Logic, language and the brain: how autists reason with rules and exceptions

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This will make you feel good ....
This will make you feel good ....

If Marian has an essay, she studies late in the library.
This will make you feel good ....

If Marian has an essay, she studies late in the library.
Marian has an essay.
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If Marian has an essay, she studies late in the library.
Marian has an essay.
Does Marian study late in the library?
This will make you feel good ....

If Marian has an essay, she studies late in the library.
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Is there a change if the following premise is added?
This will make you feel good ....

If Marian has an essay, she studies late in the library.
Marian has an essay.
Does Marian study late in the library?

Is there a change if the following premise is added?

If the library is open, Marian studies late in the library.
These problems are in fact quite natural ...
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On Schiphol Airport boarding cards one can read
These problems are in fact quite natural ...

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If it’s thirty minutes before your flight departure, make your way to the gate.
These problems are in fact quite natural ...

On Schiphol Airport boarding cards one can read

If it’s thirty minutes before your flight departure, make your way to the gate.

As soon as the gate number is announced, make your way to the gate.
These problems are in fact quite natural ...

On Schiphol Airport boarding cards one can read

If it’s thirty minutes before your flight departure, make your way to the gate.

As soon as the gate number is announced, make your way to the gate.

What to do if the gate number is announced, but it’s two hours ahead of departure?
Main themes
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• autism and its hypothesised causes
Main themes

• autism and its hypothesised causes
• a role for logic in cognitive science
Main themes

- autism and its hypothesised causes
- a role for logic in cognitive science
- logical analysis of tasks diagnostic for autism: closed world reasoning about exceptions
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• direct test of the hypothesis
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- a role for logic in cognitive science
- logical analysis of tasks diagnostic for autism: closed world reasoning about exceptions
- direct test of the hypothesis
- neurological implications
What is autism?
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  - poor or unusual social interaction skills
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• delayed development or difficulties in both verbal and non-verbal (gestures, pointing, showing, ...) communication
What is autism?

- A `pervasive developmental disorder’ (diagnosed roughly at 2) characterised by
  - poor or unusual social interaction skills
  - delayed development or difficulties in both verbal and non-verbal (gestures, pointing, showing, ...) communication
  - the presence of repetitive behaviours and an insistence on sameness
Theories of autism
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• ‘Theory of mind’ deficit (Baron-Cohen, Leslie..) (ToM) -- most prominent
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• in what sense are these different?
Some tests diagnostic for autism
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- false belief tasks (ToM)
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  • supposedly show that autistic children are unable to take someone else’s perspective
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• box task (ED)
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- box task (ED)
  - supposedly shows that autistic children suffer from ‘inability to inhibit the prepotent response’
False belief task
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Maxi puts his bar of chocolate in the green box and then leaves the room. While he is away, his Mum moves his chocolate bar to the blue box.
False belief task

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Box task
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The task is to retrieve the marble lying on the platform inside the box. If a child reaches through the opening, an infrared beam is interrupted - marble falls through trapdoor. The infrared mechanism can be deactivated using the switch on the left side of the box.
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But there are benefits of logical analysis...

• celebrated diagnostic tests such as ‘false belief task’ have a **logical form**

• this logical form is actually the same across several important tasks (some non-verbal):
  
  closed world reasoning about exceptions

• this logical form gives rise to a verbal logical task on which autists are expect to perform differently from neurotypical subjects
Executive function
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- `executive function' is an umbrella term for processes responsible for higher-level action control that are necessary for maintaining a goal and achieving it in possibly adverse circumstances.
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- we may take `executive function' to be composed of planning, initiation, inhibition, coordination and control of action sequences, leading toward a goal held in
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- basic building block of EF: inhibitable rule of the form
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- to be read as `if A and nothing abnormal is the case then E’

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  if there is no necessity to assume ab, conclude \( \neg ab \)
Logical analysis of EF: example
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**example**

- Suppose we know only $A$ and $A \land \neg ab \rightarrow E$; since there is no information about $ab$ we conclude $\neg ab$, and $E$ follows.
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- Now suppose a possible abnormality $C$ comes to light: $C \rightarrow ab$; but no other abnormalities.

- Then in fact $C \leftrightarrow ab$, so that the rule becomes $A \land C \rightarrow E$.

