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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 34(34)

ISSN
1069-7977

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Publication Date
2012

Peer reviewed

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Abstract

Previous studies reported that language comprehenders tend to preserve the initial incorrect analysis with temporarily ambiguous sentences following structural reanalysis (Christianson et al., 2001; van Gompel et al., 2006). One possible criticism is that the sentences tested in previous studies allow comprehenders to pragmatically infer that the initial misanalysis may be true. It is thus unclear whether the tendency can still be observed where such inferences are not possible. The current study therefore tested the relative clause sentences in Japanese, which are temporarily ambiguous between the main clause and relative clause analysis. Crucially, our sentences differed from those in the past studies in that the correct interpretation following reanalysis makes an interpretation for the initial analysis pragmatically incompatible. The results demonstrated that an interpretation for the initial analysis persists even without pragmatic inference and that such incomplete syntactic representations are most likely due to excessive processing load.

Keywords: good-enough representation; garden-path sentence; self-paced reading; eye-tracking; reading

Introduction

It is known that structurally ambiguous sentences such as *While the man hunted the deer ran into the woods* cause readers to experience difficulty at the point where the structure is disambiguated (i.e., *ran*), which indicates that they initially adopted an incorrect analysis (i.e., the transitive analysis). Past research showed that in processing this type of ambiguous sentences, language comprehenders tend to preserve an interpretation of the initial incorrect analysis even after the structure was fully reanalyzed and they often end up with incomplete, or so-called *good-enough* sentence representations (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Ferreira, Bailey & Ferraro, 2002). In Christianson et al. (2001), for instance, participants read sentences like (1) and were next shown comprehension questions like (2). Their results showed that participants often answered incorrectly by responding "yes". Christianson et al. (2001) argued that the reanalysis of ambiguous sentence structures is not always complete and the initial incorrect analysis often remains preserved and not fully suppressed.

(1) While Anna dressed the baby spit up on the bed.
(2) Did Anna dress the baby?

However, in their study as well as their follow-up studies (e.g., Christianson, Williams, Zacks, & Ferreira, 2006; Ferreira et al., 2002 for the review), it is arguable that the initial incorrect analysis, even though it was suppressed following reanalysis, may have been re-activated by processing the question sentences. Another criticism for their argument of incomplete representations is an influence of pragmatic inference. For example, even with their items with reflexive verbs such as (1), it is still possible to infer that the baby spit up while being dressed by Anna even though such an interpretation is not syntactically licensed. The first issue was addressed by van Gompel, Pickering, Pearson, and Jacob (2006), who reported an effect of syntactic priming for the initial incorrect analysis. In their study, participants first read a prime sentence that was either structurally ambiguous (3a) or unambiguous with a comma following the subordinate clause verb (3b). Next, they completed a sentence fragment such as *When the doctor was visiti….*

(3a) While the man was visiting the children played outside.
(3b) While the man was visiting, the children played outside.

Their results showed that participants produced more transitive sentences following (3a) than following (3b), providing evidence that the initial incorrect analysis remained activated. However again it is possible to infer that in the example (3a) the man was visiting the children who played outside. It is therefore unclear from previous studies that the initial incorrect analysis would still remain activated and its interpretation would persist even where such pragmatic inferences are not possible.

To address this issue, the current study tested Japanese relative clause structure such as (4).

(4) *Akachan-ga nomimono-o koboshita joyuu-o jitto mitusmeta.*
Subject [RC object RC verb] RC head adverb MC verb
Baby-NOM [drink-ACC spilled] actress-ACC fixedly stared at
'The baby stared fixedly at the actress who spilled the drink.'

In Japanese, relative clauses precede lexical heads without an overt complementizer and without any grammatical marking on the verb. This creates local syntactic ambiguity up to the first verb (*koboshita,* 'spilled'); on hearing the verb, the structure is ambiguous between a main clause (MC, henceforth) and a relative clause (RC). It is known that people initially analyze the first verb as a part of MC and construct a sentence representation of the sentence-initial

NP (*akachan*, 'baby') to be the agent-subject of the verb, as in (4a). Upon encountering another noun phrase (NP) following the verb (i.e., *joyuu,* 'actress'), readers are forced to reanalyze for a correct syntactic structure that the initial verb phrase is a part of an embedded RC that modifies the RC-head NP (4b).

