Processing Japanese sentences as a zero-sum game
Shodai Uchida, Manabu Arai, Edson T. Miyamoto, and Yuki Hirose

Special thanks to Takane Ito,
Douglas Roland

Expectations in comprehension

- We build expectations about upcoming material during comprehension

- Many previous studies demonstrated expectations at the lexical level (e.g., Kutas & Hillyard, 1980)

- Recent studies demonstrated expectations at the syntactic level (structural prediction) (e.g., Staub & Clifton, 2006; Lau et al., 2006)

Surprisal theory (Hale, 2001; Levy, 2008)

- Expectation is directly linked to cost
- Expected processing difficulty is proportional to the change in the probability distribution over possible structural options from one word to the next
  \[ \text{difficulty} \propto - \log P(w_i|w_{i-1}, \text{CONTEXT}) \]
- A word that triggers a large change in the distribution is difficult to process
  \[ \Rightarrow \text{Narrowing structural options (i.e., pruning) should be associated with cost} \]

Consider the following two sentences

(a) 女子高生はデザイナーにネックレスを注文した。
  school girl-top designer-dat necklace-acc
  • intransitive \(\Leftarrow\) pruned
  • transitive \(\Leftarrow\) pruned
  • ditransitive \(\Leftarrow\) pruned
  \(\ldots\)
  \(\Rightarrow\) larger cost for pruning

(b) 女子高生はデザイナーのネックレスを注文した。
  school girl-top designer-gen necklace-acc
  • intransitive \(\Leftarrow\) pruned
  • transitive \(\Leftarrow\) pruned
  • ditransitive \(\Leftarrow\) pruned
  \(\ldots\)
  \(\Rightarrow\) smaller cost for pruning

Consider the following two sentences

(a) 女子高生はデザイナーにネックレスを注文した。
  school girl-top designer-dat necklace-acc
  • intransitive \(\Leftarrow\) pruned
  • transitive \(\Leftarrow\) pruned
  • ditransitive \(\Leftarrow\) pruned
  \(\ldots\)
  \(\Rightarrow\) smaller cost for pruning

(b) 女子高生はデザイナーのネックレスを注文した。
  school girl-top designer-gen necklace-acc
  • intransitive \(\Leftarrow\) pruned
  • transitive \(\Leftarrow\) pruned
  • ditransitive \(\Leftarrow\) pruned
  \(\ldots\)
  \(\Rightarrow\) larger cost for pruning
Consider the following two sentences

(a) 女子高生は デザイナーに ネックレスを 注文した。
school girl-top designer-dat necklace-acc ordered
larger cost for pruning  \rightarrow \text{smaller cost for pruning}

(b) 女子高生は デザイナーの ネックレスを 注文した。
school girl-top designer-gen necklace-acc ordered
smaller cost for pruning  \rightarrow \text{larger cost for pruning}

⇒ processing sentences as a zero-sum game

Konieczny and Döring (2003)

• Contrasted a dative NP with a genitive NP with head-final construction in German

(a) Subject, [that NP-nom NP-dat NP-acc verb], verb ....
(b) Subject, [that NP-nom NP-gen NP-acc verb], verb....

The verb was read faster in (a) than in (b)

• The dative NP, but not the genitive NP, facilitated the processing of the verb (i.e., anti-locality effect)

What’s still missing

• If early pruning at the preverbal arguments indeed facilitated the processing at the verb, the early pruning of unlikely structural options itself should cause processing cost.

• Such pruning cost has not been documented so far

Cost of pruning

• There should be cost associated with pruning at preverbal arguments

Our study

• Contrasted the dative NP with the genitive NP with Japanese head-final construction (Konieczny & Döring, 2003)

• Investigated whether we observe increased cost at the preverbal constituents (early pruning) and reduced cost at the verb for the sentence with a dative NP

(a) NP-top NP-dat NP-acc verb

\text{cost for early pruning} \rightarrow \text{reduced cost}

(b) NP-top NP-gen NP-acc verb

\text{no pruning} \rightarrow \text{cost for late pruning}

Estimating the probability of the upcoming ditransitive structure

• We conducted a sentence completion test

• participants produced continuations to the fragments below

(a) NP-top NP-dat......
(b) NP-top NP-gen......

• We also included the fragments with an adjective and noun without case maker

(a') NP-top NP-dat Adjective Noun......
(b') NP-top NP-gen Adjective Noun......