- And $A$ is no longer sufficient to activate the rule to conclude $C$. 
A `formal’ analysis of the box task
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At first sight, nothing funny appears to be going on, so retrieve the marble. [Closed world reasoning]
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[T]aking what one might call a `defeasibility stance' towards rules is an innate human endowment - and thus one that might be innately lacking .. [H]umans appear to possess a capacity - whatever that is - for abandoning one relatively entrenched rule for some novel ad hoc procedure. The claim can be made, therefore, that this capacity is lacking in autism, and it is this that gives rise to failures on `frontal' tasks - not to mention the behavioural rigidity that individuals with the disorder show outside the laboratory (Russell 2002)
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Is the false belief task about belief only?
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  - causal relation between perception and belief
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- but much more seems to be involved
  - causal relation between perception and belief
  - inertial properties of belief
  - inhibition of response tendencies
- (and some FBTs do not involve other agents!)
The false belief task and executive function
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`executive function' contains response rules such as (*) $B(\varphi) \land \neg ab(\varphi) \rightarrow R(\varphi)$
The false belief task and executive function

`executive function' contains response rules such as (*) B(φ) ∧ ¬ab(φ) → R(φ)

`if an agent Believes φ and nothing abnormal is the case, then the agent Reports φ’
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two possibly competing instances of (*)
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1. φ is actual location of chocolate
The false belief task and executive function

`executive function` contains response rules such as (*) \( B(\varphi) \land \neg ab(\varphi) \rightarrow R(\varphi) \)

`if an agent \textbf{Believes} \( \varphi \) and nothing \textbf{abnormal} is the case, then the agent \textbf{Reports} \( \varphi \)`

two possibly competing instances of (*)&

1. \( \varphi \) is actual location of chocolate

2. \( \varphi \) is Maxi's belief about the location of the chocolate
The false belief task and inhibition
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the response rules 1. and 2. mutually inhibit each other via conditions on the abnormalities $ab(\varphi)$
The false belief task and inhibition

- the response rules 1. and 2. mutually inhibit each other via conditions on the abnormalities $ab(\varphi)$

  - e.g. relative to $B(\varphi) \land \neg ab(\varphi) \rightarrow R(\varphi)$ with $\varphi$ the actual location of the chocolate, we have a clause reflecting task understanding:
The false belief task and inhibition

- the response rules 1. and 2. mutually inhibit each other via conditions on the abnormalities \( ab(\varphi) \)

- e.g. relative to \( B(\varphi) \land \neg ab(\varphi) \rightarrow R(\varphi) \) with \( \varphi \) the actual location of the chocolate, we have a clause reflecting *task understanding*:

- \( B(B'(\neg \varphi)) \rightarrow ab(\varphi) \), where \( B' \) is Maxi's belief
The false belief task and inhibition

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  - e.g. relative to $B(\varphi) \land \neg ab(\varphi) \rightarrow R(\varphi)$ with $\varphi$ the actual location of the chocolate, we have a clause reflecting task understanding:

    $$B(B'(\neg \varphi)) \rightarrow ab(\varphi), \text{ where } B' \text{ is Maxi's belief}$$

- "If the agent believes that Maxi has a false belief ($B'(\neg \varphi)$) about the location of the chocolate, his own response is
The false belief task and inhibition
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if the agent has computed the wrong belief about Maxi, i.e. if $B(B'(\varphi))$
The false belief task and inhibition

- if the agent has computed the wrong belief about Maxi, i.e. if $B(B'(\varphi))$
- or if the inhibitory link $B(B'(-\varphi)) \rightarrow ab(\varphi)$ is not functioning
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- if the agent has computed the wrong belief about Maxi, i.e. if \( B(B'(\varphi)) \)

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The false belief task and inhibition

- if the agent has computed the wrong belief about Maxi, i.e. if $B(B'(\phi))$
- or if the inhibitory link $B(B'(-\phi)) \rightarrow ab(\phi)$ is not functioning
- then the response rule $B(\phi) \land \neg ab(\phi) \rightarrow R(\phi)$ will not be inhibited by $ab(\phi)$
- hence the agent will wrongly report the actual location of the chocolate
Conclusions from this analysis of FBT & the box task
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• this predicts asymmetric relation between FBT and EF tasks: in autists one can have intact EF while failing on FBT

• and indeed: E. Pellicano, Dev. Psych. 2007
Conclusion from this analysis of FBT and box task (2)
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A reasoning task with the same formal structure
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A reasoning task with the same formal structure

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Is there a change if the following premise is added?
A reasoning task with the same formal structure

If Marian has an essay, she studies late in the library.
Marian has an essay.
Does Marian study late in the library?

