

Effects of Semantic Information and Punctuation in Processing Japanese Garden-Path Sentences: Evidence from Pupillary Responses^{1,2}

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This study explores the effects of semantic cues and comma insertion on Japanese garden-path sentence processing based on pupil diameter measurements. Participants read Japanese relative-clause sentences with temporary structural ambiguity, with or without biasing semantic information, and/or with a comma. Both of cues were expected to decrease the garden-path effect. Pupil size increased less after the presentation of a target word when each of the cues was present, and the significant interaction between the two factors indicated that the cue effects were not additive. Each reduced the garden-path effect only when the other cue was unavailable. The dominant semantic information effect seemed to modulate the comma's influence, indicating that language comprehension involves a complex process whereby various information sources interact.

Key words: sentence processing, semantic information, punctuation, pupillometry

Many studies have demonstrated that sentences containing temporary ambiguities inhibit quick and accurate language comprehension. These temporarily ambiguous sentences are referred to as garden-path sentences (e.g., “The horse raced past the barn fell”; Bever, 1970, pp. 279-362). The measurement of interpretation errors and processing loads that occur when listening to or reading garden-path sentences allows for a better understanding of the language processing system, particularly an understanding of how we analyze sentence structure, otherwise known as syntactic parsing. However, people use a variety of information to guide syntactic parsing; for example, prosody and contextual information (e.g., Engelhardt, Bailey, & Ferreira, 2006; Kjølgaard & Speer, 1999; Speer, Kjølgaard, & Dobroth, 1996) in everyday situations. These cues can help individuals avoid garden-path interpretations (Engelhardt, Ferreira, & Patsenko, 2010; Nakamura, Arai, & Mazuka, 2012). Therefore, it is essential to investigate the role of these cues in garden-path sentence comprehension. This line of study will provide a better understanding of the language comprehension process. Thus, we examined the effects of semantic information and punctuation as two possible cues that may

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aide in sentence comprehension. Although the effects of each of these cues have been well investigated, they have rarely been looked at together.

Garden-path sentences exist in the Japanese language due to temporary ambiguities the reader encounters in unique sentence segments. See an example of a relative clause sentence (Sentence 1) below. Note that “Nom” means nominative case, and “Acc” means accusative case. The relative clause is in square brackets.

- (1) Isya-ga [kusuri-o iikagen-ni syohoosita] intyoo-o semeta.
 doctor-Nom [medicine-Acc indifferently prescribed] director-Acc blamed.
 “The doctor blamed the director who prescribed a medicine indifferently.”

In Sentence 1, it is unclear whether the simple or relative clause structure is appropriate until the presentation of the relative clause head (“intyoo [the director]”). In this type of Japanese sentence, no syntactic cues can be used to determine which structure is appropriate prior to the presentation of the relative clause head. Therefore, although Sentence 1 has the relative clause structure in which the subject of the relative clause verb “syohoosita (prescribed)” is the “intyoo,” the Minimal Attachment strategy (Frazier & Fodor, 1978) and the Japanese verb-final structure may favor a simple clause structure, which forces listeners (or readers) to interpret the relative clause verb as the matrix clause verb; that is, they may misinterpret the subject of the verb “syohoosita” as the “isya (the doctor).” Therefore, they will need to reconsider their interpretation of the sentence; thus, the simple clause structure must be reanalyzed as the relative clause. Indeed, previous studies have demonstrated that these types of sentences present increased processing difficulty compared to sentences that do not contain such structural ambiguities. Specifically, these types of sentences result in poorer comprehension or increased reading time of the relative clause head (garden-path effects). Inoue (2003) summarized research investigating garden-path effects caused by relative clause and other sentence structures in Japanese. According to his review, Sentence 1 should lead readers (or listeners) into garden paths and should require more processing costs for the relative clause head “intyoo.” Mazuka and Itoh (1995) also provided various examples of garden-path sentences in Japanese, including the relative clause sentences.

