ERP Evidence on the Time Course of Processing Demands in Wh-Dependencies

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Abstract

This study uses ERP measures to investigate the source of the ‘Length Effect’ in processing syntactic dependencies, focusing on the processing of sentences involving long-distance wh-dependencies. It is known that longer structural dependencies incur increased processing demands (Gibson, 1998), but the cause of this Length Effect is unclear. The length effect may be due to increased difficulty in storing long incomplete structural dependencies; alternatively, it may be due to increased difficulty in the integration of material at the completion of long structural dependencies. Existing behavioral results do not clearly distinguish these alternatives. These competing accounts make different predictions about the time course of resource demands, and can be distinguished using ERPs. The experiment tested 4 conditions: a long wh-dependency condition (2-clause extraction), a short wh-dependency condition (1-clause extraction), and control conditions which lacked wh-dependencies. ERPs were collected for each word, in order to track the temporal evolution of the dependency-length effect. The study shows the contribution to the dependency-length effect of both (i) the Left Anterior Negativity, an ERP component associated with storage of structural dependencies (e.g. King & Kutas, 1995), and (ii) the P600, an ERP component associated with integration of words at the completion of syntactic dependencies (Kaan et al., 2000).

The Length Effect

Although natural language grammars are recursive and unbounded, there are practical limitations on the structures that humans can process and represent. The most acute processing limitations involve the representation of incomplete structural dependencies (e.g. subject-verb dependencies, wh-dependencies).

Gibson (1998) presents important evidence for a Dependency Length Effect: longer incomplete dependencies carry additional cost. The clearest evidence for this comes from off-line complexity ratings of two types of embedded structures. Relative clauses embedded inside sentential complements are easier to process than sentential complements embedded inside relative clauses.

The Dependency Length Effect is open to at least two different interpretations.
(1) Passive Constraint: the Length Effect may reflect processing demands that apply during the storage of an incomplete dependency. Such an effect could be due to the decay of the representation of stored elements.
(2) Active Constraint: the Length Effect may reflect processing demands that apply at the point of completion of syntactic dependencies (‘integration cost’, in Gibson’s terms). Such an effect could be due to the expansion of the structural search space as dependencies become longer.

Most existing evidence is compatible with either or both of these sources for the Dependency Length Effect. In particular, evidence from off-line complexity ratings is neutral on the source of the effect. However, the two explanations of the Length Effect make different predictions about the temporal evolution of length-sensitive processing costs. If storage of incomplete dependencies is length-sensitive, then a length effect should be visible during the ‘storage interval’, prior to completion of a structural dependency. If only the completion of dependencies (‘integration’) is length-sensitive, then a length effect should be visible only at the point where a structural dependency is completed.

Design and Predictions

<table>
<thead>
<tr>
<th>Short Wh-dependency</th>
<th>Control</th>
<th>The actress wished that the producers knew that the witty host would tell the jokes during the party.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Which jokes the witty host would tell</strong> during the party.</td>
</tr>
<tr>
<td>Long Wh-dependency</td>
<td>Control</td>
<td>The producers knew that the actress wished that the witty host would tell the jokes during the party.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Which jokes the actress wished that</strong> the witty host would tell during the party.</td>
</tr>
</tbody>
</table>

Storage: Left-Anterior Negativity (LAN)

It has been claimed that the storage of a wh-phrase in an incomplete dependency is associated with a slow-wave left-anterior negativity (LAN). This effect has been observed in multi-word ERPs in comparisons of object vs. subject relative clauses in English (King & Kutas, 1995; Münte et al., 1998), and comparison of dependencies which span 3 vs. 1 adverbial PP in German (Fiebach, Schlesewsky & Friederici, 2001).

If the storage of an incomplete wh-dependency is length-sensitive, then a larger LAN should be observed to the longer wh-dependencies.

Integration: P600

Although the P600 response component is classically associated with the diagnosis and repair of syntactic anomalies (Neville et al., 1991; Osterhout et al., 1992; Hagoort et al., 1992; Friederici et al., 1993), recent reports indicate that it may also be elicited by normal structure-building processes, including the completion of wh-dependencies (Kaan et al., 2000; Fiebach et al., 2001).

If the completion of a wh-dependency is length-sensitive, then a larger P600 should be observed at the completion of the longer wh-dependencies.

Materials

Experimental sentences consisted of 160 sets of 4 sentences (i.e. 640 total), based on the examples above. Each subject saw only one sentence from each of the 160 sets (i.e. 40 sentences per condition), interspersed with 320 filler sentences of comparable length and complexity (i.e. 2.1 filler:target ratio).

Short and Long conditions were identical in overall length, and differed only in the length of the wh-dependency. Lexical material was matched across Short and Long conditions, by transposing the subject and verb of the first two clauses. In order to prevent premature completion of the long wh-dependency, all embedded verbs in these conditions were obligatory S-complement verbs.

Procedure & Participants

EEG recordings were made using a 128-channel geodesic electrode net.

Sentences were presented visually in a RSVP paradigm, at a rate of 500ms/word (300ms on, 200ms off). In order to reduce eye-blink artifacts, all trials began with a fixation point, and the subject initiated sentence presentation by pressing a button. All sentences were followed by a yes/no comprehension question, in order to ensure attention to the content of the sentences. All trials are included in the analyses that follow.

Current results are based on 15 subjects, who each participated in two 2-hour sessions (approx. 2.1/2 hour total recording time. Results from a number of additional subjects had to be discarded, due to recording difficulties.
Results

The actress wished that the producers knew which jokes the witty host would tell during the party.

Beginning

LAN-region (9 channels)

Storage

LAN-region (9 channels)

Integration

LAN-region (9 channels)

P600-region (20 channels)

P600-region (20 channels)

P600-region (20 channels)

As expected, averaged responses to words preceding the onset of the wh-dependency show no difference between conditions at either region of interest.

The figures show averaged responses to all words in the path of the short wh-dependency. Left anterior channels show a significant (p<0.05) negativity (LAN) in the wh-dependency condition, relative to the control condition. Occipital channels show no evidence of a P600 effect in this region. Multi-word ERPs could not be examined, for technical reasons.

The figures show averaged responses to the preposition following the gap-site at the completion of the long wh-dependency. At this word a non-significant positivity was observed in the wh-condition, at the posterior channels where the P600 response is characteristically observed. No P600 was observed immediately at the verb.

The figures show averaged responses to all words in the path of the long wh-dependency. Left anterior channels show a significant (p<0.05) negativity (LAN) in the wh-dependency condition, relative to the control condition. Occipital channels show no evidence of a P600 effect in this region.

The average per-word LAN is equivalent in the short and long conditions. However, the greater number of words involved in the long condition indicate a greater total negativity. This may indicate that storage of a wh-phrase is length-sensitive, but see the caveat below.

Conclusion

The goal of this study was to examine the source of the Dependency Length Effect in sentence processing, by taking advantage of the time-course information provided by ERPs.

For technical reasons, the current recordings had a relatively poor resolution, and therefore less detailed information is available than expected. For the same reasons, all conclusions should be considered preliminary, and in need of replication.

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The figures show averaged responses to the preposition following the gap-site at the completion of the long wh-dependency. At this word a non-significant positivity was observed in the wh-condition, at the posterior channels where the P600 response is characteristically observed. There is insufficient power in the current results to determine whether the P600 response indicates length-sensitivity of syntactic integration processes.

References


Acknowledgments

We would like to thank Bara Kalbik and Tom Pelleth for their help in running the experiments. This work was supported in part by a grant from the McDonnell-Pew Program in Cognitive Neuroscience and by NSF grants BCS-0196004 and SBR-9977928.