Ueno, M. & Garnsey, S.M. (in press). Gap-filling vs. filling gaps: Event-related brain indices of subject and object relative clauses in Japanese. In N. H. McGloin and J. Mori (Eds.), *Proceedings of the 15th Japanese/Korean Linguistics Conference* (pp. 288-301). Stanford, CA: CSLI Publications.

Gap-filling vs. filling gaps: Event-related brain indices of subject and object relative clauses in Japanese*

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1. Introduction

The fundamental question we aim to address in this paper is how syntactically distinct languages are processed in the brain. By investigating such a question we hope to find language-universal and -specific aspects of sentence comprehension and thereby to narrow the gap between linguistic and cognitive neuroscientific approaches to language. Event-related brain potentials (ERPs) are useful in this endeavor, as they reveal millisecond-by-millisecond changes in neural activity during language comprehension.

This study investigates the processing of Japanese subject vs. object relative clauses using both self-paced reading times and ERPs. We compare the processing of gap-filler dependencies in Japanese relative clauses to the processing of filler-gap dependencies in English. We discuss theoretical and experimental background on English and Japanese relative clauses in Section 2 and report our reading-time and ERP experiments in Sections 3 and 4. Section 5 discusses the implications of the experimental results followed by a conclusion in Section 6.

* This work was supported by the University of Illinois Research Board and by an NIMH postdoctoral fellowship (T32 MH19554) to the first author.

2. Background

2.1 English vs. Japanese relative clauses

Consider subject and object relative clauses in English in (1).

(1) a. Subject relative (SR)
the reporter [who$_i$ __$_i$ attacked the senator]
FILLER GAP

b. Object relative (OR)
the reporter [who$_i$ the senator attacked __$_i$]
FILLER GAP

A number of studies show that ORs are harder to process than SRs in English (e.g. reading times: King & Just 1991; ERPs: King & Kutas 1995; fMRI: Caplan et al. 2001). The explanation for this is often tied to the notion of filler-gap dependencies. In the psycholinguistic literature, the displaced wh-element is called a "filler" while its canonical position is called a "gap". The filler and its gap are said to be dependent on each other, as the interpretation of a gap involves associating it with its filler (cf. Fodor 1989). While the filler and its gap are immediately adjacent to each other in SRs, there are words between them in ORs, and this linear filler-gap distance is said to be the source of difficulty (e.g. Gibson 1998). Alternatively, however, it is also possible to look at the filler-gap distance in terms of hierarchical syntactic structure shown in Figure 1. There are more syntactic nodes between the filler and its gap in ORs than in SRs, and this structural distance can be another source of comprehension difficulty (O'Grady 1997).

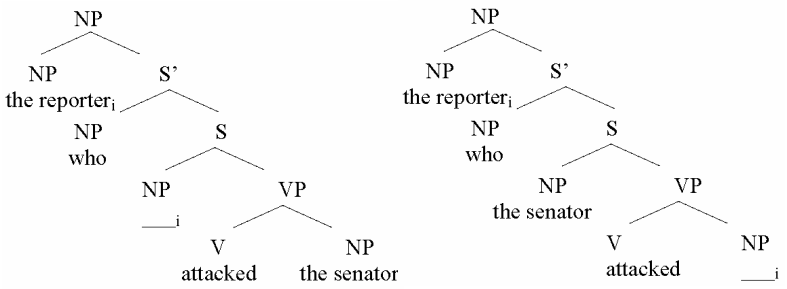

FIGURE 1. Syntactic structures for SRs and ORs in English.

Japanese relative clauses are different from English relative clauses in several ways. First, they are prenominal, as shown in (2). Second, there is no relative pronoun in Japanese, and the head noun functions as the filler in

word-by-word sentence processing. Thus, the gap precedes the filler in Japanese.

(2) a. Subject Relative (SR)

[__ 議員を　　非難した]　　記者
[__ senator-ACC　　attacked]　　reporter
GAP　　FILLER
'the reporter who [__ attacked the senator]'

b. Object Relative (OR)

[　議員が　　__　　非難した]　　記者
[　senator-NOM　　__　　attacked]　　reporter
GAP　　FILLER
'the reporter who [the senator attacked __]'

In addition to the prenominal structure and absence of overt markers indicating the beginning or end of the relative clause, Japanese allows *pro*-drop. Thus there is a temporary ambiguity up until the head noun position regarding whether a particular sentence fragment will be a relative clause or a mono-clausal sentence. In other words, a relative clause like (2a) can be interpreted initially as a mono-clausal sentence as in (3), but then when the head noun appears, it becomes clear that there is a relative clause instead.