As previously stated, we focused on the two types of cues that help people avoid garden-path interpretations. Two examples of such (Sentences 2 and 3) are presented below:

- (2) Kanzya-ga [kusuri-o iikagen-ni syohoosita ...
 Patient-Nom [medicine-Acc Indifferently prescribed ...
 Isya-ga, [kusuri-o iikagen-ni syohoosita ...
 Doctor-Nom, [medicine-Acc Indifferently prescribed ...

One type of cue is semantic, which can help a reader or listener avoid garden-path interpretations. Specifically, in Sentence 2, the matrix subject “kanza (the patient)” is a semantically implausible subject of the relative clause verb “syohoosita,” since a patient does not typically prescribe medicine. Therefore, readers are less likely to misinterpret the relative clause verb as the main clause verb, which would prevent them from making a garden-path interpretation. Actually, a large number of studies have investigated the role of semantic information on sentence processing. One such classic example, by Trueswell, Tanenhaus, and Garnsey (1994) demonstrated that the animacy of the sentence-initial noun phrase affected processing difficulties of the “reduced-relative” garden-path sentences like “The defendant examined by the lawyer turned out to be unreliable.” According to Trueswell et al. (1994), using inanimate noun phrases like “The evidence” instead of “The defendant” clearly reduced the processing difficulties of the sentence (see also Clifton, Traxler, Mohamed, Williams, Morris, & Rayner, 2003; Ferreira & Clifton, 1986; Den & Inoue, 1997; MacDonald, Pearlmutter, & Seidenberg, 1994). The second type of cue is syntactic. As shown in Sentence 3, a comma is inserted at the clause boundary position to disambiguate the sentence structure. Japanese punctuation rules do not mandate the insertion of a comma at clause boundaries; however, writers and readers generally use the presence of a comma to specify the position of a clause boundary. For instance, Niikuni and Muramoto (2014) reported that a comma inserted at the clause boundary could reduce the reading time of the relative clause head in Japanese sentences, similar to what was displayed in Sentence 1¹.

Thus, these types of cues may facilitate appropriate disambiguation of Japanese relative clause sentence structures, but they have different levels of processing. Specifically, a comma may be a lower syntactic-level cue since it gives a direct sign of syntactic boundary; however, semantic information may be a higher-level cue because listeners (or readers) are required to reference knowledge in their long-term memories to use it as a disambiguating cue. Indeed, there is some evidence suggesting that listeners use prosodic cues (prosodic boundaries) and other types of cues interactively (Engelhardt et al., 2010; Itzhak, Pauker, Drury, Baum, & Steinhauer, 2010; Kerkhofs, Vonk, Schriefers, & Chwilla, 2007; Nakamura et al., 2012).

For instance, Kerkhofs et al. (2007) reported that the size of a closure positive shift (CPS), an event-related potential (ERP) component that reflects the processing of a prosodic break (Steinhauer & Friederici, 2001), was reduced by a discourse context. Conversely, Itzhak et al. (2010) demonstrated that even when there is no prosodic break after a verb, an intransitive verb elicited a CPS while a transitive verb did not. These studies strongly indicate the integration of, and interaction between, prosodic and other information. Moreover, higher-level discourse, or semantic information, regulates the processing of prosodic information, a lower-level cue that directly induces a syntactic boundary.

To our knowledge, there have been no studies of the relations between commas and other cues in the context of written language comprehension. Some researchers argue that

¹ Naturally, in English, a language whose punctuation rules are much stricter, commas clearly play a crucial role in disambiguation, and their absence cause distinct processing difficulties (e.g., Hill & Murray, 2000; Staub, 2007)

commas and prosody play parallel roles in sentence processing. Specifically, when reading sentences, commas elicit implicit prosodic information (e.g., a pause) in mentally constructing phonological representations, thereby influencing syntactic analysis (Steinhauer, 2003; Steinhauer & Friederici, 2001). Based on this view, readers may use commas interactively with semantic information to disambiguate sentence structures, but there has been no empirical evidence attesting to this. Therefore, we are interested in whether each of these cues independently affects sentence processing and if certain interactions between the two cues can be found.

