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# Pre-verb reactivation of arguments in sentence processing

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Major models of sentence comprehension assume that a verb triggers retrieval of preceding thematic arguments from memory to establish argument-verb dependencies. If so, longer argument-verb distance should lead to higher processing load at the verb (a locality effect), since the representation of the argument should suffer from decay and/or interference. However, verb-final languages have often failed to show the expected argument-verb locality effect. A possible account of the lack of the effect is that arguments and adjuncts before the verb reactivate each other, counteracting memory degradation. In a pair of self-paced reading experiments in Japanese, a verb-final language, we found evidence of such pre-verb reactivation. Specifically, there was a locality effect and a similarity-based interference effect at the head of the adverbial that follows the subject, both of which suggest the retrieval of the subject at that point. The results are difficult to accommodate with other accounts of the lack of locality effect, such as a confounding effect of expectation and the inherent locality-insensitivity of verb-final languages. It is further argued that the constructivist analysis of verbal argument structure, which has been developed in generative syntax, provides an explanation for why such pre-verb reactivation takes place.

# 1. Background

Many studies of human real-time sentence comprehension assume that, when a verb is encountered, preceding thematic arguments are retrieved from working memory to establish argument-verb (*thematic*) dependencies (Gibson, 2000; R. L. Lewis et al., 2006; Van Dyke & McElree, 2006; Vasishth et al., 2019, among many others). For example, when *disliked* is encountered in the sentences in (1), the subject *the reporter*[1] is assumed to be retrieved from working memory.

(1) (Gibson, 2000, ex. (1))
  a. The reporter *disliked* the editor.
  b. The reporter who the senator attacked *disliked* the editor.

Such retrieval should be more difficult when the argument is more distant from the verb, since the representation of the argument in working memory should degrade gradually. This difficulty is expected to be reflected in the reading time of the verb. Thus, *disliked* should be read more slowly in (1b). Such slowdown due to dependency distance is called a *locality effect* in the literature (e.g., Bartek et al., 2011; Levy & Keller, 2013; R. L. Lewis et al., 2006, to name a few).

However, the argument-verb locality effect has not always been observed as expected. As reviewed in the rest of this section, experimental results are mixed and show a highly complex pattern. Various accounts for the mixed results have been offered in the literature. The main empirical contribution of this paper is to provide new support for one of those accounts, according to which arguments and adjuncts that precede the verb reactivate each other and thus counteract the memory degradation that would lead to a locality effect at the verb. This account is elaborated in Section 2. Section 3 reports experiments that tested its predictions. Section 4 discusses theoretical implications of the results. Specifically, it is argued that the constructivist analysis of verbal argument structure, which has been developed in generative syntax, provides an explanation for why such pre-verb reactivation takes place.

## 1.1 Processing models

As mentioned earlier, major processing models commonly assume that when a verb is encountered, preceding arguments have to be retrieved from working memory. Models differ as to what determines the difficulty of such retrieval.

The *dependency locality theory* (DLT) of Gibson (2000) assumes that the activation of a syntactic head decays as more words are processed, since the amount of activation available to the computational system is limited. In particular, processing of NPs and VPs that introduce a

[1] Precisely speaking, the subject in (1b) is the entire phrase *the reporter who the senator attacked*. However, processing studies assume that it is the position of the head that is relevant for the processing difficulty. There are opposing views as to whether the head of the phrase is the determiner or the nominal, but the current discussion does not bear much on this point.

new discourse object is assumed to consume substantial computational resources. Therefore, the cost of retrieval of an argument at a verb is contingent on the number of intervening nominal and verbal heads that introduce a new discourse object. Take (1) as an example. The matrix verb *disliked* is read more slowly in (1b) than in (1a), because retrieval of the matrix subject head *reporter* is more difficult as two new discourse referents (*senator* and *attacked*) intervene. Some recent applications of DLT simply use the number of intervening words to measure the distance (Futrell, Gibson, et al., 2020; Futrell, Levy, et al., 2020). Thus, the core prediction of DLT is that distant dependencies are more difficult to process.

The *activation model* (or ACT-R model) of R. L. Lewis and Vasishth (2005) (also see R. L. Lewis et al., 2006) also predicts locality effects. The model assumes that linguistic structures are stored in our memory as a set of feature bundles, or *chunks*. Each chunk corresponds to a maximal projection. When necessary, chunks are retrieved by the *cue-based retrieval* mechanism (McElree, 2000; McElree et al., 2003; Van Dyke & Lewis, 2003). In this mechanism, chunks are directly accessed by a set of features, or *cues*, without serially searching through the memory. The mechanism is evidenced by the presence of *retrieval interference* in various configurations, many of which are independent from locality effects (Dillon et al., 2013; Van Dyke, 2002; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006, 2011; Wagers et al., 2009, among many others; see Jäger et al., 2017, for a review and meta-analysis).