(3)　*pro* 議員を　　非難した
pro senator-ACC　attacked
'(Someone) attacked the senator'

In terms of linear distance, SRs involve a longer linear gap-filler distance than ORs in Japanese, as shown in (2). This is exactly the reverse of English relative clauses. However, Japanese relative clauses are argued to have hierarchical structures similar to English as shown in Figure 2, with a covert operator (instead of a relative pronoun) coindexed with both the head noun and the gap (e.g. Kaplan & Whitman 1995).

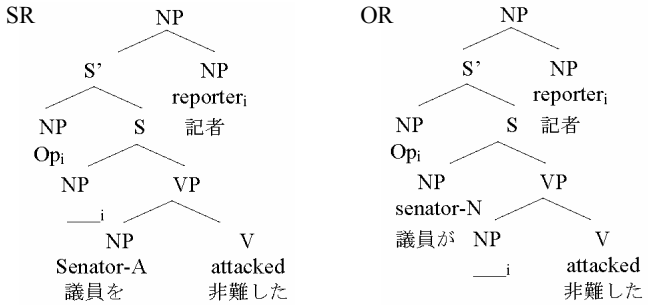

FIGURE 2. Syntactic structures for SRs and ORs in Japanese.

Thus despite surface differences between the two languages, in both languages ORs involve a longer structural distance than SRs. Therefore, unlike English, linear and structural distance accounts yield different predictions for Japanese, in that a linear distance account predicts a higher processing cost for SRs while a structural distance account predicts a higher processing cost for ORs.

2.2 Previous ERP research on English filler-gap dependencies

As discussed in Section 2.1, ORs are typically harder to process than SRs in English, possibly due to a longer linear or structural filler-gap distance. This section reviews relevant ERP studies in English. ERPs consist of positive and negative voltage peaks termed 'components', and ERP effects are examined in terms of differences in polarity (e.g. N for negative or P for positive), poststimulus latency, amplitude, and distribution over the scalp between experimental and control conditions. Some of the components occur in both slow (differences lasting several seconds) and phasic (differences a few 100 msec in duration) forms.

Earlier studies on the processing of filler-gap dependencies in relative clauses and wh-questions (e.g. Kluender & Kutas 1993; King & Kutas 1995) argued that associating a displaced wh-filler with its gap increases working memory load, and that this processing cost is reflected in an ERP component known as left anterior negativity (LAN: negative deflection of voltage that is larger at the frontal regions of the scalp, often left-lateralized) between the filler and the gap.

Instead of or in addition to LAN effects, recent studies have reported P600 effects (positive peak at around 600 msec poststimulus onset). For instance, Kaan et al. (2000) compared embedded yes-no and wh-questions and found P600 effects at the pre-gap position. They argued that although the P600 had previously been attributed specifically to syntactic reanalysis, their results showed that it can also indicate syntactic integration difficulty in general, in their case the process of integrating a wh-filler into a sentence. A more recent study (Phillips et al. 2005) has reported the combination of both LAN and P600 effects in English wh-questions.

2.3 Previous reading time research on Japanese relative clauses

In English, there is wh-movement (and resulting filler-gap dependencies) in both wh-questions and relative clauses, but in Japanese wh-words typically stay *in situ* and thus wh-questions are syntactically distinct from relative clauses. Previous ERP studies of Japanese have investigated wh-questions (e.g. Ueno & Kluender 2003), but not relative clauses, to the best of our knowledge. However, reading time studies of Japanese relative clauses (Ishizuka et al. 2003; Miyamoto & Nakamura 2003) have shown that ORs

take longer to read than SRs at or starting at the head noun position. Given the shorter linear gap-filler distance in Japanese, this may suggest that the structural distance account is more promising.

2.4 Predictions

Given the above, we wanted to test whether LAN (and/or P600) effects reflecting filler-gap associations in English would replicate with gap-filler associations in Japanese, and whether these effects in Japanese would correlate with linear or structural distance. If gap-filler association is like filler-gap association, we should see LAN effects between gap and filler possibly followed by P600 effects at the filler. Additionally, if linear distance is more important, we should see more processing costs indexed by these ERP effects for SRs than ORs. On the other hand, if structural distance is more important, we would see ERP effects indexing difficulty in ORs, as suggested by the reading time studies discussed in Section 2.3.