(4a) [*Akachan-ga nomimono-o koboshita*]
(4b) *Akachan-ga* [*nomimono-o koboshita*] *joyuu-o*

Crucially, the correct interpretation following reanalysis with Japanese RC sentences makes the interpretation of the initial misanalysis pragmatically incompatible. For the example (4), it is impossible to infer that the baby spilled milk after readers correctly reanalyze the structure. This is because Japanese RC structure does not include an implicit argument and therefore there is no ambiguity about who did the spilling action after reanalysis. On the other hand, English sentences in previous studies always included an implicit argument for the verb, which created ambiguity about the direct object.

Using this structure, we manipulated semantic bias of the direct object noun within the RC. Past research demonstrated that readers integrate non-structural information without delay in processing similar ambiguous sentences (e.g., McRae, Spivey-Knowlton, & Tanenhaus, 1998; Garnsey, Pearlmutter, Myers, & Lotocky, 1997). McRae et al. (1998) showed that when a subject noun is plausible as patient but implausible as agent (e.g., *The crook arrested by the detective was guilty…*), readers were more likely to consider the infrequent RC structure on encountering the verb and the preposition *by* within the RC. Also, Garnsey et al. (1997) demonstrated that plausibility of post-verbal nouns as a direct object immediately affected the processing of temporary ambiguous sentence complement sentences (e.g., *The senior senator regretted the decision/reporter had ever…*). Importantly, the plausibility effect interacted with structural bias of individual verbs; when the verb was biased toward the sentence complement, there was no ambiguity cost irrespective of whether the post-verbal noun was plausible as a direct object or not. These results indicate that the verb introduces possible thematic roles within its event semantics and readers check the fit with those roles for each candidate phrase and assess the probabilities of possible structures. Importantly, as Garnsey et al. (1997) suggests, the verb bias appears to exert a stronger influence than the thematic-fit of postverbal elements in English.

On the other hand, in Japanese, the semantics of any arguments may affect parsing since the head does not appear until the end of a clause/sentence. This is rather likely as many studies now demonstrated evidence for pre-head structural analysis (Kamide, Altmann, & Haywood, 2003; Miyamoto, 2002). In fact, Inoue (2006) observed greater processing difficulty with similar RC sentences when the subject noun was biased toward the MC analysis than when it was not. In the present study, we adopted a similar manipulation on the RC direct object and examine whether the preservation of the initial incorrect analysis would be observed where there is no room for pragmatic inference and, if it is, whether the difference in processing difficulty due to the manipulation of semantic bias would in any way be related to the tendency to preserve the initial analysis.

Experiment 1

We conducted a moving window self-paced reading experiment with word-by-word presentation.

Participants

Twenty-four native speakers of Japanese, recruited from the student community at the University of Tokyo, participated in the experiment in exchange for small remuneration.

Materials

We created 24 sets of experimental items such as (5). We manipulated semantic bias of the direct object for the two alternative analyses at three levels; *MC-biased* (the RC object is biased toward the MC analysis, 5a), *Neutral* (the RC object is neutral toward either the MC and the RC analysis, 5b), and *RC-biased* (the RC object is biased toward the RC analysis, 5c).

(5a) *MC-biased*
Akachan-ga miruku-o koboshita joyuu-o jitto mitusmeta.
Baby-NOM [milk-ACC spilled] actress-ACC fixedly stared at
'The baby stared at the actress who spilled the milk.'

(5b) *Neutral*
Akachan-ga nomimono-o koboshita joyuu-o jitto mitusmeta.
'The baby stared at the actress who spilled the drink.'

(5c) *RC-biased*
Akachan-ga shanpan-o koboshita joyuu-o jitto mitusmeta.
'The baby stared at the actress who spilled the champagne.'

If the manipulation of semantic bias has an influence on processing the RC sentences before the RC head is encountered, the sentences in the MC-biased condition and the Neutral condition should initially be analyzed as a MC and exhibit processing difficulty at the disambiguating region. People may commit more strongly to the MC with the former condition than the latter condition because the MC analysis is highly plausible. In contrast, the sentences in the RC-biased condition may be initially analyzed as a RC or be reanalyzed easier because of the MC analysis is less plausible and the RC analysis is highly plausible.