Retrieval interference predicts a locality effect in configurations like (1). When *disliked* is encountered, the parser attempts to retrieve the matrix subject using cues such as [+subject] and [+animate] (Van Dyke, 2002). The embedded subject *the senator* interferes with the correct target *the reporter,* since both have features that match these cues. Retrieval interference leads to a slower reading time, either because the access to the correct target becomes slower, or because an incorrect item is sometimes retrieved, in which case the parser has to try another time to retrieve the correct one (Vasishth et al., 2019).[2]

In the activation model, a locality effect can also arise from the degradation of chunks due to *time-based decay*. Each chunk has a fluctuating activation level, which determines the retrieval speed.[3] Since the activation decays as time passes, older chunks are more difficult to retrieve. Note that time-based decay makes predictions similar to the word-count-based version of DLT, with the trivial assumption that processing more words consumes more time.

Besides decay, *encoding interference* is another possible source of memory degradation, although it is not included in the activation model. Encoding interference refers to the damage to earlier items due to the encoding of new elements, especially those similar to the earlier ones.

[2] Strictly speaking, however, the effect in (1) is not an effect of locality per se, since cue-based retrieval would retrieve any item with matching cues regardless of whether the interfering item precedes or follows the correct target, as long as the interfering item has already been encountered when the retrieval is triggered.

[3] In the model, retrieval interference is also described in terms of activation.

For example, in (1), encoding *senator* can damage the representation of *reporter*, making its later retrieval more difficult. Empirical evidence for encoding interference includes slowdown due to the similarity of features that are not used as retrieval cues (e.g., Gordon et al., 2001; Villata et al., 2018), and stronger effects of retroactive (backward) interference compared to proactive (forward) interference (Van Dyke & McElree, 2011). These effects cannot be attributed to retrieval interference. Degradation of memory representations due to encoding interference should also make retrieval of distant chunks difficult.

In sum, while processing models assume different sources of processing difficulty, they agree that memory representations become more difficult to retrieve as they become distant. If representations of arguments are subject to such degradation and they have to be retrieved at the verb, then these models predict argument-verb locality effects.

## 1.2 Experimental results and explanations

**Table 1** lists previous experimental studies that investigated the argument-verb locality effect and their results. The results have been mixed, but they are not completely random. Below we review key experimental results and existing explanations for them.

**Table 1:** Previous experimental results regarding locality effects. SPR = self-paced reading; ET = eyetracking. 'Environment' indicates the syntactic environment in which the argument-verb dependency is located: RC = relative clause; CC = complement clause. Yes = a locality effect was observed; No = no locality effect was observed.

| Study | Method | Language | Environment | Result |
|---|---|---|---|---|
| Grodner and Gibson (2005) | SPR | English | Matrix, RC | Yes |
| Bartek et al. (2011) | SPR, ET | English | Matrix, RC | Yes |
| Levy et al. (2013) | SPR | Russian | RC | Yes |
| Vasishth and Drenhaus (2011) | SPR, ET | German | RC | Yes |
| Levy and Keller (2013) | ET | German | RC | Yes |
| Levy and Keller (2013) | ET | German | Matrix | No (anti-locality) |
| Konieczny (2000) | SPR | German | Matrix | No (anti-locality) |
| Vasishth and Lewis (2006) | SPR | Hindi | CC, RC | No (anti-locality) |
| Safavi et al. (2016) | SPR, ET | Persian | Matrix | Yes |
| Ono and Nakatani (2014) | SPR | Japanese | CC with *wh* | Yes |
| Nakatani (2021a) | SPR | Japanese | Matrix with NPI | Yes |
| Nakatani and Gibson (2008) | SPR | Japanese | Matrix | No (null) |
| Nakatani and Gibson (2010) | SPR | Japanese | Matrix, CC | No (null) |

Grodner and Gibson (2005) is a classic case for locality effects. They conducted a self-paced reading (SPR) experiment using sentences like (2), manipulating the distance between the subject *the nurse* and the verb *supervised,* and whether the clause is embedded as a relative clause (RC) or not. Based on DLT, they predict a main effect of distance and an interaction of distance and embedding. The latter is predicted because processing a verb in an RC involves additional retrieval of the relative pronoun *who*.

(2) a. The nurse {∅ / from the clinic / who was from the clinic} *supervised* the administrator while ...
b. The administrator who the nurse {∅ / from the clinic / who was from the clinic} *supervised* scolded the medic ...

