Executive function and rule-following in psychiatric disorders

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A common failure in psychiatric disorders: executive function

- patients suffering from psychiatric disorders often have planning problems of subtly different kinds
- 'executive function' umbrella term for processes responsible for higher-level action control that are necessary for maintaining a goal and achieving it in possibly adverse circumstances
- executive function comprises planning, inhibition, coordination and control of action sequences
- autism: behavioural rigidity (stereoyped and /or contextually inappropriate behaviour)
- OCD: infeasible notion of 'good plan', leading to impossibility to act (in seleccted domains)
- ADHD/Tourette: difficulty with stimulus-controlled task-switching

Executive function in cognition

- executive function is 'the' cognitive capacity which allows one to maintain a goal and to initiate and inhibit physical and mental actions appropriate to achieving that goal'
- example of task where this function is supposedly exercised: Stroop task – 'read the following word: red'
- example of brain lesion where this function is compromised: frontal lobe lesion leading to utilization behaviour
- at a logical level, the operation of executive function can be described as rule-following and aberrations thereof
- two examples considered today:
  - behavioural rigidity in autism
  - executive dysfunction, deviant narration and verb tenses

What is autism?

- a clinical syndrome first described by Leo Kanner in 1943, characterized by deficits in three domains: social interaction, communication, executive function
- patient often referred due to delayed language onset [but symptoms visible in retrospect]
- and/or a deficit in affective relations and communication, refusal of eye-contact, repetitive movements, indifference to pain, ...
- autistic children do not engage *spontaneously* in phantasy play, but can do so when instructed
- all severities – from complete lack of language and severe retardation continuous with 'normal' range of personalities/IQs
- sometimes savant abilities, but most are *not* high functioning
- Asperger's – 'autism without language impairment'?

Theories of autism: 1. ToMM deficit theory

- originating in Premack's work on chimpanzees – who seem to lack a 'theory of mind'
- claims to explain two key deficits:
  - paucity of spontaneous pretend play ('lack of imagination')
  - delayed performance/failure on false-belief tasks ('inability in perspective-taking')
- this it does by positing a *module* for ToM (Leslie) which can be lacking while other cognitive skills are intact, leading to autism
- matures according to a fixed schedule in normally developing children, delayed or impaired in autists
- final stages involve the acquisition of the concept of mental 'metarepresentation' – a theory of how beliefs are formed in oneself and others
- (but modularity is not such a good idea . . .)

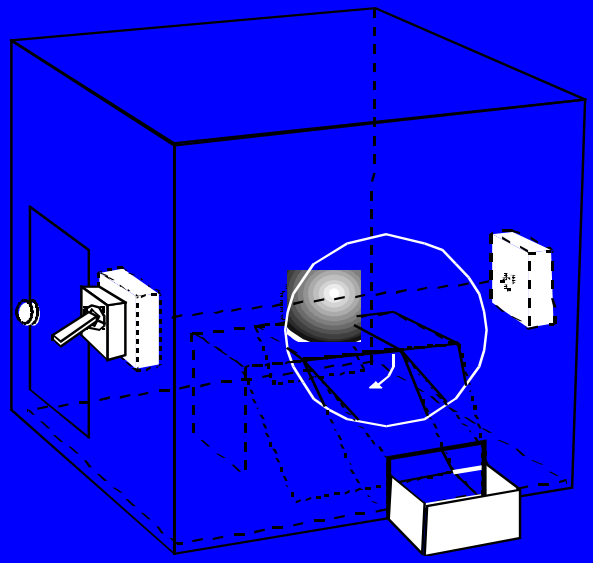
Theories of autism: 4. Executive disorder theory (ED)

- executive functioning is (roughly) 'the appropriate initiation and inhibition of physical and mental action'
- one possible deficit: *inability to inhibit pre-potent response*
- evidence for ED in autism
  - strategic planning, motor planning
  - set-shifting; shift of (visual) attention
  - generating novel actions
  - example: failure in box task (see below)
- link to ToM: false belief task requires subjects to inhibit a pre-potent response ('I know!') while holding other 'action-relevant' information in working memory
- we will connect executive function to rule-following and *closed world reasoning*