Design

Three experimental lists were created using a Latin square design, in which each experimental item appears only once in one condition in each list. Each list contained 72 fillers. The comprehension questions followed all the 24 experimental items and 72 fillers. All the questions following the experimental items inquired about the agent of the event denoted by the relative clauses with two options shown below the questions (e.g., *Who spilled the milk? BABY / ACTRESS* for (5a)).

Procedure

Before each trial, participants saw a star that appeared on the left edge of the screen. They then pressed the space bar to reveal the first word in the sentence. They pressed the space bar to reveal the next word, following which the previous one was masked again. They continued doing so until they reached the end of the sentence. The experimental session began with two practice items.

Results

Reading Times We removed all trials including a region with a reading time that was either extremely long (8000 ms or over) or extremely short (250 ms or under) (Sturt, Pickering, & Crocker, 1999). This resulted in the exclusion of 5.0% of the whole data. For the remaining data, all reading times over 2.5 standard deviations either side of the mean for each participant and each region were replaced with the cut-off value (Sturt, Pickering & Crocker, 1999). We analyzed the reading times using Linear Mixed Effects models (e.g., Baayen, 2008; Baayen, Davidson, & Bates, 2008), including Semantic Bias as a fixed effect with Number of Characters as a covariate. We also included participants and items as random effects. Furthermore, we checked whether the model improved its fit by adding random slopes for each participant and item with a forward-selection approach. Figure 1 shows the mean reading times in the disambiguating region; the RC head (e.g., actress-ACC) per condition.

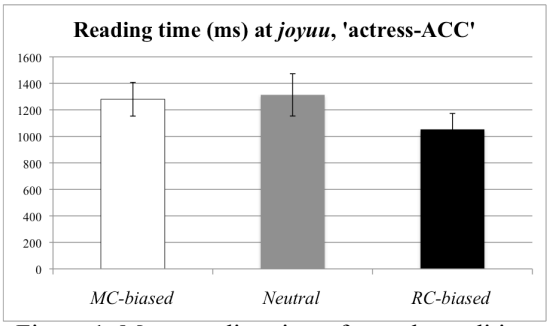

Figure 1: Mean reading times for each condition (Experiment 1). Error bars denote 95% confidence intervals.

The analysis on the reading time in the disambiguating region revealed significant differences between the conditions. In the RC-biased condition, the disambiguating region was read faster compared to the other two conditions (β = -217.9, t = 2.94, p < 0.01 for RC biased vs. MC biased; β = -245.9, t = 3.33, p < 0.01 for RC biased vs. Neutral). There was no difference between the MC-biased and the Neutral conditions (t < 1).

Comprehension Accuracy Table 1 shows the percentage of correct answers for comprehension questions. We analyzed the log-odd of correct answers using LME models with a binomial function following the same model selection procedure as for the reading time analysis.

The results showed no difference between the conditions (z < 1 for MC-biased vs. Neutral; β = 0.03, z = 1.50, p = 0.13 for MC-biased vs. RC-biased, β = -1.49, z = 1.66, p = 0.10 for RC-biased vs. Neutral).

Table 1: Percentage of Correct Answers for the Comprehension Questions.

MC-biased	96.1%
Neutral	95.6%
RC-biased	98.9%

Experiment 2

In Experiment 1, we observed a difference in reading times due to bias of the RC direct object but failed to observe its effect on the responses to the comprehension questions. One possibility for this is that processing of the RC structure may have been relatively easy despite the difference in the reading times (i.e., a ceiling effect). In Experiment 2, we thus used sentences with the longer ambiguous region in an effort to increase the processing cost by leading participants to commit to the MC analysis for a prolonged period.

Participants

Thirty native speakers of Japanese were recruited from the same population as in Experiment 1. None of them participated in the previous experiment.

Materials, Design, and Procedure

The material and design were identical to those in Experiment 1, except that we added two adverbial phrases (underlined) to lengthen the ambiguous region in the relative clause as in (6).

(6a, b, c) *MC-biased / Neutral / RC-biased*
Akachan-ga miruku / drink / shanpan-o <u>te-buru-de hade-ni</u> koboshita joyuu-o jitto mitusmeta.
'The baby stared at the actress who spilled the milk / drink / champagne <u>wildly on the table</u>.'

Results

The reading time at the disambiguating region and the responses to the comprehension questions were analyzed following the same procedure as in Experiment 1.