As expected, they found that the verb was read more slowly when the subject was more distant, and this effect was stronger in an RC. Bartek et al. (2011) confirmed their predictions in eyetracking experiments using the same structures. Notably, Bartek et al. found simple effects of distance even in the matrix clause condition (2a), where no additional retrieval of a relative pronoun is involved. This suggests that argument-verb dependencies themselves are subject to the locality effect.

However, several studies in verb-final languages have failed to find such a locality effect (Konieczny, 2000; Levy & Keller, 2013; Nakatani & Gibson, 2008, 2010; Vasishth & Lewis, 2006). Various factors are claimed to be responsible for the lack of a locality effect.

One such factor is *expectation*. Consider the following German sentences, used in Konieczny (2000)'s SPR study. The distance between the object NP (*die Rose* 'the rose') and the verb participle (*(hin)gelegt* 'laid (down)') was manipulated by the position and length of an RC that modifies the object NP, and the presence and length of a PP that modifies the verb, as shown in (3).

(3) a. Er hat die Rose ([$_{RC}$ ...]) *hingelegt* ([$_{RC}$ ...]), und ...
he has the rose laid.down and
b. Er hat die Rose ([$_{RC}$ ...]) auf den Tisch *gelegt* ([$_{RC}$ ...]), und ...
he has the rose on the table laid and
c. Er hat die Rose ([$_{RC}$ ...]) auf den kleinen runden Tisch *gelegt* ([$_{RC}$ ...]), und ...
he has the rose on the small round table laid and
'He has laid the rose [$_{RC}$ ...] (on the (small round) table) and ...'

Konieczny (2000) found that the verb participle was read *faster* when more words intervene between the object and the verb, contrary to the prediction. Such speed-up with an increased argument-verb distance is called an *anti-locality effect*. Levy (2008) attributed the anti-locality effect in such verb-final configurations to the increased expectation for the verb (also see Konieczny, 2000; Levy & Keller, 2013).

Another factor that may be responsible for the anti-locality effect is *reactivation* (Vasishth & Lewis, 2006). Attaching a modifier to an argument (e.g., attaching an RC to the object *die Rose* in (3)) involves retrieval of the argument. In the activation model, such retrieval boosts the activation of the argument and makes its later retrieval at the verb easier. Similarly, attaching an adverbial to the predicted verbal node boosts the activation of the verbal node, making its retrieval at the verb easier.

A problem with explanations based on expectation or reactivation is why we do not find a similar anti-locality effect in English sentences like (2), where the subject-modifying RC should reactivate the subject and increase the expectation for the appearance of the verb.[4] Still, these explanations for anti-locality effects tell us that expectation and reactivation have to be controlled for in order to investigate the underlying locality effect.

Other factors are also claimed in the literature to affect the presence or absence of a locality effect. Nakatani and Gibson (2010) (also see Nakatani & Gibson, 2008) report that no argument-verb locality effect was observed in a Japanese SPR experiment that controlled for expectation and reactivation factors. They used center-embedded sentences like (4) and manipulated the argument-verb distance by scrambling the complement clause to the front. For example, the matrix subject *syoki-ga* 'secretary-NOM' is more distant from the verb *hookokusita* 'reported' in (4a) than in (4b).

(4) a.

| | | | |
|---|---|---|---|
| [syoki-ga | [daigisi-ga | [syusyoo-ga | utatanesita-to] |
| secretary-NOM | congressman-NOM | prime.minister-NOM | dozed-that |
| koogisita-to] | hookokusita-node] ... | | |
| protested-that | reported-therefore | | |

b.

| | | | |
|---|---|---|---|
| [[daigisi-ga | [syusyoo-ga | utatanesita-to] | koogisita-to] |
| congressman-NOM | prime.minister-NOM | dozed-that | protested-that |
| syoki-ga | hookokusita-node] ... | | |
| secretary-NOM | reported-therefore | | |

'Because the secretary reported that the congressman had protested that the prime minister had dozed, ...'

Nakatani and Gibson (2010) found no significant correlation between DLT's integration cost (i.e., argument-verb distance) and the reading time at the verb. It is difficult to attribute this observation to the aforementioned confounding factors of expectation and reactivation, since all conditions use the same subjects and objects, and they always appear before the verb. It should be noted, however, that the use of scrambling may have masked the underlying locality effect by increasing the processing cost in (4b), as the authors admit.

[4] Vasishth and Lewis (2006)'s answer to this problem was that the locality effect in English that Grodner and Gibson (2005) observed could be due to spillover. However, Bartek et al. (2011) later showed that the effect is still present even when spillover is statistically taken into account.

