Neural mechanisms for the processing of movement and scrambling constructions

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Introduction

Languages feature sentences that implement rather similar meanings through varied word orders. As the resulting representations are related, syntactic theory assumed the existence of a basic word-order, from which others are derived. Movement, an operation of central syntactic significance is assumed in order to capture such regularities (1, 2). Typically, the moved element ("filler") precedes the position from which it is extracted in the base ("gap"). In addition to standard linguistic evidence, there exists behavioral (3-5) and neurological (6-10) evidence for the filler-gap link - a relation of central importance to sentence processing. Cross-linguistic differences complicate the picture. Languages like German, Japanese, and Hindi seem to allow more possible word-orders than English, for which an operation called scrambling (11) is invoked. It is similar to movement in that it maintains filler-gap relations, but is potentially different (12) as it is language specific, and subject to different constraints (13-15). To elucidate whether or how the brain mechanisms differ between the processing of sentences made by movement and scrambling, the present fMRI study examined neural correlates for the processing of sentences constructed by both operations. We tested in German that has both movement and scrambling relations. Secondly, we contrasted the parametric effect of filler-gap distance, thereby overcoming the problem in the direct comparison of two different surface structures.

1 **Movement in topicalization**

I used to sweep these steps with a broom.

Topicalization

These steps, I used to sweep t with a broom.

gap

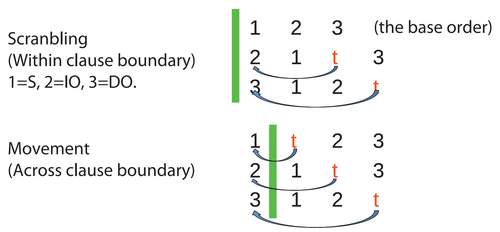
filler

2 **Free word order in German**

The teacher hits the schoolboy.
The schoolboy hits the teacher.
Der Lehrer schlägt den Schüler.
Den Schüler schlägt der Lehrer.

	German	English
Case making(der/den)	+	-
Word order	free	fixed

3 **Schematic representation of scrambling and movement construction**



Methods

Procedure

- Event-related design with pseudo-random order
- Six conditions (S0, S1, S2, M0, M1, M2)
- 9 words/phrases are visually presented one by one with duration of 500 ms and inter-word-interval of 100 ms, →5300 ms per trial

  Gerstern nacht,| glaube ich,| zeigte| dieser |Mann| den| Onkel | dem |Kind.
- Jittered 0 and 800 ms (TR 1600 ms)
- Mean Sentence onset asynchrony is 11.2 s (= 7 vol).
- 40 distinct sentences per condition are given, →240 trials are tested within 45 min
- Comprehension question (yes/no) in 20 % trials
- 1 session
- 22 subjects. Reading span 3.0–5.5

MRI data acquisition

- Axial slices, 24 slices (24 x 3 mm = 72 mm)
- 2.5 mm slice thickness + 0.5 mm gap
- Voxel volume: 3 x 3 x 3 mm^3
- 19.2 cm FOV
- TR = 1600 ms

4 **Experimental stimuli examples**

1. Scr 0
(Adv, glaube ich, V S IO DO.)
Gerstern nacht, glaube ich, zeigte dieser Mann dem Kind den Onkel.

2. Scr 1
(Adv, glaube ich, V IO S t DO.)
Gerstern nacht, glaube ich, zeigte diesem Kind der Mann *t* den Onkel.

3. Scr 2
(Adv, glaube ich, V DO S IO t.)
Gerstern nacht, glaube ich, zeigte diesen Onkel der Mann dem Kind *t*.

4. Mov 0
(S, glaube ich, V t IO DO Adv.)
Dieser Mann, glaube ich, *t* zeigte den Onkel dem Kind gerstern nacht.

5. Mov 1
(IO, glaube ich, V S t DO Adv.)
Diesem Kind, glaube ich, zeigte der Mann *t* den Onkel gerstern nacht.

6. Mov 2
(DO, glaube ich, V S IO t Adv.)
Diesen Onkel, glaube ich, zeigte der Mann dem Kind *t* gerstern nacht.

Analysis

- SPM8. 2 x 3 within subject ANOVA Type(SCR/MOV) x Distance(3 levels)

Results

Behavioural results

2 x 3 within subject ANOVA **TYPE** (SCR/MOV) x **DISTANCE** (3 levels)

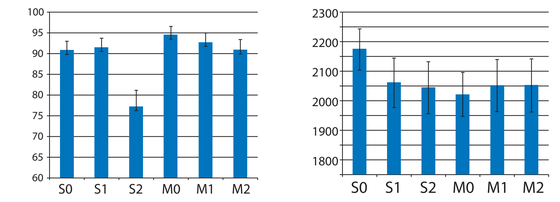
Accuracy

Interaction F(2,40)=5.06 (p<0.05)
Effect of **TYPE** at Distance 2, F(1,20)=14.01 (p<0.01)
Effect of **DISTANCE** at SCR, F(2,40)=11.47 (p<0.01)

RT n.s.

Correlation between Accuracy and RT = -0.26

5 **Accuracy (%) and Reaction time (ms)**



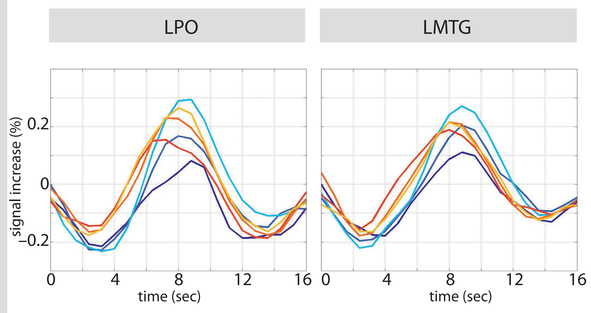
Imaging results

Main effect of DISTANCE
(as t contrast for S0<S1<S2, M0<M1<M2)
Bilateral inferior frontal gyrus, inferior parietal lobuli, and left middle temporal gyrus.

Main effect of TYPE
(as t contrast MOV>SCR)
Bilateral occipital regions

Interaction
No significant interaction was found.

7 **BOLD signal increase and DISTANCE**

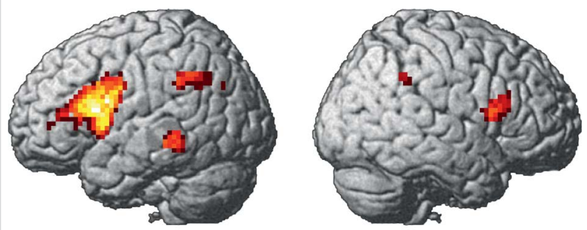


S0, S1, S2, M0, M1, M2

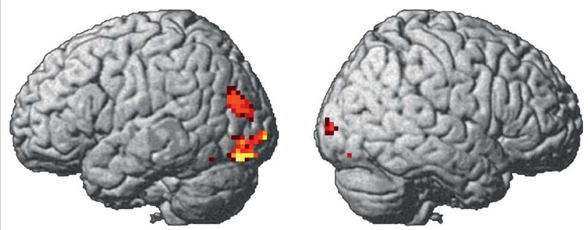
Trial time courses are extracted from 6 mm spherical VOIs from individual data and averaged.

6

A. Main effect of DISTANCE, T contrast for S(M)0<1<2.



B. Main effect of TYPE , T contrast for MOV>SCR.



Discussion

- Processing of scrambling construction seems to be similar to that of movement construction.
- Linking a filler and the gap relies on the bilateral inferior frontal gyrus (including PO), inferior parietal lobuli, left middle temporal gyrus , and left thalamus/basal ganglia.

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