Reading Times Figure 2 shows the mean reading time in the disambiguating region; the RC head (e.g., actress-ACC) for each condition.

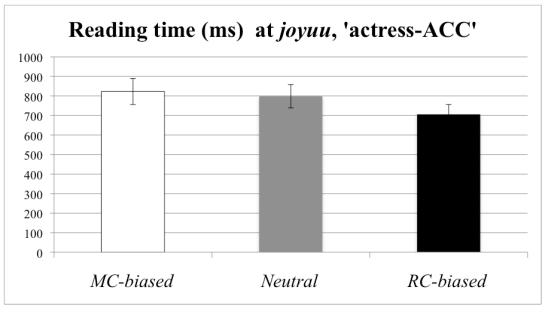

Figure 2: Mean reading times for each condition (Experiment 2). Error bars denote 95% confidence intervals.

We removed invalid trials with the same criteria as Experiment 1, which resulted in exclusion of 8.3% of the whole data. The results showed that the reading time in the disambiguating region was significantly longer in the MC-biased and Neutral conditions compared to that in the RC-biased condition (β= -108.78, t = 3.63, p < .001 for RC-biased vs. MC-biased; β= -83.78, t = 2.78, p < 0.01 for RC-biased vs. Neutral). There was no difference between the MC-biased and Neutral conditions (t < 1).

Comprehension Accuracy Table 2 shows the percentage of correct answers for the comprehension questions in Experiment 2. The analysis revealed that participants answered more incorrectly in MC-biased condition than in RC-biased condition (β= -1.17, z = 2.11, p < 0.05). No significant difference was observed between the Neutral and RC-biased conditions (β= 0.94, z = 1.64, p = 0.10), or between the MC-biased and Neutral conditions (z < 1). The results demonstrate that when the RC direct object was biased toward the MC and the RC was relatively long, participants tended to preserve the initial incorrect analysis compared to when it was biased toward the RC. The Neutral condition showed a similar pattern to the MC-biased condition, which may suggest that the difference in plausibility for the RC interpretation (i.e., champagne or drink for an actress) did not influence the persistence of the initial analysis. However, the effect was weaker and did not turn out to be fully significant.

Table 2: Percentage of Correct Answers for the Comprehension Questions

MC-biased	92.9%
Neutral	93.8%
RC-biased	97.1%

Experiment 3

Experiment 2 revealed both the difference in reading time and that in question accuracy, suggesting that preservation of the initial analysis is related to the processing cost. However, the results from Experiment 1, which showed only the difference in reading time, are inconsistent with this. Since the semantic bias and the length of ambiguous region were not tested in a single experiment, it is not clear if the processing cost was any greater in Experiment 2 than 1. Thus, in the next experiment, we crossed the two factors to examine the interaction of the two manipulations. Also, since people could not make any regressions to earlier regions with the self-paced reading task and it is arguable that people may have adopted some task-specific strategy to deal with the structural ambiguity. The next experiment therefore examined eye-movements in normal reading of these sentences. In this experiment, we focus on the interaction between the semantic bias and clause length and its influence on processing cost. We did not include comprehension questions as unrestrained regressive eye-movements make it unlikely to find a subtle difference in response accuracy.

Participants

Twenty-eight native speakers of Japanese were recruited from the same population as in experiment 1 and 2. None of them participated in the previous experiments.

Materials and Design

We created 24 sets of experimental items such as (6) with a 2 × 2 design (Semantic Bias [*MC-biased*, *RC-biased*]) × RC Length [*Short RC*, *Long RC*]). For the analysis, each sentence was divided into six regions as shown below, separated by vertical lines (|).

(6a) *MC-biased + Short RC*
Akachan-ga | miruku-o | koboshita | joyuu-o | jitto | mitusmeta.
'The baby stared at the actress who spilled the milk.'

(6b) *MC-biased + Long RC*
Akachan-ga | miruku-o | te-buru-de hade-ni koboshita | joyuu-o | jitto | mitusmeta.
'The baby stared at the actress who spilled the milk wildly on the table.'

(6c) *RC-biased + Short RC*
Akachan-ga | shanpan-o | koboshita | joyuu-o | jitto | mitusmeta.
'The baby stared at the actress who spilled the champagne.'