Nakatani and Gibson (2010) offer two possible accounts of why the locality effect is absent in some experiments, including theirs. One possibility is that the processing strategy is parametrized depending on the language, and head-final languages are "heavily expectation-oriented" (p. 108) so that there is no cost for distant dependencies. Another possibility is that locality only affects processing of certain types of dependencies, such as filler-gap dependencies, and not argument-verb dependencies. This account is corroborated by the observation that the lack of a locality effect is concentrated on plain thematic dependencies, i.e., argument-verb dependencies without additional complexities such as relativization, a *wh*-dependency, or negative concord (Nakatani, 2021a; Ono & Nakatani, 2014).

Levy and Keller (2013)'s eyetracking data in German also suggests that the strength of a locality effect depends on the configuration. The sentences they used are schematically shown in (5). In Experiment 1, the distance between the subject and the verb was manipulated by insertion of an AdvP and/or a dative NP, which are shown in parentheses in (5a). In Experiment 2, the entire clause was embedded as an RC (5b). (6a,b) shows actual sentences corresponding to (5a,b), with both the AdvP and dative NP present in the critical clause.

(5) a. AdvP Aux NP$_{nom}$ (AdvP) (NP$_{dat}$) NP$_{acc}$ V
b. AdvP Aux NP$_{nom}$ [who$_{nom}$ (AdvP) (NP$_{dat}$) NP$_{acc}$ V Aux] NP$_{acc}$ V

(6) (Levy & Keller, 2013, exx. (4d), (7d))

a. Nachdem der Lehrer den Strafunterricht verhängte, hat Hans
after the.NOM teacher the.ACC detention.classes imposed, has Hans
Gerstner [$_{AdvP}$ zur zusätzlichen Ahndung des mehrfachen Fehlverhaltens]
Gerstner as additional payback for multiple wrongdoings
[$_{NPdat}$ dem ungezogenen Sohn des fleißigen Hausmeisters] den
the.DAT naughty son the.GEN industrious janitor the.ACC
Fußball versteckt, und damit die Sache bereinigt.
football hidden, and thus the.ACC affair corrected
'After the teacher imposed detention classes, Hans Gerstner hid the football from the naughty son of the industrious janitor as additional payback for the multiple wrongdoings, and thus corrected the affair.'

b. Nachdem ... verhängte, hat der Mitschüler, [$_{RC}$ der [$_{AdvP}$ zur ...]
After imposed has the.NOM classmate who as
[$_{NPdat}$ dem ...] ... versteckt hat,] die Sache bereinigt.
the.DAT hidden has the.ACC affair corrected
'After the teacher imposed detention classes, the classmate who hid the football from the naughty son of the industrious janitor as additional payback for the multiple wrongdoings corrected the affair.'

They found an anti-locality effect due to the dative NP in Experiment 1. However, this effect disappeared in Experiment 2 when both the AdvP and the dative NP were present. Levy and Keller's account for this result was as follows. Generally, both expectation and locality affect reading times. The relative weighting of these factors is language-dependent, and speakers of verb-final languages are less prone to locality, since they are more practiced at non-local dependencies. Therefore, in German, a locality effect surfaces only when it is strong enough to overwhelm the expectation-based effects. Unlike Nakatani and Gibson (2010), this account does not take the type of dependency as the sole decisive factor. Rather, reading times are assumed to result from an interplay between expectation and locality effects (also see Vasishth & Drenhaus, 2011, for a similar proposal).

In short, Nakatani and Gibson (2010) and Levy and Keller (2013) both suggest that the type of the dependency and the word order (verb-final or verb-medial) are relevant for the presence or absence of a locality effect. Both suggest that plain thematic dependencies in verb-final languages do not exhibit a locality effect. However, there is evidence that plain thematic dependencies can exhibit a locality effect even in verb-final languages. Safavi et al. (2016) conducted SPR and eyetracking experiments in Persian, a verb-final language, and showed that plain thematic dependencies can yield a locality effect. In this study (Experiments 2 and 4), they manipulated the distance between the matrix arguments and the verb by the length of the NP in the intervening PP, as shown in (7). This design is intriguing, because the distance is manipulated without bringing confounding factors in. Neither the predictability of the verb nor the activation of the matrix arguments are affected by the additional NPs inside the PP.[5] The linear order of the arguments is constant across conditions (i.e., no scrambling is used). They also manipulated the predictability of the verb from the object using object-verb complex predicates, such as *a:rezouyee kard* 'wish do (make a wish)'.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (7) | Ali | shokola:t-i | bara:ye | (doost-e | xa:har-e) | man | *xarid* | va | ... |
| | Ali | chocolate-INDEF | for | friend-EZ | sister-EZ | 1SG | buy.PAST | and | ... |

'Ali bought a chocolate for (a friend of a sister of) me, and ...'