The many faces of closed world reasoning

- lists (train schedules, airline databases, . . .)
- diagnostic reasoning and abduction
- unknown preconditions [fails in autism, OCD]
- causal and counterfactual reasoning [fails in autism, OCD]
- attribution of beliefs and intentions [fails in autism]
- closed reasoning (also) involves 'preprocessing': *encoding* of the law-like features of a situation in a particular type of premisses
- laws always allow exceptions, and skill at 'exception handling' is required – which involves identifying (encoding) the *relevant* exceptions
- autists appear to be doing worse than normals on this last aspect, although they behave normally w.r.t. the closed world inferences themselves
- patients with OCD seem incapable of closed world reasoning in selected domains

Unknown preconditions and the box task



- Hughes & Russell's 'box task': to get the marble you have to flip the switch first, or the marble drops out of reach when the light-beam is broken
- instructions to subject involve pointing this out *explicitly*

Executive function and performance in the box task

- executive functioning is (roughly) 'the appropriate initiation and inhibition of physical and mental action'
- one possible deficit: *inability to inhibit pre-potent response*
- 'prpotent response' here is to reach for the marble, which must be inhibited to achieve correct response
- 'neurotypical' children older than 4yrs manage this, younger children don't
- autists go on failing this task for a long time, so lack the flexibility to switch from one rule to another (at least in the box task)

Russell's comments

"[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 behavioral rigidity that individuals with the disorder show outside the laboratory. . . "

Russell goes on to say that one way this theory might be tested is through the implication that "children with autism will fail to perform on tasks which require an appreciation of the defeasibility of rules such as 'sparrows can fly'."

Closed world reasoning in the box task: 'exception handling'

- hypothesis: in box task, the 'frame problem' of AI is at work – in general one cannot list beforehand all preconditions of an action (hence one has to be prepared to adapt to circumstances)
- normally developing children learn to interpret conditional as allowing for exceptions or *ab*normalities: the general form is

$$p \wedge \neg ab \rightarrow q,$$

  where conditions $A \rightarrow ab$ may be added; then apply closed world reasoning to ab
- conditional here: 'if you reach for the marble *and there is nothing funny going on*, you can retrieve the marble'
- hence if you cannot retrieve the marble, something funny may be going on (and the rule may still be correct!)
- need to see that after flipping the switch there are no further problems

Attribution of beliefs in the false belief task (Wimmer & Perner)

Does the following task tap a different set of cognitive capabilities?

- doll (Maxi) and child witness chocolate placed in the fridge
- exit Maxi
- the child sees the experimenter move chocolate from fridge to drawer
- re-enter Maxi
- child is asked 'where will Maxi look for the chocolate?'
- before about 4 yrs, 'neurotypical' child responds where *child* knows chocolate to be [drawer]
- after 4 yrs, child responds where *Maxi* falsely believes chocolate to be [fridge]
- autists go on failing this task for a long time – although they may eventuallly learn the correct answer

Inertia and closed world reasoning: finding a common denominator of the two tasks

1. one assumes that only those events (affecting the entity of interest, say the chocolate) occur which are forced to occur by the data – here the only such event is the chocolate's change of location from box to drawer
2. one also assumes that events only have those causal effects which are described by one's background theory – e.g. a person's thoughts do not have a causal effect on the location of the chocolate
3. no spontaneous changes occur, that is, every change of state or property can be attributed to the occurrence of an event with specified causal influence

Attribution of beliefs and closed world reasoning

- FBT requires awareness of the causal relation between perception and belief, which can be stated in the form: 'if φ is true in scene S, and agent a sees S, then a comes to believe φ'
- thus Maxi comes to believe that the chocolate is in the fridge
- an application of the principle of inertia (cf. 3 above) yields that Maxi's belief concerning the location of the chocolate persists unless an event occurs which causes him to have a new belief, incompatible with the former
- the story does not mention such an event, whence it is reasonable to assume – using 1 and 2 – that Maxi still believes that the chocolate is in the fridge when he returns
- the causal relation between perception and belief is an essential ingredient in the false belief task, not present in the box task – although both can be seen as executive tasks