Psycholinguistic studies have used reading time, reaction time, eye movement, or ERPs to indicate dynamic changes in cognitive load during the syntactic processing in a sentence comprehension task. However, these measures may not only be sensitive to cognitive load but also to other cognitive processes, including perceptual decoding, attentional fluctuation, and response control. Therefore, in this study, pupil size was measured to monitor fluctuations in processing load during sentence comprehension (Engelhardt et al., 2010; Just & Carpenter, 1993; Piquado, Isaacowitz, & Wingfield, 2010; Schluroff, 1982). Since pupil diameter is a direct index of noradrenergic neuronal activity (Aston-Jones & Cohen, 2005), it may directly reflect the number of cognitive resources used by syntactic processing. Specifically, higher arousal levels would be reflected by larger pupil size. Indeed, cognitive studies have demonstrated that pupillary dilatation increases as task difficulty increases, and this includes mental arithmetic (Hess & Polt, 1964) and digit-span tasks (Kahneman & Beatty, 1966). Few studies have examined pupillary responses to language stimuli during sentence processing; however, more recent psycholinguistic studies have begun to use pupillometry as a measure of cognitive load (e.g., Seeber & Kerzel, 2012; Sevilla, Maldonado, & Shalom, 2014).

Therefore, in this study, we focused on the pupillary response to the presentation of the relative clause head noun (“intyoo-o,” in Sentence 1), which was expected to cause garden-path effects. Specifically, we examined two independent variables: semantic information (absent/present) and comma insertion (absent/present). Semantic information and comma insertion were expected to reduce the processing costs of the head noun. Therefore, the pupil size increase would be smaller in the conditions that contained either or both of the two cues (semantic information and comma insertion) than in the condition where both of the cues were absent. Moreover, we expected that the effects of these two cues on disambiguation might result in three possible outcomes.

First, it was possible that they would independently reduce the costs of disambiguation (i.e., an additive effect); in this case, the main effects of both factors were likely to be found, but an interaction would not be found. However, this possibility was less expected because a previous study (Engelhardt et al., 2010) indicated that the redundant cues for disambiguation did not work additively. Alternatively, the second possibility was that either the semantic information or the presence of a comma would reduce the costs only when the other cue was unavailable. The third possibility was that the combination of semantic information and the comma would work over-additively to reduce costs. In these latter two cases, an interaction

between the two factors is predicted, which is consistent with previous work. Indeed, Engelhardt et al. (2010) reported that when listeners were presented with an appropriate visual context for disambiguation, prosodic information did not result in reducing processing loads. However, when an inappropriate context or no context was presented, prosodic information affected the processing cost of disambiguation. Thus, Engelhardt et al. (2010) suggested that contextual information modulates the influence of prosodic information. This finding is most consistent with the second possibility outlined above. Therefore, we predicted an interaction between the two factors, indicating that the presence of semantic information or the insertion of a comma reduces cognitive load only when the other cue is absent.

In addition, we hypothesized that the amount of cognitive cost may differ before the relative clause head. For instance, a punctuated word may require more cost to process than a non-punctuated one because extra information (i.e., a comma) should be recognized and processed. Moreover, the costs of processing the relative clause verb (“syohoosita,” in Sentences 1 and 2) may vary with the absence or presence of the semantic information because when the semantic information was present (Sentence 2), this verb was temporarily inconsistent with the matrix subject, but when the semantic information was absent (Sentence 1), there was no inconsistency. Therefore, in addition to the relative clause head, we checked pupil size changes associated with the other words.

In short, our objective was to examine whether semantic cues and punctuation can help readers process sentences with temporary structural ambiguities and to elucidate the relation between the effects of the two cues. By measuring pupillary responses, we were able to demonstrate that each of the cues reduced the costs of sentence processing, but there was no further reduction in cognitive load when both of the cues were available, thus supporting our hypothesis.

Methods

Participants

Twenty-four graduate and undergraduate students at a Japanese university participated (10 male and 14 female; M age = 20.33 years, SD = 1.34 years). All participants were native Japanese speakers and had normal or corrected-to-normal vision. Each participant gave written informed consent. The experiment was approved by the ethics committee of the Graduate School of Information Sciences, Tohoku University.