They found a clear locality effect at the verb. This is unexpected if plain thematic dependencies are inherently locality-insensitive, as Nakatani and Gibson (2010) suggested. There was also an effect of predictability, but it did not interact with the locality effect. This indicates that locality

[5] Konieczny (2000) also manipulates the argument-verb distance by the length of the PP, as shown in (3). However, a possible confound in that design is the predictability of the PP-internal noun (*Tisch* 'table' in (3)). The adjectives inserted before it should increase the expectation for the noun that heads the object of the preposition, and the facilitation effect of that expectation could have spilt over to the following verb. In Safavi et al. (2016)'s design, there is no such increase (or decrease) of expectation.

and expectation are two independent factors that both affect reading times, in line with Levy and Keller (2013)'s view (also see Ono & Sugi, 2018). The Persian data is still problematic for Levy and Keller (2013)'s account since it shows a locality effect in an arguably very simple argument-verb dependency in a verb-final language. A possible explanation for this data will be discussed in Section 2.

Summarizing the review so far, the argument-verb locality effect is predicted from two assumptions: representations in human working memory degrade gradually, and arguments have to be retrieved at the verb. However, experimental results have been mixed. In particular, several studies on verb-final structures have failed to observe the effect. Various explanations for the mixed results can be grouped into two views. The *underlying locality view* points to confounding factors that may have masked the underlying locality effect, such as expectation, reactivation by modification, and scrambling. In the current study, these factors are controlled for. We add the lack of statistical power to detect the locality effect as another possibility along this line. The *inherent insensitivity view* states that certain languages and certain types of dependencies are inherently insensitive to locality. Namely, thematic dependencies in verb-final languages are argued to be insensitive. We have seen that there is a counterexample to this view, however. In the next section we argue for another view, the *pre-verb reactivation hypothesis*, which is able to account for the counterexample *and* the general lack of locality effects in verb-final thematic dependencies at the same time.

# 2. Pre-verb reactivation hypothesis

## 2.1 Pre-verb reactivation based on a dependency chain

As mentioned in Section 1, Japanese fails to show a locality effect in plain thematic dependencies, but does show an effect when the dependency involves a *wh* element or a negative polarity item (NPI). Nakatani (2021a) proposes an account for this contrast based on the pre-verb reactivation of the arguments and adjuncts (also see Nakatani, 2021b). He assumes that elements that (are predicted to) depend on the same head form an object called *dependency chain*, and the chain is reactivated every time another member is added to it. Such reactivation counteracts the degradation of the representations of the thematic elements, which could lead to a locality effect. Non-thematic dependencies, on the other hand, do not receive such intermediate reactivation, and are therefore subject to a locality effect. Consider the Japanese SOV sentence (8a), for example. The matrix elements gradually form a chain ⟨*John, in a park, apple, ate*⟩ as the sentence unfolds. Since the chain that contains *John* is reactivated every time one of these elements is added, there is no processing difficulty due to the surface distance between *John* and the verb *tabe-ta* 'ate.' If the sentence involves an NPI *sika* 'only,' as in (8b), there is an additional chain ⟨*only,* NEG⟩, hence processing difficulty due to the distance between *sika* and NEG. Nakatani also applies this account to locality effects observed in RCs, which have a distinct dependency chain between the relative pronoun and the trace.

(8) a. John-ga kooen-de ringo-o tabe-ta.
John-NOM park-in apple-ACC eat-PAST
'John ate an apple in a park.'

b. John-sika kooen-de ringo-o tabe-nakat-ta.
John-only park-in apple-ACC eat-NEG-PAST
'Only John ate an apple in a park.'

While Nakatani (2021a) argues that the dependency chain hypothesis explains why thematic dependencies are insensitive to locality, it also predicts locality effects between adjacent clausemates, in our view. This prediction is consistent with the aforementioned Persian data (7). In that experiment, there was a locality effect between the prepositional head and the verb. This is predicted by the dependency chain hypothesis as follows. The chain that would be formed in this sentence is ⟨*Ali, chocolate, for, bought*⟩. The chain is retrieved when, and only when, each of these elements is encountered. Therefore, the distance between *for* and *bought* causes a locality effect at the latter.