Is there a change if the following premise is added?

If the library is open, Marian studies late in the library.
Similarly for the argument form `affirmation of consequent’
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Similarly for the argument form `affirmation of consequent’

If Marian has an essay, she studies late in the library.
Marian studies late in the library.
Does Marian have an essay?
Is there a change if the following premise is added?

If Marian has a textbook to read, she studies late in the library.
A reasoning task with the same formal structure
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- we’ve just seen two conditions in the suppression task (R. Byrne 1989): MP and AC
A reasoning task with the same formal structure

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A reasoning task with the same formal structure

- we’ve just seen two conditions in the suppression task (R. Byrne 1989): MP and AC
- supplying an additional [‘library open’] premise makes MP drop from 90% to 60%
- supplying an alternative premise [‘textbook’] makes AC drop from 55% to 15%
- a logical analysis will show the formal similarity to the previous tasks:
Computation in the suppression task
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- Stenning-vL hypothesise that the underlying representation of the conditional is
Computation in the suppression task

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If Marian has an essay and nothing abnormal is the case, then she studies late in the library.
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• this suggests autists will suppress MP (and MT) much less!
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- Oaksford & Chater, ‘Bayesian Rationality’, BBS 2008; commentary by SvL
A reasoning experiment*
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- Materials: MP, MT, AC, DA for 2 or 3 premises, with additional or alternative conditionals
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• reaction times measured
Predictions
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- Otherwise, they should perform as controls
- Although they may have a stronger tendency to apply classical logic
- Reaction times: in both groups
  - Backward inferences (MT, AC) should be slower
  - Processing of additional premises should be slower
  - Suppression must take more time than non-suppression
Typical results, including how autists differ from controls

<table>
<thead>
<tr>
<th>% responses</th>
<th>ASD</th>
<th></th>
<th></th>
<th></th>
<th>ASD</th>
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<td></td>
<td>yes</td>
<td>no</td>
<td>maybe</td>
<td></td>
<td>yes</td>
<td>no</td>
<td>maybe</td>
<td></td>
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<tr>
<td>MP</td>
<td>89.6</td>
<td>0.0</td>
<td>10.4</td>
<td></td>
<td>96.1</td>
<td>2.5</td>
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<tr>
<td>MP add</td>
<td>71.0</td>
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<td>28.0</td>
<td></td>
<td>51.1</td>
<td>0.7</td>
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<td></td>
<td>97.5</td>
<td>0.7</td>
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<td>79.6</td>
<td>19.0</td>
<td></td>
<td>2.5</td>
<td>92.8</td>
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<td>MT add</td>
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<td>62.1</td>
<td>37.1</td>
<td></td>
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<td>45.0</td>
<td>54.3</td>
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<td>0.4</td>
<td>90.3</td>
<td>9.3</td>
<td></td>
<td>1.1</td>
<td>95.0</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>45.0</td>
<td>1.1</td>
<td>53.9</td>
<td></td>
<td>67.1</td>
<td>2.1</td>
<td>30.7</td>
<td></td>
</tr>
<tr>
<td>AC add</td>
<td>28.1</td>
<td>1.1</td>
<td>70.9</td>
<td></td>
<td>35.7</td>
<td>0.0</td>
<td>64.3</td>
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<tr>
<td>AC alt</td>
<td>12.2</td>
<td>2.2</td>
<td>85.7</td>
<td></td>
<td>9.6</td>
<td>0.0</td>
<td>90.4</td>
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<tr>
<td>DA</td>
<td>1.1</td>
<td>48.0</td>
<td>50.9</td>
<td></td>
<td>0.4</td>
<td>69.1</td>
<td>30.6</td>
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</tr>
<tr>
<td>DA add</td>
<td>2.9</td>
<td>28.9</td>
<td>68.2</td>
<td></td>
<td>2.5</td>
<td>33.6</td>
<td>63.9</td>
<td></td>
</tr>
<tr>
<td>DA alt</td>
<td>3.2</td>
<td>15.7</td>
<td>81.1</td>
<td></td>
<td>1.1</td>
<td>10.4</td>
<td>88.5</td>
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Table 5. Proportion of responses for the simple task and the suppression task.
add = additional and alt=alternative premise.
Results of the reasoning experiment: two premises
Results of the reasoning experiment: two premises

