaeken, W., Schroyens, W., & d'Ydewalle, G. (2000). Strategies during complex conditional inferences. *Thinking and Reasoning*, *6*(12), 125–169.

DSM-IV. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.

Frith, U., & Snowling, M. (1983). Reading for meaning and reading for sound in autistic and dyslexic children. *Journal of Developmental Psychology*, *1*, 329–342.

Geis, M. L., & Zwicky, A. M. (1971). On invited inferences. *Linguistic Inquiry*, *2*, 561–566.

Geurts, H., Verte, S., Oosterlaan, J., Roeyers, H., & Sergeant, J. A. (2004). How specific are executive functioning deficits in attention deficit hyperactivity disorder and autism. *Journal of Child Psychology and Psychiatry*, *45*(4), 836–854.

Goel, V., & Dolan, R. J. (2004). Differential involvement of left prefrontal cortex in inductive and deductive reasoning. *Cognition*, *93*(3), 109–121.

Grant, C. M., Riggs, K. J., & Boucher, J. (2004). Counterfactual and mental state reasoning in children with autism. *Journal of Autism and Developmental Disorders*, *34*(2), 177–188.

Happé, F. (1997). Central coherence and theory of mind: Reading homographs in context. *British Journal of Developmental Psychology*, *15*, 1–12.

Hill, E. L. (2004a). Evaluating the theory of executive dysfunction in autism. *Developmental Review*, *24*, 189–233.

Hill, E. L. (2004b). Executive dysfunction in autism. *Trends in Cognitive Sciences*, *8*(1), 26–32.

Horn, L. (2000). From *if* to *iff*: Conditional perfection as pragmatic strengthening. *Journal of Pragmatics*, *32*, 289–326.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: Its implications for theories of autism. *Developmental Psychology*, *29*(3), 498–510.

Jolliffe, T., & Baron-Cohen, S. (2000). Linguistic processing in high-functioning adults with autism or Asperger's syndrome: Is global coherence impaired? *Psychological Medicine*, *30*, 1169–1187.

Just, M. A., Cherkassky, V. L., Keller, T. A., Kana, R. K., & Minshew, N. J. (2007). Functional and anatomical cortical underconnectivity in autism: Evidence from an FMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex*, *17*(4), 951–961.

Just, M. A., Cherkassky, V. L., Keller, T. A., & Minshew, N. J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: Evidence of underconnectivity. *Brain*, *127*(8), 1811–1821.

Knauff, M., Mulack, T., Kassubek, J., Salih, H. R., & Greenlee, M. W. (2002). Spatial imagery in deductive reasoning: A functional MRI study. *Cognitive Brain Research*, *13*(2), 203–212.

Kooij, J. J. S., Buitelaar, J. K., van den Oord, E. J., Furer, J. W., Rijnders, C. A. T., & Hodiamont, P. P. G. (2005). Internal and external validity of attention-deficit hyperactivity disorder in a population-based sample of adults. *Psychological Medicine: A Journal for Research in Psychiatry and the Allied Sciences*, *35*, 817–827.

Leevers, H. J., & Harris, P. L. (2000). Counterfactual syllogistic reasoning in normal 4-year-olds, children with learning disabilities, and children with autism. *Journal of Experimental Child Psychology*, *76*(1), 64–87.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685.

Monti, M. M., Osherson, D. N., Martinez, M. J., & Parsons, L. M. (2007). Functional neuroanatomy of deductive inference: A language-independent distributed network. *Neuroimage*, *37*(3), 1005–1016.

Ozonoff, S. (1997). Components of executive functions in autism and other disorders. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 179–214). Oxford: Oxford University Press.

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders*, *29*(2), 171–177.

Ozonoff, S., Strayer, D. L., McMahon, W. M., & Filloux, F. (1994). Executive function abilities in autism and Tourette syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry*, *35*(6), 1015–1032.

Parsons, L. M., & Osherson, D. (2001). New evidence for distinct right and left brain systems for deductive versus probabilistic reasoning. *Cerebral Cortex*, *11*(10), 954–965.

Perner, J., Leekam, S. R., & Wimmer, H. (1987). Three-year olds' difficulty with false belief: The case for a conceptual deficit. *British Journal of Developmental Psychology*, *5*, 125–137.

Peterson, D. M., & Bowler, D. M. (2000). Counterfactual reasoning and false belief understanding in children with autism. *Autism*, *4*, 391–405.

Politzer, G., & Bourmaud, G. (2002). Deductive reasoning from uncertain conditionals. *British Journal of Psychology*, *93*(Pt 3), 345–381.

Riggs, K. J., Peterson, D. M., Robinson, E. J., & Mitchell, P. (1998). Are errors in false belief tasks symptomatic of broader difficulty with counterfactuality? *Cognitive Development*, *13*, 73–90.

Rumain, B., Connell, J., & Braine, M. D. S. (1983). Conversational comprehension processes are responsible for reasoning fallacies in children and adults: IF is not the biconditional. *Developmental Psychology*, *29*(4), 471–481.

Rush, A. J., Gullion, C. M., Basco, M. R., Jarrett, R. B., & Trivedi, M. H. (1996). The Inventory of Depressive Symptomatology (IDS): Psychometric properties. *Psychological Medicine*, *26*(3), 477–486.

Russell, J. (Ed.). (1997). *Autism as an executive disorder*. Oxford: Oxford University Press.

Scott, F. J., & Baron-Cohen, S. (1996). Logical, analogical and psychological reasoning in autism: A test of the Cosmides theory. *Development and Psychopathology*, *8*, 235–245.

Scott, F. J., Baron-Cohen, S., & Leslie, A. (1997). 'If pigs could fly': A test of counterfactual reasoning and pretence in children with autism. *British Journal of Developmental Psychology*, *17*, 349–362.

Sheehan, D. V., Lecrubier, Y., Sheehan, K. H., Amorim, P., Janavs, J., Weiller, E., et al. (1998). The Mini-International Neuropsychiatric Interview (M.I.N.I.): The development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. *Journal of Clinical Psychiatry*, *59*(suppl 20), 22–33.

Stenning, K., & Van Lambalgen, M. (2005). Semantic interpretation as computation in nonmonotonic logic: The real meaning of the suppression task. *Cognitive Science*, *29*, 919–960.

Stenning, K., & Van Lambalgen, M. (2007). Logic in the study of psychiatric disorders: Executive function and rule-following. *Topoi*, *26*, 97–114.

Stenning, K., & Van Lambalgen, M. (2008). *Human reasoning and cognitive science*. Massachusetts: MIT Press.