Thus, pre-verb retrieval of arguments based on dependency chains is able to account for the complicated pattern of argument-verb locality effects observed in previous studies. However, theoretical questions remain. What is a dependency chain, and why does adding an element to a chain result in cancelling the decay of all the elements that belong to that chain? That is not expected under the standard notion of dependency. For example, a subject and an object are not usually considered to form a dependency, hence an object is not expected to trigger the retrieval of the preceding subject. A possible answer to these questions will be discussed in 4.2. We will use the term *pre-verb reactivation hypothesis* in a sense that is neutral with respect to the underlying syntactic representation. It refers to the psycholinguistic hypothesis that arguments and adjuncts can be reactivated when a new clausemate is encountered.

## 2.2 Locality effects between adjacent clausemates

The pre-verb reactivation hypothesis makes a unique empirical prediction: there should be locality effects between adjacent clausemates. For example, sentences (9a,b) differ in the distance between the subject *John-ga* and the head of the locative adverbial *kooen-de* 'in a park.' The current hypothesis predicts that the reading time at *kooen-de* is longer in the long distance condition than in the short distance condition.

(9) a. (Short distance; = (8a))
John-ga kooen-de ringo-o tabe-ta.
John-NOM park-in apple-ACC eat-PAST
'John ate an apple in a park.'

b. (Long distance)

| | | | | | |
|---|---|---|---|---|---|
| John-ga | totemo | hiroi | kooen-de | ringo-o | tabe-ta. |
| John-NOM | very | large | park-in | apple-ACC | eat-PAST |

'John ate an apple in a very large park.'

Let us formalize this prediction using the activation model of R. L. Lewis and Vasishth (2005). As mentioned earlier, this model assumes that each chunk (maximal projection) has a fluctuating activation that reflects its encoding and retrieval history. The base level activation of item *i* is given by the equation

$$B_i = \ln\left(\sum_{j=1}^{n} t_j^{-d}\right)$$

where $t_j$ is the time since *j*th encoding or retrieval of the item, and *d* is the fixed decay rate. We adopt $d = 0.5$, following R. L. Lewis and Vasishth (2005). We further assume that every region takes a constant time (500 ms) to read. We admit that this is a huge simplification. But calculating exact reading times from the model requires specification of numerous factors, including the exact structure for the entire sentence, all the cues used in all the retrievals, a linking hypothesis between the retrieval time and reading time, and so on. That is beyond the scope of this paper. Another problem is that the standard activation model does not take encoding interference into account, despite its empirical plausibility (see Section 1). The crucial prediction is not affected by such details, however. What is important is that the two conditions substantially differ in the time that passes between the encoding of the subject and its first retrieval at the locative adverbial. We therefore confine the use of the activation model to the simulation of activation fluctuation that varies by the distance manipulation, and combine the simulation results and other considerations to obtain predictions. **Figure 1** shows how the activation of the subject noun *John-ga* in (9) would fluctuate under the current assumptions. As presented in the figure, the locative adverbial is predicted to show a locality effect due to the distance from the subject. The subject is also retrieved at the object and at the verb, but these retrievals should result in little locality effect because the activation of the subject has become largely equal between the Short and Long Distance conditions once it is activated at the locative adverbial.

An important assumption here is that the parser analyzes the locative adverbial, the accusative-marked noun, and the verb as clausemates of the subject. Previous experimental results support the view that the parser adopts such a single clause analysis unless the input suggests the contrary (Kamide et al., 2003; Miyamoto, 2002).

In summary, we argued that (i) pre-verb reactivation of arguments can account for the complicated facts regarding the presence and absence of the argument-verb locality effect, and (ii) the pre-verb reactivation hypothesis predicts locality effects between adjacent clausemates. The next section reports two experiments that test this prediction. To anticipate the results, the experiments show locality effects between the subject and a locative adverbial (like *kooen-de* 'in a park' in the example above), lending support to the pre-verb reactivation hypothesis.

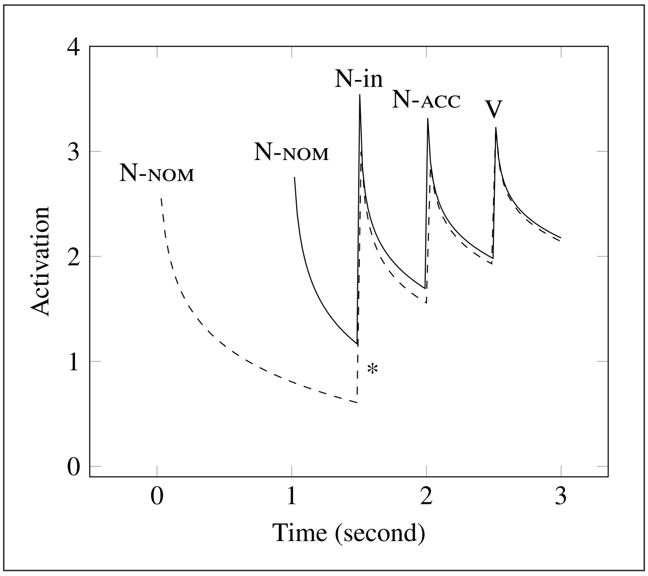


**Figure 1:** Simulated fluctuation of the activation of the subject in the sentences in (9). Solid line: short distance condition; Dashed line: long distance condition. The asterisk indicates where the locality effect is predicted.

