An empirical question

Is the brain sensitive to grammar complexity as we know it from computational models?

The new challenge

That language depends on brain activity is well known since the XIX century.

The new question is whether the format of grammar rules depend on it as well.

Ideology vs. biology

"A biological investigation into language must seem paradoxical as it is so widely assumed that languages consist of arbitrary, cultural conventions."

(Lenneberg 1967)

Beyond pathology: the revolution of neuroimaging

- By measuring brain haemodynamics we can get information on local metabolism of brain activity of in vivo and healthy subjects.
- This is considered a sign of the underlying neural activity which is proportional to oxygen level carried by the blood (Friston 1996).

The limits of technology: there are no immediate data.

Since the brain is always entirely active one must at least compare two distinct activities (subtraction) or two different moments of the same activity (parametric analysis).
**Example of subtraction**

First measure: the subject at rest counts backwards from 100 to 0.
Second measure: the subject at rest counts backwards from 100 to 0 and touches his left thumb with the other left fingers.
Second measure minus first measure corresponds to finger movement.

**Step One: on the autonomy of syntax**

Is syntax represented in the brain in an autonomous network?

**An indirect strategy**

Syntax and the Brain: Disentangling Grammar by Selective Anomalies

Syntax is a definitive property of language. As such it cannot be “suspended”. Specific errors at different levels of representation were designed to stimulate selective neural networks.

**A potential problem: syntactic errors may induce semantic ambiguity**

1. A tiger has killed a hen
2. A a has tiger hen killed
3. A snake has killed a hen
4. A a has snake hen killed

**Examples of pseudosentences (English)**

- The gulk ganfed the brals
- Many gluxes atted
- Every blick has blooked the flust
- The coives were searted
- The gulk has blooked the flust
- Every blick atted
- The brals were searted

**Selective errors as detectors of syntax**

- The gulk ganfed the brals (phonological)
- The guls ganfes the brals (morphosyntactic)
- Gulk the ganfes brals the (syntactic)
A selective network for syntax

Broca’s area (Ba 44/45) and the Left Nucleus Caudatus are selectively involved in syntactic processing.

After all, syntax is not just a descriptive artifact.

Further confirmations and new perspectives

The boundaries of language and thought: neural basis of inference making

Step two or the boundaries of Babel

Why aren’t all conceivable grammars realized in the languages of the world?

A simple case study

A friend of mine is happy

Is a friend of mine happy?

#happy is mine of friend a?

A challenging absence

Can it all be explained by assuming a common historical origin for human species or is it rather connected with the neurobiological structure of the brain?

New comparative paradigms

Comparison has always been the elective methods in linguistics.

The new strategy is to test the brain reaction to possible vs. an impossible syntactic rules.
On the neuropsychological reality of phrase structure

The Cortical Representation of the Constituent Structure of Sentences

Cutting different portions of the phrase

A definition of syntactic recursion

| A structure is recursive whenever a structure of type X contains a structure of the same type: |
| \[ \ldots X \ldots \] |

* trivially so if "..." must be empty as in Regular Grammars
The principle of Antisymmetry (Kayne 1994, Moro 2000)

An effect of the recursion: the structure dependence principle

No syntactic rule can refer to the specific position of a word in the linear sequence where it occurs.

Testing the hypothesis: learning impossible rules

Three different experiments tested the rCBF and BOLD signal in Broca’s area during grammaticality judgments of possible vs. impossible rules.

Examples of Recursive Rules

- pro drop
- passivization
- yes/no question formation

Push Down Automata (Finite State Automata plus a memory buffer) are the minimal computational devices that can generate these rules.

Examples of Non-Recursive Rules

Given a sentence consisting of k-words

i A specific word is always inserted in the i-th position.
ii The first word always agrees with the last one
iii The linear order of all words is inverted

The simplest automata, i.e. a Finite State Automata without pumping (Regular Grammars without recursion), can generate these rules.
Possible vs. impossible rules in Italian

<table>
<thead>
<tr>
<th>Rule type</th>
<th>Italian</th>
<th>German</th>
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</thead>
<tbody>
<tr>
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</tr>
<tr>
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<tr>
<td>Region</td>
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<td>Statistical significance</td>
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<td>$P&lt;0.05$</td>
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</table>

The activation rCBF of Broca’s area augmented when the accuracy of possible rules increased, whereas it diminished when the accuracy of impossible rules increased.

Further evidence (I): pseudo-words

- The acquisition of impossible rules was tested with pseudosentences.
- In this case there was no teaching the subjects had to figure out themselves what the rules were.

Further evidence (II): empty ideograms

Possible vs. impossible rules in Japanese

<table>
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Further evidence (II): empty ideograms
Non-rigid

Rigid

Corresponding phenomena

A clear dissociation

Blood flow in Broca’s area augmented when the accuracy of possible rules increased, whereas it diminished when the accuracy of impossible rules increased. No difference was measured in behavioural tests.

Summary

The absence of non-recursive languages cannot be considered a mere historical accident nor a cultural or a conventional fact; this fact must correlate with the functional structure of the human brain.

Step three: brain and complexity

Is the brain sensitive to the different complexity degree of the rules tested in these experiments?

Complexity ranking

Theorem: recursive rules are less complex than non-recursive rules in that they require less memory load.

Corollary: in non-recursive rules, the following ranking of complexity holds i ≡ ii ≥ iii

Language Complexity blindness

The brain distinguishes recursive vs. non-recursive rules without inducing any behavioural difference

The brain does not distinguish among different types of non-recursive rules in terms of complexity.
Kataptation or the lost reasons of Babel.

"Kataptation" or the QWERTY-effect in language evolution

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Abstract

We describe a previously unreported effect of keyboard use on the evolution of language, the "Kataptation" phenomenon. The phenomenon occurs in people with no neurological disorders, but who use the QWERTY keyboard layout. The left hand is more strongly proportional than the right hand, possibly due to the disproportionate use of the left hand during keyboard use. This phenomenon is likely to have important implications for the understanding of language evolution.

References