3. Experiment 1: Self-paced reading times

Experiment 1 used the self-paced reading task to examine reading times for the experimental stimuli as a first step, in order to determine whether our stimuli would show the same pattern of results as previous studies.

Stimuli consisted of pairs of sentences with singly-embedded (a) subject relatives (SRs) and (b) object relatives (ORs), as shown in (4).

(4) a. Subject Relatives (SRs)
[新任の 議員を 非難した] 記者には 長年の 相棒が いた。
new senator-ACC attacked reporter-DAT-TOP long-term colleague-NOM existed
'The reporter [who attacked the new senator] had a long-term colleague.'

b. Object Relatives (ORs)
[新任の 議員が 非難した] 記者には 長年の 相棒が いた。
new senator-NOM attacked reporter-DAT-TOP long-term colleague-NOM existed
'The reporter [who the new senator attacked] had a long-term colleague.'

In order to confirm that nouns used at the head noun position were equally plausible as the subject or the object of the relative-clause verb, 20 native speakers of Japanese (who did not participate in Experiment 1 or 2) rated sentences created by replacing the gap with the corresponding head noun, as in 'The reporter attacked the senator' vs. 'The senator attacked the reporter', on a scale from '1' (strange) to '5' (natural). There were no significant differences in the ratings [$F_1(1,18) = 1.02$, $p > .1$; $F_2(1,78) = 2.58$, $p > .1$] regardless of whether the head noun was used as the subject (mean rating = 4.4) or the object (4.3). Another norming study was conducted to test whether the verbs used in the sentences were transitive-biased. The 69

different verbs used in the relative clause of the stimulus sentences and 31 filler verbs were combined and pseudo-randomized. Ten native speakers of Japanese, a subset of those who had already participated earlier in either Experiment 1 or 2, were presented with the verbs and asked to type the first sensible sentence that came to mind. Collapsed across participants, 96% of the sentences with the relative-clause verbs contained overt direct objects, showing that these verbs were highly transitive-biased. (Interestingly, 35% of the sentences had subject-drop in the total absence of discourse context.)

Eighty sets of experimental sentences were placed in a Latin square design to create two parallel lists. 80 filler sentences were added to each list, and then sentences in these two lists were pseudorandomized and divided into 5 blocks of 32 sentences each.

Forty native speakers of Japanese were timed in a word-by-word self-paced non-cumulative reading task. Stimuli were presented in the center of the computer screen in Japanese characters one word at a time. Yes/no comprehension questions were presented after each sentence to ensure that participants were paying attention.

Reading times were trimmed so that data points beyond 2 standard deviations from the relevant subject x condition x position cell mean were replaced with the corresponding cutoff value, affecting 5% of the data. For each sentence position as well as for the post-relative clause region, a repeated measures ANOVA was conducted with 'relative clause type' as a within-group factor, and either 'subject' (with 'list' as a nested factor) (F1) or 'item' (with 'item group' as a nested factor) (F2) as a random factor.

Figure 3 shows the trimmed reading times by sentence position.

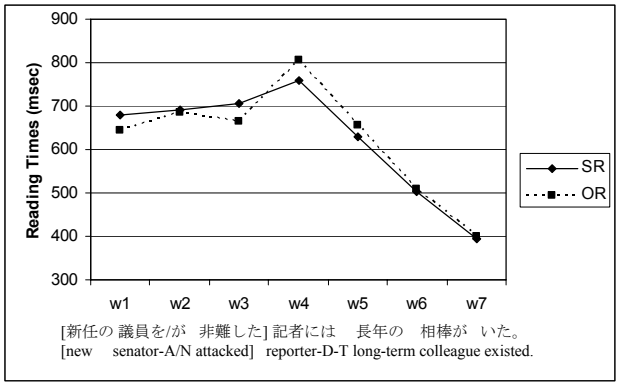

FIGURE 3. Trimmed reading times for each sentence position.

