Logic, language and the brain: a closer look at processing data

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NWO project ‘Reasoning and the brain’
1) From semantics to neuroscience

2) Role of prefrontal cortex in computing meaning

3) Three EEG experiments on meaning processing

4) Towards a neurobiology of meaning
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What has logic got to do with brain and behavior?
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- We’ll discuss what it takes to get to a neurobiology of meaning.
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• These are descriptions of structural properties of and relations
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• These are descriptions of structural properties of and relations
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• Are they neutral with respect to processing architectures and neural
  implementation? Do they place constraints (however soft) on these?
Productivity
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• We are able to produce and understand novel utterances:
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  *My hotel room has no telephone because it was stolen.*
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  ‣ Where do we draw a line between storage and computation?
  ‣ How is this division mapped onto brain structure and function?
Monotonicity/immediacy
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  ‣ How does the brain realize minimal models and recomputation?
Compositionality
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  ‣ How does the brain implement this ‘enriched’ composition?
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- Testing processing consequences of PToE and HRCS using EEG/ERPs
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  - The result is an ERP waveform for a particular condition
  - Each waveform is constituted by different components
Jenny put the sweet in

![Brain波图](image)

- Pz
- 2μV

- Low cloze
- High cloze

0 300 600 900 1200 1500 1800 (msec)

her pocket mouth after the lesson.
The boiled watering-can

Pz

5μV

P600/SPS

Gram. correct

Gram. incorrect

0 600 1200 1800 (msec)

smokes the telephone in the cat.

* smoke
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Left prefrontal cortex
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  - Cytoarchitectonic differences within left PFC (and Broca’s complex)
Memory, Unification, Control

MEMORY: storage of phonological/syntactic/semantic structures (‘frames’) associated to a given construction (morpheme, word, phrase etc.)

UNIFICATION: binding of ‘frames’ associated to different constructions

CONTROL: coordination of retrieval/unification mechanisms, interfacing with other systems (e.g. planning, attention, sensory-motor) etc.
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  - BA 45, 47: semantics
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• How does unification interact with executive control (e.g. planning)?
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  - To what extent is recomputation allowed?
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The progressive
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  2. The girl was writing letters when her friend spilled coffee on the paper.
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- Recomputation: in (4) the completion is first inferred, then suppressed
Behavioural data on the progressive

yellow: atelic  blue: telic

<table>
<thead>
<tr>
<th></th>
<th>main clause</th>
<th>neutr sub. cl.</th>
<th>dis. sub. cl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>yellow: atelic</td>
<td>97.08%</td>
<td>79.58%</td>
<td>72.92%</td>
</tr>
<tr>
<td>blue: telic</td>
<td>94.17%</td>
<td>79.19%</td>
<td>72.86%</td>
</tr>
</tbody>
</table>
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'The girl was writing letters when her friend spilled coffee on the tablecloth.'

(B) Het meisje was brieven aan het schrijven toen haar vriendin koffie op het papier morste. (Activity, disabling)

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• Incremental interpretation, balanced by processes where representations that are no longer consistent with the input are adjusted or discarded
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- SAN effect might index ‘surprise’ or ’entropy’, but also these presuppose some expectation which is ‘defeated’ (defeasibility) by novel information.

- Reasoning and planning are non-monotonic: it would be surprising if language was the exception, assuming it builds upon reasoning and planning.
Complement coercion
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• Compositionality: complex semantic representations are built up based on lexical meanings and syntactic structure only
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• Enriched composition: in (2) a full event sense representation is computed
Coercing - The journalist began the article before his coffee break.

Anomalous - The journalist astonished the article before his coffee break.

Control - The journalist wrote the article before his coffee break.
Coercing-Neutral

300-550 ms

Anomalous-Neutral

300-550 ms

Coercing-Neutral

700-1000 ms

Anomalous-Neutral

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- such a clause triggers first a search for ground atoms \( \text{Initiates}(\text{begin}, \ldots, t) \) and then a unification \( f = \ldots \)
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- roughly speaking these correspond to waves of different frequencies
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• θ band (4-8Hz): search

• Υ band (25-65Hz): unification
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- which is definitely not simple bottom-up compositionality
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• Complex meanings are the result of syntactic combination of lexical meanings plus ‘pragmatic’ information (world knowledge, perception etc.)
1) From semantics to neuroscience

2) Role of prefrontal cortex in computing meaning

3) Three EEG experiments on meaning processing

4) Towards a neurobiology of meaning
Semantics in processing time

- Three time windows in which semantic computation occurs:

  200-400 ms: solving constraints bound to word form (e.g. tense suffixes)

  (‘Yesterday, Vincent paints his house.’)
Three time windows in which semantic computation occurs:

300-600 ms: unification of higher-order semantic features (sense, lexicon)
Semantics in processing time

- Three time windows in which semantic computation occurs:

  400-800 ms: adjusting discourse-level structure (minimal model)
Attractor dynamics in language processing

• Expectations, predictive inferences, semantic plausibility, deduction...

(1) *This morning I had coffee with milk and ____* (attractor: sugar)

(2) *The girl was writing a letter* (attractor: a complete letter)

(3) *The hearty meal was devouring the kids* (attractor: was devoured by)

(4) *If Mary has an essay to write, she studies late in the library.*

   *Mary has an essay to write.* (attractor: she studies late in the library)

• Minimal models, fixed points, stable/attractor states in PFC networks
Circuits for modeling PFC function

Trappenberg (2002)  

Durstewitz et al. (2000)
Attractor behavior of recurrent networks

Durstewitz et al. (2000)
Take home messages
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