Materials

Initially, 36 pairs of Japanese relative clause sentences were created, similar to Sentences 1 (semantic-information-absent condition) and 2 (semantic-information-present condition). Each pair of sentences was different only in the matrix subject (“*isya* [the doctor]” / “*kanzya* [the patient]”, in Sentences 1 and 2, respectively). In a pilot study, the semantic consistency between the matrix subject (the doctor/patient) and the embedded verb phrase (prescribed a

medicine) of the sentences was assessed by 40 native Japanese speakers who did not participate in the experiment. The sentences were presented randomly (see, for example, Sentences 4 and 5, which consist of the matrix subject and the subordinate verb phrase extracted by an original sentence), and the participants of this preliminary test were asked to evaluate the semantic plausibility of each sentence on a 7-point scale (1: *not plausible at all* to 7: *very plausible*).

- (4) Isya-ga kusuri-o syohoosita.

“The doctor prescribed a medicine.”

- (5) Kanzya-ga kusuri-o syohoosita.

“The patient prescribed a medicine.”

Based on the evaluation, 16 pairs of sentences with large differences in plausibility ratings were selected. Importantly, a higher plausibility rating in the evaluation indicated the absence of semantic information in the original sentence, while a lower plausibility rating indicated the presence of semantic information. The mean plausibility ratings of the final 16 sentences were 6.45 ($SD = 0.31$) for the semantic-information-absent condition and 2.59 ($SD = 0.68$) for the present condition. In addition, 80 fillers consisting of 4- to 6-word segments, or *bunsetsu*, were used. In Japanese, a *bunsetsu* consists of an independent word like “isya (doctor)” and optional function words like “-ga (-Nom).” Thirty-two of the fillers contained a relative clause, and the rest did not. For each target and filler sentence, we added a yes/no comprehension question (e.g., “Did the doctor prescribe the medicine?”). For half of the questions, the correct answer was “yes,” and for the other half the answer was “no.”

Apparatus

The stimuli were displayed on a 19-inch liquid crystal display. The experiment was controlled with an in-house program on MATLAB, version 7.0.1 (MathWorks, Inc.), which was enhanced by a graphic subroutine (Cogent 2000²) for stimulus presentation and response control. Pupil diameter was measured with a video measurement system for industrial use (Keyence: XG-7000). The measurement system recorded the left eye of the participant at a sampling rate of 23 Hz and calculated the pupil diameter online.

Design

The experiment implemented a 2 (semantic information: absent/present) \times 2 (comma: absent/present) repeated measures design. The absence or presence of semantic information was accomplished by changing the sentence-initial noun (i.e., the matrix subject) of the sentence pairs, as shown in Sentences 1 and 2. In terms of the examples, Sentence 1 was assigned to the semantic-information-absent condition, and Sentence 2 was assigned to the

² This experiment was realized using Cogent 2000 developed by the Cogent 2000 team at the FIL and the ICN and Cogent Graphics developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience.

present condition. In the comma-present condition, a comma was inserted just after the first *bunsetsu*, as shown in Sentence 3, while in the corresponding comma-absent condition there was no comma in the sentences (compare Sentences 1 and 3). For fillers, a comma was inserted either at the major or minor syntactic boundaries for half of the filler sentences, or it was absent.

Procedure

The target relative clause sentences were placed in eight lists by counterbalancing semantic information (absent/present), comma insertion (absent/present), and the correct response to the comprehension question (yes/no). A Latin square design was followed. Each participant read each sentence once.

Before the experimental session, participants received brief instructions and completed eight practice trials. The entire session lasted approximately 40 minutes, with a short break in the middle. During the trials, the participants were asked to rest their chin on a chinrest, press their forehead firmly against a headrest, and refrain from blinking when reading the sentence. They were allowed to blink during the comprehension question phase.

In the comma-present condition, a comma was presented on the same screen as a punctuated word. In contrast, the *kuten*, usually used instead of a period in Japanese to announce the end of a sentence, appeared singly after the final word segment in the sentence. As stated, the semantic information condition was manipulated by changing only the sentence-initial noun phrase (see Sentences 1 and 2).