In the relative clause region (words 1-3), SRs took longer to read than ORs at the first word position [$F1(1,38) = 4.74$, $p < .05$; $F2(1,78) = 8.10$, $p < .01$], although items were completely identical across conditions at this po-

sition. There was no significant difference at word 2 [Fs < 1]. At word 3 (the relative clause verb, 'attacked'), however, SRs took longer than ORs, but this was reliable only in the item analysis [F1(1,38) = 2.27, p > .1; F2(1,78) = 8.25, p < .01]. In the post-relative clause region (words 4-7), ORs took longer than SRs at the head noun (word 4) [F1(1,38) = 5.60, p < .05; F2(1,78) = 4.79, p < .05], and also at the following word 5, though only marginally so [F1(1,38) = 2.89, p < .1; F2(1,78) = 3.30, p < .1]. There were no significant differences at word 6 [Fs <1] or word 7 [F1(1,38) = 1.19, p > .1; F2(1,78) = 1.01, p > .1]. When reading times for the entire post-relative clause region (w4-w7) were collapsed together, ORs were read significantly more slowly than SRs [F1(1,38) = 8.24, p < .01; F2(1,78) = 6.99, p < .01].

Slow reading times in word 1 must have been due to noise, given that the word in that position was identical in both conditions. The slowdown did not continue on the following word and so will be ignored in the remainder of discussion. At word 2, different case-markers (nominative in ORs and accusative in SRs) on the noun did not lead to reading time differences, even though it is more typical to start a sentence with a nominative- than accusative-marked noun. However, in the self-paced reading paradigm effects are often delayed a word, so we could speculate that the accusative-marked noun in SRs caused a slowdown one word later at word 3, although the difference was reliable only by items. Upon reaching the head noun position, ORs took longer than SRs at the head noun (word 4) and the following word (word 5) and when the reading times across the entire post-relative clause region were combined (words 4-7). Thus there seems to be a reliable processing cost to ORs, starting from the position which clearly indicates the relative clause structure. This replicates the previous studies in support of the structural distance account.

4. Experiment 2: ERPs

Experiment 2 investigated ERPs in response to SRs and ORs. Thirty-three native speakers of Japanese participated in the study. The stimuli were identical to Experiment 1, but instead of self-paced presentation, they were presented at a rate of 650 msec per word. The electroencephalogram (EEG) was recorded from 25 electrodes.

ERP waveforms were examined using two-word averages to reveal phasic effects, and four-word averages for longer-lasting effects. The statistical analyses were done separately on midline (Fz, Cz, Pz), parasagittal (AF3/4, F3/4, FC3/4, C3/4, CP3/4, P3/4, PO7/8), and temporal (F7/8, FT7/8, T3/4, T5/6) electrodes as well as on individual electrodes, using 'relative clause type', 'anteriority', 'hemisphere', and 'subject' (with 'list' as a nested factor) as factors.

Sentences were compared at the relative clause region (relative clause+head noun), to see how gap-filler dependencies in Japanese relative clauses were processed, and at the post-relative clause region (head noun+remainder of the sentence), to see whether there were any effects after the gap was filled by the head noun.

Visual inspection of the relative clause region showed bi-lateral anterior negativity at the relative-clause verb and head noun position of ORs (Figure 4). ANOVAs performed in the latency window of 300 to 1250 ms after the onset of the relative clause verb 'attacked', encompassing the 300-600 msec (standard latency for LAN) windows of both 'attacked' and 'reporter-DAT-TOP', revealed a significant or marginal main effect of relative type in the midline [$F(1, 31) = 7.36$, $p < .05$] and parasagittal [$F(1, 31) = 3.04$, $p < .1$] arrays. Additionally, there was a marginal interaction between condition and anteriority in the midline array [$F(2, 30) = 3.04$, $p < .1$]. ANOVAs run on individual electrodes in the same latency window revealed a significant main effect of relative clause type at Fz, AF3, F4, FC4, and C4, as well as a marginal main effect at Cz, F3, and C3. These effects indicated that ORs were more negative than SRs, especially at frontal regions.

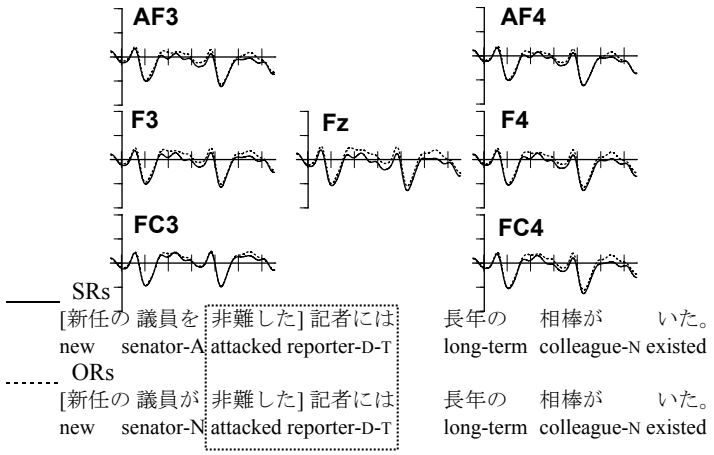

FIGURE 4. ERPs from frontal (AF3/4, F3/4, FC3/4, Fz) electrodes to the relative verb and head noun positions of SRs vs. ORs. Negativity is plotted up.