(6d) *RC-biased + Long RC*
Akachan-ga | shanpan-o | te-buru-de hade-ni koboshita | joyuu-o | jitto | mitusmeta.
'The baby stared at the actress who spilled the champagne wildly on the table.'

Procedure

Four lists of items were created following Latin square design. Each list included 72 fillers and was presented in pseudo-random order. The eye-movements were recorded using Eye-link Ⅱ (SR Research) at the sampling rate of 500 Hz. Participants first underwent a brief calibration procedure. Before each trial, participants were required to fixate a square box that appeared in the position of the first character of the sentences, which triggered the presentation of sentences. They pressed the space bar when they finished reading each sentence. Thirty-two comprehension questions were included to keep the participants focused.

Results

We removed fixations that were either extremely long (1200 ms or over) or extremely short (80 ms or under). For statistical analysis, we focus on two eye-movement measures; first-pass reading times and second-pass reading times. *First-pass reading times* are the sum of the fixations in the region following the first entry in the region until the first fixation outside the region (either to the left or the right). *Second-pass reading times* are the sum of fixations made in a region after the region has already been exited to the right. The former measure did not include trials when the region was skipped (i.e., the value of zero) whereas the latter measure did. It is generally assumed that first-pass reading times reflect the early stage of processing and second-pass the late stage. Table 3 shows mean reading

times from Region 2 to Region 5 per condition. In the LME model, we included Semantic Bias (MC-biased vs. RC-biased) and RC Length (short RC vs. long RC) as well as the interaction of the two factors as fixed factors, and participants and items as random factors. Random slopes of the two fixed factors and of the interaction were included for participants and items.

First-pass reading times In Region 2, there was an effect of Semantic Bias (β = 29.2, t = 3.64, p < 0.001). Participants read this region slower with the sentences in the RC-biased than in the MC-biased condition. In Region 3, we found an effect of RC Length (β = 22.6, t = 10.86, p < 0.001), which simply reflects that the longer region took longer to read. In Region 5, which is the *spill-over* region following the disambiguating phrase, there was an interaction between the two factors (β = 19.2, t = 3.21, p < 0.01). Further analysis on the effect of Semantic Bias for each level of RC Length showed that the two simple effects were in the opposite direction and were both marginally significant (β=-19.2, t = 1.93, p = 0.06 for Short RC condition; β=18.7, t = 9.93, p = 0.07 for Long RC condition); Participants tended to read this region faster in the MC-biased than in the RC-biased condition when the RC was long, but they did slower in RC-biased condition than in MC-biased condition when the RC was short. In fact, the mean fast-pass time in the MC-biased and long RC condition was shortest across conditions and this appears prima facie at odds with our prediction. However, an additional analysis on the regression-out rate (the probability of regressive eye-movements) revealed that participants made the highest rate of regressive eye-movements in this region in MC-biased + Long RC condition (0.42). The analysis with the LME model showed an effect of Semantic Bias (β= 0.5, z = 4.59, p < 0.001) showing that there were more regressions in the Long RC condition than in the Short RC condition. There also was a marginally significant effect of Semantic Bias (β= -0.2, z = 1.88, p = 0.06), showing that there was more regressions in the MC-biased condition than in the RC-biased condition. This indicates that the shortest first-pass time in the MC-biased + Long RC condition was not a reflection of reduced processing difficulty but on the contrary it reflected the excessive processing difficulty that forced participants to immediately regress to the previous region for reanalysis.

Second-pass reading times In Region 2, there was a main effect of RC Length (β= 61.2, t = 4.65, p < 0.001). This suggests that in this region participants experienced greater cost for reanalysis when the RC was long than it was short. From Region 3 to Region 5, there were effects of Semantic Bias (β= -136.9, t = 3.41, p < 0.01 in Region 3; β= -37.9, t = 3.22, p < 0.01 in Region 4; β= -44.2, t = 3.60, p < 0.001 in Region 5) and those of RC Length although that in Region 5 was marginal (β= 455.1, t = 8.67, p < 0.001 in Region 3; β= 36.0, t = 3.32, p < 0.05 in Region 4; β= -41.2, t = 3.46, p = 0.07 in Region 5). This suggests that in these regions participants experienced greater cost for reanalysis when the RC direct object was biased toward the MC than when it was toward the RC and also did so when the RC was long than when it was short. Importantly, there was an interaction between the two factors in Region 3 (β= -86.8, t = 2.35, p < 0.05). Further analysis revealed that the effect of Semantic Bias was larger when the RC was long (β=-224.9, t = 3.63, p < 0.001) compared to when it was short (β=-50.9, t = 2.41, p < 0.05).