A trial began with the presentation of a 1000-ms fixation point. Then, a sentence was presented word segment by word segment (i.e., *bunsetsu* by *bunsetsu*) at the center of the screen. Each word segment was presented for 700 ms (Nagata, 1993). After the sentence was read, a blank screen appeared for 700 ms, followed by the presentation of the comprehension question. Participants responded to the question by pressing one of two keys. Pupil diameter was recorded from the start of a sentence until the response to the comprehension question was logged. The sentences were presented in random order.

Results

Data analysis

Two participants' data were discarded due to a video camera malfunction during pupil monitoring. Any pupil diameter samples that were contaminated by various noise signals, mostly due to eye blinks, were also discarded. Based on previous studies (Engelhardt et al., 2010; Just & Carpenter, 1993), the data acquisition window was set to 1200 ms \pm 200 ms, starting from the onset of the target word segment (i.e., relative clause head, "intyoo-o" in Sentence 1). The pupil diameters collected in this range were standardized by dividing them by the mean diameter during a 200-ms baseline period that immediately preceded the target window. In addition, data were not used: if the value was more than the condition mean + 2.5 SD or less than the condition mean - 2.5 SD; less than half the samples were valid

(i.e., were not contaminated by noise); and/or the participant responded incorrectly to the comprehension questions.

The *lmer* function within the *lme4* package in the R programming language was used for all statistical analyses. Logistic mixed effects models were used to assess comprehension accuracy, and linear mixed effects models were used to assess pupil diameter. In all regression models, we included semantic information and comma insertion as fixed effects, with the interaction between the two factors being allowed (Baayen, Davidson, & Bates, 2008). Participants and items were random effects. Each fixed factor was effect-coded (i.e., each absent condition was coded as -0.5, and each present condition was coded as 0.5). A backward stepwise selection method including the likelihood ratio test was used in selecting the final regression models (Baayen, Davidson, & Bates, 2008; Brown, Savova, & Gibson, 2012). For the linear mixed effects models, *p*-values were obtained for each estimate using the *lmerTest* package.

Comprehension accuracy

Prior to pupil diameter analysis—the main measure of this study—we verified the accuracy rate for the comprehension questions. Correct answers were coded as 1 and incorrect answers as 0. Table 1 shows the mean accuracy rates for the comprehension questions in each condition. A logistic mixed effects model revealed that the main effect of semantic information was significant ($\beta = 1.65$, $SE = 0.57$, $z = 2.90$, $p < .01$), which indicated that the accuracy rate was significantly higher in the semantic-information-present condition than in the absent condition. The effect of the comma and the interaction between the two factors were non-significant ($p > .10$).

Pupil response

Prior to analysis, we confirmed that pupil sizes during the 200-ms baseline period were equivalent across conditions. The mean pupil sizes during the baseline period were compared, and a linear mixed effects model showed no significant main effects or interaction effect ($ps > .10$).

Figure 1 shows the mean pupil size ratios (i.e., pupil size change relative to the baseline)

Table 1. The Percentages (Standard Error by Participants) of the Correct Answers to the Comprehension Question in Each Experimental Condition.

Semantic information	Comma	Accuracy rate (<i>SE</i>)
Absent	Absent	87.50% (4.58)
Absent	Present	89.77% (3.55)
Present	Absent	97.73% (2.27)
Present	Present	96.59% (1.87)

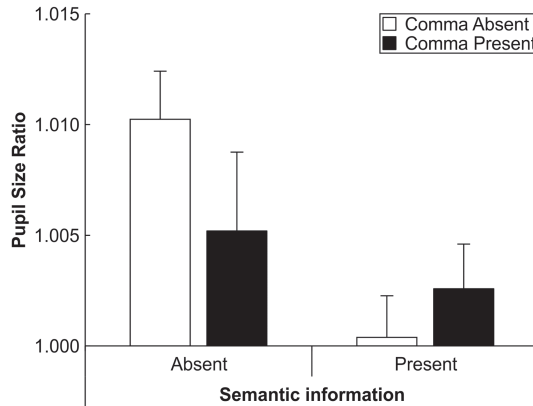


Figure 1. Mean pupil size ratios for the target word segment (relative clause head). Pupil size ratios were calculated by averaging standardized samples collected during the 1200 ± 200 ms target window, beginning with the onset of the target word. During the standardization, each sample was divided by the mean diameter during a 200-ms baseline period that immediately preceded the target window. Error bars show the standard errors of the mean by participants.