Figure 5 shows the comparison at the post-relative clause region. Visual inspection of these four-word averages showed a long-lasting continuous positivity to ORs, starting at about 500 ms poststimulus onset of the head noun and continuing throughout the epoch to the sentence end. ANOVAs performed in the latency window of 500 ms to 2950 ms poststimulus onset (starting at the head noun and continuing to the end of the sentence) revealed a significant or marginal main effect of relative clause

type in all three arrays [midline: $F(1, 31) = 7.77$, $p < .01$; parasagittal: $F(1, 31) = 4.82$, $p < .05$; temporal: $F(1, 31) = 3.36$, $p < .1$], as well as a significant relative clause type x anteriority interaction in the temporal array [$F(3, 29) = 3.38$, $p < .05$]. ANOVAs run on individual electrodes in the same time window revealed a significant main effect of relative clause type at Fz, AF4, T4, C4, T5, T6, CP3, P3, and P4, as well as a marginal main effect at Cz, C3, PO7, and PO8. These effects indicated that ORs were more positive than SRs, especially at centro-posterior sites.

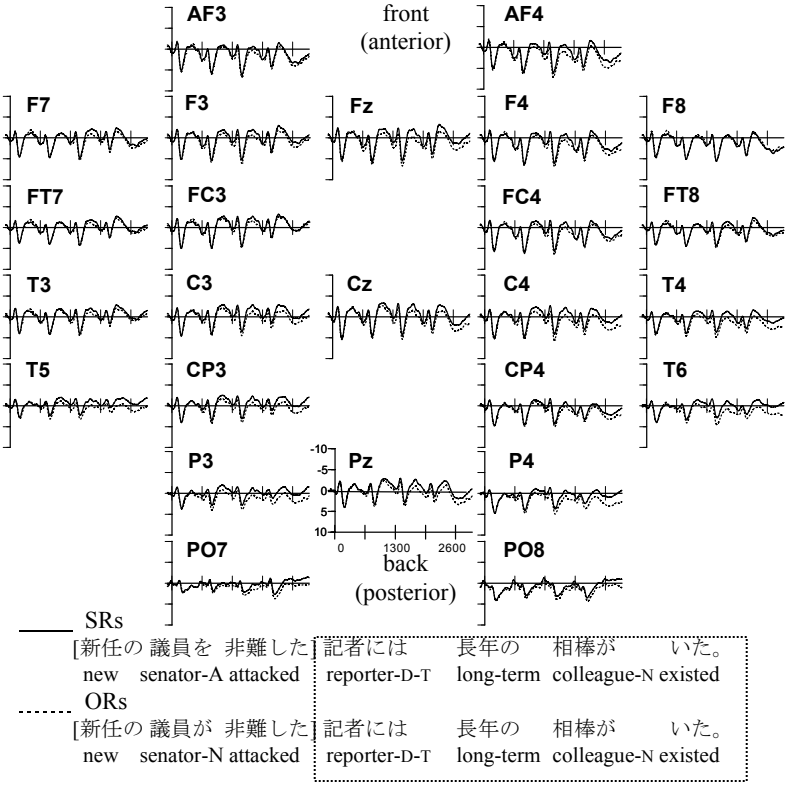

FIGURE 5. ERPs from all electrodes to the post-relative clause region (from the head noun to the sentence-end) of SRs vs. ORs. Negativity is plotted up.

To summarize, ORs elicited bilateral anterior negativity at the relative verb and head noun positions and continuous centro-posterior positivity from the head noun to the sentence-end, compared to SRs. The anterior effect has the typical latency and scalp distribution for anterior negativity, a variant of LAN. The centro-posterior effect has a reasonable scalp distribution for a P600 effect, but shows a steady long-lasting positive shift instead of a local peak. However, LAN effects have been reported in both local

and long-lasting versions (e.g. Kluender & Kutas 1993; King & Kutas 1995), and the same might be true for P600 effects. In fact, Van Petten and Kutas (1991) reported a slow positive shift in response to syntactically incoherent sentences, such as *Be place prefer the was city it and sure be perfume*, and more recently, Casado et al. (2005) reported a long-lasting positive shift for a phrase structure reallocation process in Spanish. These effects are argued to index syntactic processes typically related to the P600, and the positivity effect in our experiment may be a similar variant.

