Processing Japanese sentences as a zero-sum game

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Abstract
As people read sentences word by word, they continuously predict upcoming information. Such expectations have been formalized by surprisal theory (Hale, 2001; Levy, 2008). According to surprisal, in head-final constructions, pre-head constituents can be used to predict the type of upcoming verb (e.g., intransitive, ditransitive), thus facilitating processing when the verb is read. Results in head-final constructions in German support this prediction (Konieczny and Döring, 2003). However, these results only address surprisal’s predictions at the verb. The facilitation at the verb should be preceded by pruning cost when the pre-head constituents are processed. We conducted an eye-tracking reading experiment and confirmed the two sides of surprisal’s predictions: early pruning of irrelevant interpretations leads to slowdowns at the preverbal arguments and facilitation later at the verb. And further analyses confirmed that the early cost of pruning and later facilitation are directly linked within individual trails.

1 Introduction
As people read sentences word by word, they continuously predict upcoming information. Many previous studies demonstrated expectations at the lexical level (e.g., Kutas & Hillyard, 1980). Recent studies also demonstrated expectations at the syntactic level which are often called structural prediction (e.g., Staub & Clifton, 2006; Lau et al., 2006). Such expectations have been formalized by surprisal theory (Hale, 2001; Levy, 2008) providing a direct link between expectations during sentence comprehension and processing cost at each point of the sentence being processed. According to surprisal, processing difficulty is proportional to the change in the probability distribution over possible structural options at each word. So a word that triggers a large change in the distribution is predicted to be difficult to process. This suggests that the operation of narrowing the possible structural options, or pruning, should be associated with a cost. For example, if NPs in head-final constructions are used to narrow down the types of possible upcoming verbs (e.g., intransitive verbs are unlikely to follow an accusative NP), then they should lead to long reading times. But this early pruning should facilitate processing later in the sentence as less pruning will be required when the verb is read.

The prediction for facilitation at the verb was confirmed by a study using head-final constructions in German (Konieczny and Döring, 2003) as the embedded verb was read faster after dative-accusative arguments compared to genitive-accusative arguments. However, this result only supported surprisal’s predictions at the verb. If the facilitation at the verb was indeed due to early pruning of unlikely structural options, the pruning itself at the pre-head constituents should incur a processing cost. But such pruning cost has not been documented so far. In this study, we contrasted dative NPs with genitive NPs in Japanese head-final ditransitive constructions and investigated whether the reduced cost at the verb was preceded by increased difficulty at the preverbal constituents due to early pruning.

2 Experiment 1: Sentence Completion Task
In order to better evaluate the results of the eye-tracking reading-time experiment, we conducted a sentence completion study to estimate the probability of the ditransitive structure following the dative or genitive NP as well as following the adjective and noun after the dative or genitive NP. We recruited 32 students from the University of Tokyo, who were all native speakers of Japanese. The participants were asked to produce continuations to the fragments in (1a-d). In (1a, c), the case maker of the NP1 (“designer”) was dative, and in (1b, d), it was genitive.

(1a/b) sono josikosei-wa dezaina-ni/no ..... that school girl-TOP designer-DAT/GEN ..... (1c/d) sono josikosei-wa dezaina-ni/no koseitekina iyaringu ..... that school girl-TOP designer-DAT/GEN unique earring ..... 

We coded whether the completions were ditransitive structures or not. In general, the ditransitive
structure was more likely to be produced after the dative NP in (1a, c), than after the genitive NP in (1b, d) (45% after the dative NP in (1a), and 3% after the genitive NP in (1b), p<.001; 88% after the dative NP in (1c), and 1% after the genitive NP in (1d), p<.001). Moreover, the ditransitive structure was produced more often for (1c) than for (1a), but there was no difference between (1b, d) (interaction: p<.001). The results of the sentence completion task suggest that the preverbal dative NP led to the prediction of the ditransitive structure, and that prediction became stronger with an additional adjective and noun after the dative NP. On the other hand, the ditransitive structure was not predicted by the genitive NP (only 3%) and that prediction did not become stronger with an additional adjective and noun after the genitive NP.