- both groups (autists, controls) showed high rates of endorsement of MP and MT
Results of the reasoning experiment: two premises

- both groups (autists, controls) showed high rates of endorsement of MP and MT
- but autists showed considerably more `maybe’ responses than controls ($p = 0.001$)
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Results of the reasoning experiment: two premises

- both groups (autists, controls) showed high rates of endorsement of MP and MT
- but autists showed considerably more `maybe’ responses than controls (p = 0.001)
- autists endorsed AC and DA less than controls (p = 0.006)
- reaction times tend to show that backward inferences (MT, AC) are slower for autists than controls (p = 0.053); for controls no significant difference between forward and backward
Results of the reasoning experiment: three premises
Results of the reasoning experiment: three premises

- in case of an additional premise, autists suppressed MP and MT significantly less than controls ($p = 0.025$; conditionalised on endorsement of two premise inference)
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- no significant differences between groups for additional premises in AC and DA
Results of the reasoning experiment: three premises

- in case of an additional premise, autists suppressed MP and MT significantly less than controls ($p = 0.025$; conditionalised on endorsement of two premise inference)

- no significant differences between groups for additional premises in AC and DA

- no significant differences between groups for alternative premises in all inferences
Reaction time experiment: three premises
Reaction time experiment: three premises

- processing of additional premises takes significantly longer ($p = 0.000$; no difference between groups)
Reaction time experiment: three premises

- processing of additional premises takes significantly longer ($p = 0.000$; no difference between groups)
- backward inferences slower than forward inferences ($p = 0.000$; no difference between groups)
Reaction time experiment: three premises

- processing of additional premises takes significantly longer ($p = 0.000$; no difference between groups)
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Reaction time experiment: three premises

- processing of additional premises takes significantly longer ($p = 0.000$; no difference between groups)
- backward inferences slower than forward inferences ($p = 0.000$; no difference between groups)
- inferences involving a negation are slower than those without ($p = 0.000$; no difference between groups)
- suppression of MP takes longer than non-suppression ($p = 0.038$)
What to conclude from this?
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• AC/DA: different behaviour of autists not due to failure to integrate second conditional premise, as WCC would perhaps suggest
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• the theoretical model proposed by Stenning-vL predicts that suppression in MP and MT is due to incorporation of exceptions

• on this model, the observations imply that autists `do not’ incorporate exceptions

• the same phenomenon was uncovered in our analysis of box task and FBT!
Neural correlate of well-founded semantics
Neural correlate of well-founded semantics
Abnormalities
Inhibition in the autistic brain
Inhibition in the autistic brain

- the neural correlate of the computational theory predicts that an inhibitory neuron interrupts the link from `has an essay' to `studies in library'
Inhibition in the autistic brain

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• there are indications that at the neural level inhibition is compromised in autists
  • immature inhibitory interneurons due to brain growth spurt
  • deficient GABA production
  • imbalance between excitatory and inhibitory neurons
  • (at least) 2 types of inhibitory interneurons: *basket cells* (local connectivity) and *Lugaro cells* (long range)
An ERP study

Disabling context (MPdis):
The library has restricted opening hours because of vacation. If Mary has an exam, then she will study in the library. Mary has an exam. Mary will study in the library.

Neutral context (MPneut):
The library is in a large monumental building. If Mary has an exam, then she will study in the library. Mary has an exam. Mary will study in the library.
ERP waveforms

AUTISM GROUP n=17

STUDENT GROUP n=18
A puzzle?
A puzzle?

• in the new condition, the behavioural data of autists are not significantly different from those of neurotypicals
A puzzle?

• in the new condition, the behavioural data of autists are not significantly different from those of neurotypicals

• yet the ERP waveforms are significantly different!
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• in the new condition, the behavioural data of autists are not significantly different from those of neurotypicals
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• look again at the experimental material...
A puzzle?

• in the new condition, the behavioural data of autists are not significantly different from those of neurotypicals

• yet the ERP waveforms are significantly different!

• look again at the experimental material...

• the new premises can be taken as inconsistent!
Book

Keith Stenning & Michiel van Lambalgen
`Human reasoning and cognitive science’
MIT Press 2008 (esp. chapters 7, 8, 9)