Experimental results as failures in closed world reasoning

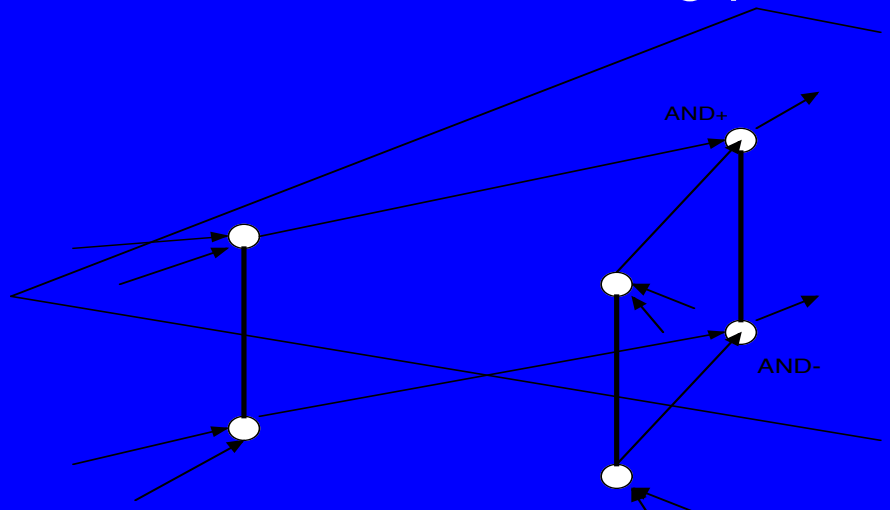
(Stenning-vL, *Human reasoning and cognitive science*, MIT Press 2006)

- FBT: involves notion that *there are only a few specified ways* in which beliefs can form, e.g. by seeing, by being told, and by inference – failure to grasp this leads to wrong answer
- box task: failure to link the observation of the switch to the unknown precondition – leaving the subject with the exceptionless rule

  'reach $\mapsto$ grasp'
- link between executive function and closed world analysis: when a rule of the form $p \wedge \neg ab \longrightarrow q$ is interpreted via closed world semantics, ab acts as inhibitor of q (and there may be something wrong with inhibitory (GABA-ergic) neurons) – more on this presently

More on the neural substrate of closed world reasoning

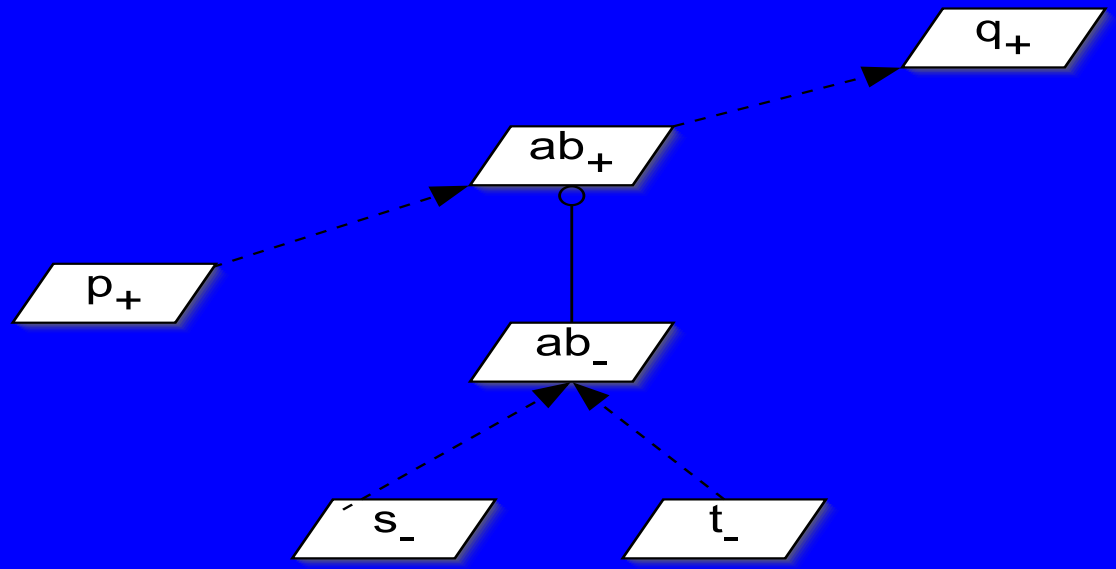
- closed world reasoning can be implemented by a type of neural network known to occur in the brain:
- two (roughly) isomorphic sheets of units connected by inhibitory interneurons, as in the following picture



- this is a consequence of the completeness of closed world reasoning w.r.t. three-valued Kleene logic (Kunen): now represent 'true' as (1,0), 'false' as (0,1), 'undecided' as (0,0)
- the upper sheet computes truth, the lower computes falsity – mutual inhibition preserves sanity

More on the neural substrate of abnormalities in

$$\{p \wedge \neg ab \rightarrow q,\ \neg s \rightarrow ab,\ \neg t \rightarrow ab\}$$



An abnormality ab is represented as the pair of neurons (ab_+, ab_-), where ab_- inhibits ab_+ via an interneuron.