## 3. Experiments

In this section, we report two SPR experiments in Japanese. These experiments aim to adjudicate between the underlying locality view, the inherent insensitivity view, and the pre-verb reactivation hypothesis. In the underlying locality view, a subject-verb locality effect is expected if the experiments control for confounding factors and have sufficient statistical power. The pre-verb reactivation hypothesis instead predicts a locality effect between adjacent clausemates. The inherent insensitivity view predicts neither type of locality effect.

We conducted the two experiments in parallel. The basic design is common to both experiments. As shown schematically in (10), the distance between the subject and other matrix elements is manipulated by where the RC is placed. It is attached either to the subject or to the genitive noun (Japanese RCs are exclusively pre-nominal). The genitive noun modifies the following noun, marked with the locative marker *-de* 'at', which functions as an adverbial and typically denotes the location in which the event takes place. We refer to this element as the locative adverbial. The RC in the Long Distance condition is attached to the noun inside the locative adverbial, rather than the locative noun, to prevent the reading time at the locative noun from being contaminated by the RC processing.

(10) a. (Short Distance condition)
[$_{RC}$ ...] noun-NOM noun-GEN noun-at noun-ACC adverb verb …

b. (Long Distance condition)
noun-NOM [$_{RC}$ ...] noun-GEN noun-at noun-ACC adverb verb …

Note that this design is free from the confounding factors pointed out in the literature. The expectation for the verb is arguably constant across conditions, since the matrix elements are the same. There is no reactivation of any matrix element due to modification, since modifiers always precede the modified. Scrambling is not used.

The Distance factor is crossed with the Interference factor, which manipulates the degree of similarity-based interference between the matrix subject and the first overt noun in the RC. In Experiment 1, the morphological case of the RC noun is manipulated by changing the voice of the RC. In Experiment 2, the animacy of the RC noun is manipulated. These manipulations are added to confirm that the locality effect is due to the retrieval of the subject, rather than some other functional head (see 3.1.2 below for details).

The participants were 102 university students who were native speakers of Japanese. They received an Amazon Gift Card equivalent to 700 yen for participation. They were randomly assigned to one of the two experiments. Data from two participants who completed the experiment were lost due to technical errors. Of the remaining participants, 51 were assigned to Experiment 1 and 49 were assigned to Experiment 2.

The number of participants and items was determined by a simulation-based power analysis (DeBruine & Barr, 2021). Reading time data was simulated by sampling from a maximal linear mixed effects model specified in 3.1.4, and a model was fit using the same method as the actual analysis. The coefficient for the distance factor was assumed to be 0.03 (in log milliseconds). With the grand mean 6.0 (and the sum coding used here), this means that the Long Distance conditions are slower by 24 milliseconds compared to the Short Distance conditions. This is a relatively conservative assumption given the data from previous studies.[6] The simulation was repeated 500 times. The results indicated that with 50 participants and 32 items, an experiment can detect the distance effect with a probability of 93.8%.[7]

Half of the target sentences in the two experiments are the same. After the experiments, we noticed that the same sentences were processed differently in these experiments. We therefore

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[6] In Safavi et al. (2016, Experiment 2), the distance effect due to the object-verb distance in Persian plain SOV structures (see (7)) is estimated to be 0.0397. In Ono and Nakatani (2014)'s experiment in Japanese, the reading time at the verb is reported to be more than 100 milliseconds slower when the *wh*-subject is distant from the verb than when it is adjacent.

[7] Due to technical errors and the initial screening process, the actual numbers of the participants and the items were smaller than initially planned. This does not result in a large reduction of statistical power: with 49 participants and 31 items, as in Experiment 2, the power is 92.2%.

conducted a post-hoc between-experiment analysis to investigate the difference. This analysis and its implications are discussed in 3.3.

## 3.1 Experiment 1

### 3.1.1 Design

(11) shows an example set of target sentences. As already mentioned, the subject-verb distance is crossed with the voice of the RC. These manipulations are confined to Regions 1 to 4. All conditions are identical from Region 5. Regions 11 to 14 are added to prevent a wrap-up effect from showing up at the matrix verb at Region 10.