Table 3: Mean reading times for first-pass and second-pass.

	Region 2 (milk/champagne-ACC)	Region 3* (spilled (wildly on the table))	Region 4 (actress-ACC)	Region 5 (fixedly)
First-pass reading time				
MC-biased + short relative clause	283	260 (56)	262	316
MC-biased + long relative clause	288	701 (54)	265	275
RC-biased + short relative clause	330	283 (62)	283	278
RC-biased + long relative clause	356	735 (57)	265	313
Second- pass reading time				
MC-biased + short relative clause	337	353 (78)	253	239
MC-biased + long relative clause	464	1462 (116)	329	331
RC-biased + short relative clause	281	251 (54)	182	159
RC-biased + long relative clause	403	1006 (79)	249	244

*Region 3 differs in the number of words across conditions, so that the reading time per character is provided in brackets.

General Discussion

Experiment 1 showed that participants experienced greater difficulty at the disambiguating information when the direct object in the relative clause was biased toward the main clause compared to when it was toward the relative clause. However, there was no effect of the manipulation on the responses to comprehension questions. Experiment 2 showed the same pattern of results for reading times when the relative clause was lengthened. Importantly, the results from the comprehension questions showed the effect of semantic biases; participants responded less accurately when the direct object was biased toward the main clause compared to when it was toward the relative clause. In

Experiment 3, the results of eye-tracking reading data showed participants had more difficulty for reanalysis when the direct object was biased toward the main clause than when it was toward the relative clause. It also showed that the reanalysis cost was greater when the relative clause was longer than when it was short. Importantly, the effect of semantic biases was larger when the relative clause was long than when it was short. The results taken together provided evidence that the initial incorrect analysis persisted even in absence of pragmatic inference and that it is related to how much people commit to the initial analysis and how much difficulty they experience for reanalysis. We argue that our results are consistent with previous studies in English which showed that the more committed readers were to the initial analysis, the more difficulty they experienced in reanalysis (i.e., "digging-in" effect, Tabor & Hutchins, 2004; see also Ferreira & Henderson, 1991; Ferreira & Henderson, 1998; Frazier & Clifton, 1998; Warner & Glass, 1987).

In a previous study, there was no clear evidence for the effect of phrase/clause length on the persistence of the initial incorrect structure (Experiment 1 in van Gompel et al., 2006) and also for that of the manipulation of plausibility (Experiment 2 in the same study). One possible reason for this discrepancy is that these two factors were tested independently. Yet, another possibility is that this is due to a qualitative difference in how these ambiguous sentences were processed between English and Japanese. With English, it has been shown that readers adopt an inappropriate transitive analysis even when the post-verbal noun phrase is semantically inappropriate as a direct object (Pickering & Traxler, 1998). It is likely that this is at least partly due to head-driven parsing; speakers of English check the fit as a direct object for a post-verbal noun phrase regardless of the verb type (except unaccusative verbs; see Staub, 2007). On the other hand, in the head-final Japanese, it is possible that the plausibility of arguments influences the pre-head structural analysis independently of the verb. That is, in some trials under the RC-bias condition, participants may have not adopted the main clause analysis even as an initial analysis and this may have resulted in the higher accuracy to the comprehension questions in Experiment 1 and 2 and in the less reanalysis cost compared to the MC-bias condition in Experiment 3.

To summarize, the current study provided evidence that comprehenders tend to preserve the initial analysis even when the sentence structure does not permit pragmatic inferences. Our finding of the effects of semantic biases and clause length revealed that such a tendency is related to the degree of processing difficulty that reflects how much people committed to the misanalysis. The results of eye-tracking data showed that participants indeed experienced excessive processing cost with the sentences when both the semantic bias and clause length encourage the main clause analysis. The current study also provided evidence for pre-head processing in Japanese and also demonstrated that the persistence of initial misanalysis that has been reported in a head-initial language such as English occurs in typologically different head-final language.

Acknowledgments

We would like to thank Edson T. Miyamoto and Yuki Hirose for their help on Experiment 3.

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