The neuron ab_- collects contextual information, which is computed in the 'false' sheet, indicated by the subscripts '–'.

Possible neurological correlates of failed inhibition in autism

- Levy (2004) pointed out the importance of numbers of units and the balance of excitation/inhibition as modelling factors in understanding autism
- Courchesne (2005): abnormal growth spurt in autistic brain (in particular frontal lobes), followed by abnormally reduced brain growth
- affects large neurons, especially pyramidal cells and inhibitory interneurons
- Dayer et al (2005) present evidence for adult neurogenesis of specific GABA-ergic inhibitory interneurons
- Frith (2003) has proposed that some aspects of autists' functioning may be explicable in terms of abnormalities in pruning
- pruning differentially affects excitatory and inhibitory synapses, reducing the number of the former far more than of the latter

. . . and how this relates to logical processing

- if less pruning goes on in autists' brains, then the result will be more excitatory synapses relative to inhibitory ones
- under-pruning may lead to autists' over-specific, bottom-up style of cognition
- both processes combined (under-developed interneurons, fewer inhibitory synapses) could affect the network for closed world reasoning:
  - since computations on inhibition dictated by context take place in the 'false' sheet of the network
  - and the results of these computations are communicated to the 'true' sheet via inhibitory interneurons
  - if inhibitory neurons/synapses are under-developed, the inhibiting aspect of context cannot be incorporated properly

Executive function and verb tenses

- 'executive function' umbrella term for processes responsible for higher-level action control that are necessary for maintaining a goal and achieving it in possibly adverse circumstances
- so far we have been concerned with inhibition – will now turn to goal maintenance and control of action sequences
- difficulty to maintain goal in working memory: ADHD/Tourette in Go/NoGo tasks
- difficulty in keeping track of where one is in the action sequence: schizophrenia/psychosis (see below)
- these difficulties are likely to show up in deviant verb tenses

From executive function to verb tenses via planning

- in *The proper treatment of events* (vL– Hamm, Blackwell 2004) the construction of event structures from discourses, using tense and aspect, is viewed as a planning problem
- verb tenses are represented as *goals* in the same sense as goals are used in planning
- in both comprehension and production, the goal is to introduce the event corresponding to the tensed VP into the event structure
- goal has to components:
  1. location of event in time
  2. meshing it with other events

From executive function to verb tenses via planning

- example: comprehending the mini-discourse

  'Max fell. John pushed him.'

- goals in this case:
- '`update discourse with past event` e_1 = *fell(m) and fit* e_1 *in context*'
- '`update discourse with past event` e_2 = *push(j,m) and fit* e_2 *in context*'
- planning must determine the event structure; here it tries to determine the order of e_1, e_2
- to determine the order of e_1, e_2, the planning system recruits causal knowledge as well as the principle that causes precede effects

From executive function to verb tenses via planning

- compare this with, say, planning the steps which lead to a pile of pancakes – e.g. causal knowledge dictates that one must pour oil in the frying-pan before putting in the batter
- applied to the case at hand, the planning system scans declarative memory for causal connections between e_1 and e_2 and finds (roughly) 'e_2 causes e_1'
- this fixes the temporal order of e_1 and e_2
- neurophysiological prediction for language comprehension:
  - re-planning must lead to characteristic EEG signal: 'Max fell. John pushed him, or rather what was left of him, over the edge.' – order of e_1 and e_2 can now be different
  - currently tested at F.C. Donders Centre for Neuroimaging Nijmegen (with Hagoort, Baggio)

Production: deviant verb tenses and ADHD

- recall the goal corresponding to a verb tense consists of two components
  1. location of event in time
  2. meshing it with other events
- if someone has trouble maintaining a goal in working memory, this may lead to a simplification of the goal
- in the case of verb tenses most likely simplification to ' location of event in time' (never mind the meshing with other events)
- in the case of the simple past tense, this could lead to a decrease in context-setting verbal material – compare
- ♯ 'John arrived late.'
- 'The workshop dinner was held in 'la Rive'. John arrived late.'

Example: narration in schizophrenia

(J. Wrobel, Language and schizophrenia)

Q. Which of your relatives is still alive?

A. One of my uncles is alive in France. He died already in some kind of car accident.

- evidence of unstable 'now' – corresponds to not knowing where one is in action sequence
- related to 'goal-directed serial alternation task': starting from the number 101, do the following until one reaches 54

  1. subtract 7
  2. add either 1,2 or 3