The anterior negativity observed during the relative clause may be due to the demands placed on working memory by both the storage of a gap and its subsequent retrieval for gap-filling (cf. Kluender & Kutas 1993). On this interpretation, the parser recognizes the gap in ORs upon seeing a transitively biased verb immediately following a nominative-marked noun, since there is no object in the usual position. This leads to processes that tax working memory until the object-gap in the relative clause is filled by the head noun. The parser would also recognize a gap in SRs at either the accusative-marked noun or the relative clause verb (as a scrambling interpretation is possible at the noun position itself) of SRs, but this seems to be easier, as indicated by the ERP results.

Another possible explanation has to do with differences in the likelihood of subject- and object-drop in Japanese. It is much more common to drop subjects than objects with transitively biased verbs like those used in this experiment (as shown in our norming test). If the sentence is parsed as a simple mono-clausal sentence up until the head noun, at the relative clause verb the ORs appear to be missing an object, while SRs appear to be missing a subject. Since missing objects are less common, the appearance of a missing object in the ORs may contribute to greater processing cost.

The continuous positivity starting at the head noun is more clearly due specifically to relative-clause processing, since there is no longer any ambiguity. Consistent with previous results obtained by Kaan et al. (2000), this positivity seems to index the greater syntactic integration costs of filling object-gaps. This fits well with the structural distance account, in that the object gap position is more deeply embedded and thus more structurally distant from the head noun, leading to more retrieval and integration costs.

5. General Discussion

The two experiments reported here have shown that Japanese ORs are harder to process than SRs. In both reading times and ERPs, the extra processing cost was clearly shown starting at the head noun and continuing to the end of the sentence.

Our reading time study replicated the results of previous studies finding that ORs took longer to read than SRs starting at the head noun position.

Our ERP study showed further that similar ERP components were elicited by English and Japanese ORs: anterior negativity effects between filler and gap or gap and filler and positivity effects when and after the gap was filled. If we interpret the anterior negativity effect in the relative clause region as associated with gap-filler dependencies, we could further say that the pattern of results suggests similar parsing operations for both filler-gap and gap-filler dependencies. However, as discussed in Section 4, there is an alternative possible interpretation of the anterior negativity that is not specifically about relative clause processing. Therefore, what we can say with more certainty is that gap-filler association in Japanese relative clauses seems to involve a long-lasting integration process after the filler, as indexed by the continuous positivity in ORs. If we take this approach and assume that the continuous positivity indicates greater syntactic integration cost for ORs, both ERP and reading time data are more consistent with a structural rather than linear distance account of relative clause processing difficulty in Japanese.

We have been focusing on the linear vs. structural distance accounts, but we are aware that this is not the only possible interpretation. It could be that the discourse prominence of subjects over objects causes the extra processing cost to ORs. Some linguists have proposed that Japanese relative clauses do not involve syntactic movement and that gaps are actually *pro*s instead of traces (e.g. Murasugi 2000). On this interpretation, a cataphoric relationship links the gap and the filler at the head noun. Then rather than gap-filler distance (either linear or structural), what actually matters is that the subject *pro* is easier to link cataphorically with the head noun than the object *pro*, possibly due to its discourse prominence. Related to this, several ERP studies (e.g. van Berkum et al. 2003; Cowles et al. 2003) have reported anterior negativity and/or P600 effects in the establishment of anaphoric links. Cowles et al. (2003), in particular, reported a sustained anterior negativity when the parser is carrying referential ambiguity, as well as a P600 effect when that referential gap was filled. Thus the present results could be linked with this type of interpretation, and we hope to move the discussion forward by exploring more types of filler-gap/gap-filler dependencies in our future research.

6. Conclusion

To conclude, our experiments have shown that Japanese ORs are harder to process than SRs. Our data also suggest that gap-filler association in Japanese relative clauses involve a long-lasting integration process after the filler, as indexed by the continuous positivity to ORs. Finally, both ERP and reading time data seem more consistent with a structural distance account than a linear distance account, at least for Japanese relative clauses.

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