• We had 24 items and tested 32 native speakers of Japanese
A significant main effect of NP1 Case ($p < .001$)

1. More ditransitive sentences with dative NPs than with genitive NPs

A significant interaction between case (dative/accusative) and construction type (+/- adjective + noun) ($p < .001$)

2. Even more ditransitive sentences when the dative NP followed an adjective + noun

More ditransitive sentences with dative NPs than with genitive NPs

…

Our study: Manipulation

- Manipulated case for NP1 (dative vs. genitive)
- Also manipulated case for NP2 (accusative vs. nominative)

The probability of the ditransitive structure

(a) NP-top NP1: dat
(b) NP-top NP1: gen

more ditransitive structures are predicted

⇒ processing cost is predicted to be larger in (a) than (b)

less ditransitive structures are predicted

no difference

The majority of the prediction after the NP-dat was ditransitive. The majority of prediction of the ditransitive structure will be pruned by the NP-nom.

Cost of early pruning at preverbal NPs

NP1

(a, c) NP-top NP1: dat Adjective + NP2

pruning cost

(b, d) NP-top NP-gen Adjective + NP2

no pruning

In the dative condition (a,c), options other than ditransitive structure are pruned at NPs.
**Prediction II**
- Reduced cost at the ditransitive verb (V1) following NP\-dat

<table>
<thead>
<tr>
<th>Case</th>
<th>NP1</th>
<th>NP2</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>NP-top</td>
<td>NP-dat Adjective no pruning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>NP-top</td>
<td>NP-gen Adjective no pruning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>NP-top</td>
<td>NP-dat Adjective pruning cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>NP-top</td>
<td>NP-gen Adjective pruning cost</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) < (b)  
(c) ≈ (d)

- Measured eye-movements during reading using EyeLink II (SR Research)

**Method**
- Created 24 items
- N=32 native speakers of Japanese (One participant excluded due to low comprehension question accuracy)

**Data analysis**
- We focus on the following measures
  - First pass (fp) = 1 + 2
  - Regression path (rp) = 1 + 2 + 3 + 4
  - Second pass (sp) = 8
- Reading times were analyzed using Linear Mixed Effects models
- The best-fit model with the optimal random slope structure was selected using a backward selection approach

**Regions of our interest**
We report the results for the following regions

<table>
<thead>
<tr>
<th>Subject</th>
<th>NP1</th>
<th>Adjective</th>
<th>NP2</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>That school girl</td>
<td>the designer</td>
<td>unique earing</td>
<td>ordered want</td>
<td>seem</td>
<td>said</td>
</tr>
<tr>
<td>-top</td>
<td>-dat/gen</td>
<td>-acc/nom</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NP1 Region**
- No main effects or interaction in any measures

**Adjective Region (first pass no regression)**
- A main effect of NP1 Case (p<.05)

- NP1 dative slower than NP1 genitive
- The cost of early pruning (= Prediction I)

<table>
<thead>
<tr>
<th>Subject</th>
<th>NP1</th>
<th>Adjective</th>
<th>NP2</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>That school girl</td>
<td>the designer</td>
<td>unique earing</td>
<td>ordered want</td>
<td>seem</td>
<td>said</td>
</tr>
<tr>
<td>-top</td>
<td>-dat/gen</td>
<td>-acc/nom</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Summary of results

<table>
<thead>
<tr>
<th>Subject</th>
<th>NP1 Case</th>
<th>Adjective</th>
<th>NP2 Case</th>
<th>V1 Case</th>
<th>V2 Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>That school girl</td>
<td>top</td>
<td>the designer</td>
<td>unique</td>
<td>earring</td>
<td>ordered</td>
</tr>
</tbody>
</table>

- **NP-dat > NP-gen**
  - Increased cost due to early pruning before the verb
- **NP-dat NP-acc < NP-gen NP-acc**
  - Reduced cost at the verb following the early pruning

However, we are still not sure whether increased cost and reduced cost are directly related in individual trials.

---

### Further Analysis

**Link between early pruning cost and late reduced cost**

- All the previous analyses examined reading times in each region separately.
- We still do not know whether the slower reading times at Adjective were indeed paired with the faster reading times at V1 in individual trials.
- We paired the first pass no regression times at Adjective with second pass times at V1 for each trial and calculated their log-ratio.

### Further Analysis

**Link between early pruning cost and late reduced cost**

- A significant interaction between NP1 Case and NP2 Case ($p<.05$)
- The same pattern of interaction in total times at V1 ($p<.05$)
Further Analysis

Link between early pruning cost and late reduced cost

- The ratio in dative-accusative was greater than genitive-accusative (dative: 3.22; genitive: 2.42; p < .05)
- No difference between dative-nominative and genitive-nominative (p > .1)

Reading times at the Adjective region and those at V1 region are linked

Summary of further analyses

In ditransitive structure,

Conclusions

- Confirmed two predictions based on surprisal
  1. early increased cost at nouns
     - Two preverbal arguments pruned structural options, causing early pruning cost
     (new finding for this study)
  2. late reduced cost at verb
     - The cost at the ditransitive verb was reduced due to early pruning
     (replication of Konieczny and Döring (2003))

- 1. and 2. are related within individual trials
  ⇒ underscoring the zero-sum nature of the processing

Thank you for listening!!