3 Experiment 2: An eye-tracking reading experiment
3.1 Method
Twenty-four pairs of stimuli were constructed in Japanese sentences as in (2). We manipulated case markers at two points in a 2 x 2 design. NP1 Case (dative or genitive) marked NP1 “designer”. NP2 Case (accusative or nominative) marked NP2 “earring”. When NP1 Case is dative, NP1 is the indirect object of an upcoming verb; when NP1 Case is genitive, NP1 modifies NP2 (“designer’s unique earring”). When NP2 Case is accusative, NP2 is the direct object of V1 (“ordered”); when NP2 Case is nominative, NP2 is the object of V1 (“want”).

Examples: Subject NP1 Adjective NP2 V1 V2
(2a/b) sono josikosei-wa dezaina-ni/no koseitekina iyaringu-o chumonsita rasii that school girl-TOP designer-DAT/GEN unique earring-ACC ordered seem “That school girl seems to have ordered the unique earring to/of the designer.”
(2c/d) sono josikosei-wa dezaina-ni/no koseitekina iyaringu-ga hosii-to itta that school girl-TOP designer-DAT/GEN unique earring-NOM want-COMP said “That school girl said that she wants the unique earring to/of the designer.”

Thirty-two students from the University of Tokyo, who were all native speakers of Japanese, were paid to participate in the reading-time experiment.

3.2 Predictions
3.2.1 Prediction I
Considering the results of the sentence completion task, we expect to observe cost of early pruning at NP1, or possibly at NP2 as well. Pruning may occur at the dative NP to eliminate alternatives other than ditransitive verbs, so the dative NP should incur a cost related to early pruning in (2a, c) compared to the genitive NP in (2b, d).

3.2.2 Prediction II
The ditransitive verb V1 should be easier to process in (2a) than in (2b), because alternatives (e.g., transitive verbs) that were eliminated during early pruning in (2a) have to be eliminated in (2b). On the other hand, in (2c) and (2d), because the nominative NP violates the prediction of the ditransitive structure and the sequence “NP2-NOM V1” is unexpected (less than 5% in the sentence completion task), so we expect to find large processing difficulty for both verbs in (2c) and (2d). In short, at V1, we expect to observe an interaction in the reading times.

3.3 Procedure and eye-tracking measures
Participants’ eye movements were monitored using an eye tracker (EyeLink II, SR Research) while they read sentences such as those in (2). Before each trial, a small black square appeared and as soon as participants fixated it, the sentence was displayed on the screen. When participants finished reading the item, they pressed a button on a controller. In about one third of the trials, balanced across conditions, a comprehension question was displayed before proceeding to the next trial. Participants responded to the questions using buttons on a controller and did not receive feedback. Twenty-four sets of experimental
stimuli were distributed into four lists according to a Latin-Square design and shown together with 48 distractor sentences in pseudo-random order. We report first pass reading times (the time spent in a region before moving on or looking back) and regression path reading times (the time from first entering a region until moving the eyes beyond that region, including regression time) as first pass measures and second pass times (duration of re-fixation) as re-reading measure.

3.4 Data analysis

One participant was excluded from the analysis due to low comprehension question accuracy (M = 93.9%; SD = 7.2%; the accuracy of this participant was 67%, whereas that of the others were more than 83%). Data beyond three standard deviations from each condition-region mean were eliminated. The trimming procedure affected less than 2% of the reading-time data in each region and measure. The reading times were analyzed using linear mixed effect (LME) models.

3.5 Results

3.5.1 Preverbal regions in first pass measures

There were no differences at the subject or at NP1 in first pass measures. At the adjective “unique”, there was a main effect of NP1 Case in first-pass no regression reading times (the dative conditions (2a, c) were read more slowly than the genitive conditions (2b, d), p<.05; see Figure 1) suggesting that the adjective after the dative NPs led to more pruning.