for each condition. A linear mixed effects model revealed that the main effect of semantic information and the interaction between the two factors were both significant (see Table 2). The main effect of the comma was not significant. The simple main effect of semantic information was significant only in the comma-absent condition ($\beta = -0.00994$, $SE = 0.00249$, $t = -4.00$, $p < .001$), but it was not significant in the comma-present condition ($p > .10$). The simple main effect of comma was significant only in the semantic-information-absent condition ($\beta = -0.00470$, $SE = 0.00233$, $t = -2.02$, $p < .05$) but it was not significant in the semantic-information-present condition ($p > .10$). In short, either semantic information or a comma was necessary to reduce the pupillary dilatation (i.e., the processing costs) for the target word, but no further reduction was found when both of the cues were available. The main effect of semantic information may indicate that this type of cue globally dominated disambiguation.

In addition, we examined pupil diameter changes in each non-target word segment in an identical fashion to the analysis of the target word segment. For all non-target word segments, linear mixed effects models yielded no significant effects for either factor or for the interactions between them ($ps > .10$), except that the effect of semantic information was marginally significant in the sentence-final verb segment ($\beta = -0.00428$, $SE = 0.00253$, $t = -1.69$, $p = .09$), in which the pupil diameter change was smaller in the semantic-information-present condition (M pupil size ratio = 0.99119, SE by participants = 0.00199) than in the absent condition (M pupil size ratio = 0.99534, $SE = 0.00182$).

Table 2. Final Linear Mixed-Regression Model Parameters of Pupil Responses to the Target Word Segment.

	β	<i>SE</i>	<i>t</i>	
Intercept	1.00464	0.00176		
Semantic information	-0.00654	0.00181	-3.61	$p < .001$
Comma	-0.00132	0.00181	-0.73	<i>ns</i>
Interaction	0.00710	0.00361	1.97	$p = .05$

Thus, as predicted, semantic information and comma use affected the cognitive load required for processing the relative clause head. However, the comma effect was not found in the matrix subject, which was punctuated in the comma-present condition. Moreover, the no-semantic-information effect was found in the embedded verb. This segment was locally inconsistent with the matrix subject in the semantic-information-present condition.

Discussion

The results of the experiment showed that comprehension accuracy improved when semantic information was present, but no significant effect of comma presence was found. Furthermore, there was no significant interaction between the two factors. However, in addition to a main effect for semantic information, pupil diameter did reveal a significant interaction between the two factors. Therefore, it could be that measures of pupillary dilation are more sensitive to dynamic changes in cognitive load during sentence processing. As predicted, pupil diameter increased more after the presentation of the relative clause head in the condition where neither syntactic nor semantic information was present than in the condition where either of the cues was present. This finding indicates that the presence of either type of information is sufficient to reduce the cognitive load involved in processing the relative clause head. That is, the presence of either semantic or syntactic cues enable participants to avoid the costs associated with garden-path interpretations.

Moreover, the significant interaction between the two factors indicates that the effects of the cues did not show an additive relationship; therefore, readers may not use these two types of information independently. This is consistent with the results of previous studies, where prosody and other non-syntactical information interactively affected the processing costs of disambiguation (Engelhardt et al., 2010). Therefore, our results indirectly support the idea that commas in written language and prosody in spoken language have parallel functions (Steinhauer, 2003; Steinhauer & Friederici, 2001).

Interestingly, semantic information reduces pupil diameter change only when a comma is absent, and comma presence reduces pupil diameter change only when semantic information is absent. However, semantic information is the only significant main effect predictor, and it affects not only pupillary responses but also performance of comprehension questions. Thus, it

appears that semantic information makes the predominant contribution to reducing the costs of processing the target word. Specifically, the processing load of the head noun is sufficiently reduced by semantic information alone. It is only when semantic information is not available that the comma is used to disambiguate the sentence structure. In other words, semantic information plays a decisive role in helping readers to avoid garden paths, and it may modulate the influence of a comma similar to the way that (visual) context modulates the influence of prosody (Engelhardt et al., 2010).

Our findings indicate that higher stage processes that deal with semantic or discourse-level cues supersede the use of lower syntactic-level cues. Therefore, sentence comprehension does not simply proceed from lower to higher stages. Instead, it involves a complex process, whereby numerous sources at different levels interact. This interactive utilization may be a cross-language and cross-modal feature of language comprehension. Indeed, recent studies (Itzhak et al., 2010; Kerkhofs et al., 2007) have indicated that disambiguating cues at different levels (i.e., prosody and other information) are integrated online and used interactively. In sentence comprehension, we think many other types of information (e.g., frequency, preceding contexts, and, particularly in written Japanese, orthographic information) are utilized. Thus, it is important to elucidate how various types of information are used to analyze sentence structures, as this would provide for a better understanding of the process of language comprehension.

Finally, it is notable that no significant differences in pupil diameter change were found until the target word was presented. Some researchers have reported in studies of eye-tracking and self-paced reading experiments that it takes longer for the individuals to read punctuated words (Hill & Murray, 2000; Niikuni & Muramoto, 2014). However, the comma effect was not significant in the presentation of the matrix subject, which was punctuated in the comma-present condition but not in the comma-absent condition. Thus, longer reading times for punctuated words may not be a reflection of heavier processing load but of other factors. In fact, a pause may be induced by a comma during the phonological decoding process (Steinhauer, 2003; Steinhauer & Friederici, 2001). Interestingly, if this phonological view of punctuation is correct, our results imply that a comma automatically induces prosodic information in a way that produces very little cognitive effort.

In addition, it is also possible that in the semantic-information-present condition, processing loads would temporarily become larger when the relative clause verb “syohoosita (prescribed)” was presented, since it is inconsistent with the matrix subject “kanza (the patient).” However, the analysis for the relative clause verb found no significant effect of semantic information. Therefore, participants may come to predict a relative clause structure before the relative clause head is presented, regardless of the presence or absence of the cues. Thus, they may withhold attaching the verb to the subject until the relative clause head appears, resulting in no difficulties in processing the relative clause verb in the semantic-information-present condition.

However, this seems unlikely because a marked increase in the pupil diameter reflects a

strong garden-path effect. Indeed, this increase in pupillary diameter is found in the condition where both the semantic information and the comma are absent. This indicates that, at least in this condition, participants prefer the simple clause structure until they encounter the relative clause head. Alternatively, it may be that participants delay making a main or relative clause interpretations until the verb appears. Therefore, they may have accessed the semantic content of the verb and then selected the structure immediately after the presentation of the verb. This would enable participants to avoid attaching a semantically inconsistent verb phrase to the matrix subject in the semantic-information-present condition. However, the results presented herein cannot resolve this point, so this should be a focus of future studies. Specifically, future studies should further investigate how semantic information regulates the online analysis of syntactic structure.

Conclusion

The results of the present study indicated that the presence or absence of semantic information and commas affected the processing costs for ambiguity resolution of Japanese relative clause sentences. They help readers avoid garden-path interpretations. We utilized pupillary response as a direct measure of dynamic change in cognitive loads, which enabled us to isolate and monitor the processing costs (reflecting processing difficulties) for online sentence comprehension. Our results indicate that semantic information and correct comma use reduce the costs of processing the relative clause head; that is, each of the cues certainly helps readers avoid garden paths.

Moreover, the significant interaction between the two factors indicated neither an additive nor an over-additive effect of the two cues. Each of the cues reduced the costs only when the other was absent. Since the semantic information globally dominated the cost reduction, we conclude that the processing costs reflecting the garden-path effects are sufficiently reduced by semantic information alone. Only when semantic information is not available the comma does affect the processing of the relative clause head. This is similar to the way that (visual) context modulates the influence of prosody (Engelhardt et al., 2010) and indicates that language comprehension is a complex process in which various different level cues work interactively. Although the process of using redundant cues for sentence comprehension is complex, many other sources of information are available in everyday situations. Therefore, for a better understanding of the process of language comprehension in future work, it would be useful to examine how these sources are used and how they interact in online sentence processing.

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