At the NP2 region, the accusative NP was read more slowly than the nominative NP in regression path times (p<.05). This was not expected because the nominative continuation was unexpected and thus should take longer. We suspect this is due to parafoveal preview because the verbs in the following region were different. We therefore included the number of characters of the following verbs in analysis, and the result of the main effect disappeared (p>.1).

3.5.2 Verb regions in first pass measures

There was an interaction at the verb V1 in right-bounded times (p<.01; also in regression path times, p<.01). The verb following the dative-accusative sequence (i.e., NP1 Case dative; NP2 Case accusative) was read faster than that following the dative-nominative sequence (p<.05); whereas the verb following the genitive-accusative sequence and the verb following the genitive-nominative sequence did not differ (p>.1). The same pattern of interaction was observed at the verb V2 in first pass no regression times (p<.001).

3.5.3 Re-reading measures

At the NP1 region, there was an interaction in total times (p<.05; also a marginal effect in second pass times, p=.084) as there was a trend for the NP1 in the dative-accusative sequence to be read faster than that in the dative-nominative sequence.

At the verb V1, there was an interaction in second pass times (p<.05; also in total times, p<.05) as in Figure 2. The verb following the dative-accusative sequence was faster than that following the dative-nominative sequence (p<.01); whereas the verb following the genitive-accusative sequence and that following the genitive-nominative sequence did not differ (p>.1).

Figure 1: First pass no regression reading times in the Adjective region.  
Figure 2: Second pass reading times in the V1 region.
4 Further Analyses

4.1 Further Analyses I: early pruning

To investigate what incurred the cost of early pruning at the adjective, we modeled the early cost of pruning with the estimated probability for the ditransitive structure from our sentence completion test (mentioned in 2). We calculated the probability for the ditransitive structure for each item. In the LME model, we entered the item-by-item probabilities for the ditransitive structure and tested whether these probabilities could account for first pass no regression reading times at the Adjective region. In the first analysis, we entered the item-by-item probabilities estimated for the fragment up to NP1 (1a, b) as a single fixed factor in the LME model. However these probabilities did not account for the reading times at the Adjective region (p>.1). In the second analysis, we entered the item-by-item probabilities estimated for the fragment up to NP1 with an adjective and noun (1c, d) as a single fixed factor in the LME model. The result showed a marginally significant effect (p=.067) and this suggests that early pruning cost reflected the probability up to N2 without case maker.

4.2 Further Analysis II: relation between early pruning and facilitation at the verb

All the previous analyses examined reading times in each region separately. Hence, it is unclear whether the slow reading times at the Adjective region were related to the fast reading times at the V1 region in individual trials. So we conducted another analysis to investigate this possibility. We calculated the log-transformed ratio (log-ratio) between the initial cost of pruning (in the first-pass times with no regressions in the Adjective region) and the later cost reduction (in the second pass times in the V1 region) for each trial while controlling for the influence of word length in these regions (i.e., log(first pass no regression times at Adjective / second pass times at V1)). This ratio indexes a change in processing cost from the former region to the latter (a larger value indicates greater reduction of cost in the latter region relative to the former region). The analysis showed a significant interaction between NP1 Case and NP2 Case (p<.05). When NP2 Case was nominative, there was no reliable difference for NP1 Case (p>.1). When NP2 Case was accusative, there was a significant effect for NP1 Case (dative: 3.00; genitive: 2.42; p>.05). This indicates that the effects within individual trials were linked: pruning costs observed early were associated with ease of processing later in the accusative conditions (2a, b) but not in the nominative conditions (2c, d). Comparable results were observed when total times were used instead of the second pass times for the V1 region.

5 Discussion

In sum, we confirmed the two sides of surprisal’s predictions: early increased cost at the two preverbal arguments to prune irrelevant structural options (i.e., early pruning) led to reduced costs later at the ditransitive verb. The results are compatible with the interpretation that dative markers are more felicitous followed by accusative markers (see Kamide et al., 2003, for related results) than nominative markers. In contrast, genitive markers only require a noun to come next without restricting its case marker.

References