(11) a. (Short Distance, Low Interference)

| | | | | | |
|---|---|---|---|---|---|
| | Byooin-de[1] | itizitekini[2] | yatow-are-ta[3] | gekai-ga,[4] | … |
| [$_{\text{RC}}$ | hospital-at | temporarily | hire-PASS-PAST] | surgeon-NOM | |

b. (Short Distance, High Interference)

| | | | | | |
|---|---|---|---|---|---|
| | Byooin-ga[1] | itizitekini[2] | yatot-ta[3] | gekai-ga,[4] | … |
| [$_{\text{RC}}$ | hospital-NOM | temporarily | hire-PAST] | surgeon-NOM | |

c. (Long Distance, Low Interference)

| | | | | | |
|---|---|---|---|---|---|
| Gekai-ga,[1] | | byooin-de[2] | itizitekini[3] | yatow-are-ta[4] | … |
| surgeon-NOM | [$_{\text{RC}}$ | hospital-at | temporarily | hire-PASS-PAST] | |

d. (Long Distance, High Interference)

| | | | | | |
|---|---|---|---|---|---|
| Gekai-ga,[1] | | byooin-ga[2] | itizitekini[3] | yatot-ta[4] | … |
| surgeon-NOM | [$_{\text{RC}}$ | hospital-NOM | temporarily | hire-PAST] | |

| | | | | | | |
|---|---|---|---|---|---|---|
| kangosi-no[5] | mae-de[6] | kogarana[7] | kanzya-o[8] | yasasiku[9] | nade-ta[10] | kotode[11] |
| nurse-GEN | front-at | small | patient-ACC | gently | stroke-PAST | because |

| | | |
|---|---|---|
| sonoba-no[12] | hun'iki-ga[13] | yawarai-da.[14] |
| that.place-GEN | atmosphere-NOM | soften-PAST |

'As the surgeon {a. who was hired temporarily at the hospital / b. who the hospital hired temporarily} gently stroked the small patient in front of the nurse {c. who was hired temporarily at the hospital / d. who the hospital hired temporarily}, the atmosphere there softened.'

In the Long Distance conditions, there is a clause boundary between Region 1 and 2. The parser should be able to detect that in the Long Distance, High Interference condition thanks to the two consecutive nominative nouns in these regions (Miyamoto, 2002). In the Long Distance, Low Interference condition, it is only at Region 5 that it becomes evident that the Region 4 verb heads an RC, and the Region 1 noun cannot be the subject of that RC. Logically, in this case, the clause boundary can be placed anywhere between Regions 1 to 4. But the *tooten* (Japanese comma; indicated by commas in (11)) should help identify the boundary between Regions 1 and

2.[8] This ambiguity could potentially increase the reading time at Region 5 in the Long Distance, Low Interference condition, but we did not observe such an effect. Nor did the comprehension accuracy show any indication of confusion in this condition due to this ambiguity. A tooten is also added to the matrix subject in other conditions for consistency.[9]

### 3.1.2 Predictions

The three views we are considering make different predictions regarding the reading times, as summarized in **Table 2**. The underlying locality view predicts a classic argument-verb locality effect. That is, the Long Distance conditions should be slower at the matrix verb, because retrieval of the subject is more difficult when it is more distant. Panel A of **Figure 2** illustrates the simulated fluctuation of the subject's activation under this view. The inherent insensitivity view simply predicts no locality effect. To state such a prediction within the activation model, one would have to argue either that the decay rate of the relevant element is exceptionally low, or that the effect of the activation level of the relevant element on its retrieval latency is exceptionally small. Panel B of **Figure 2** illustrates the former possibility, with the decay rate $d = 0.25$ instead of $d = 0.5$ (the latter possibility is not represented since the activation profile would be the same as Panel A). Finally, the pre-verb reactivation hypothesis predicts a locality effect between the subject and the locative adverbial (Panel C).

**Table 2:** Predictions of different views and results of the experiments. D indicates a main effect of Distance; (D) means that the main effect of Distance is not predicted explicitly in the literature, but should be predicted if adjunction of the adverbial is taken into account; D:I indicates Distance-Interference interaction; – means neither effect is predicted or observed.

| | **Adverbial** | **Verb** |
|---|---|---|
| Underlying locality | (D) | D, D:I |
| Inherent insensitivity | – | – |
| Pre-verb reactivation | D, D:I | – |
| Result – Experiment 1 | D, D:I | – |
| Result – Experiment 2 | D, D:I | – |

[8] There is no strict orthographic rule for the use of the tooten in Japanese. A tooten is neither necessary nor sufficient to indicate a clause boundary. However, it can be used to help disambiguate a potentially ambiguous noun sequence, as we do here.

[9] The tooten could induce an unnecessary clause boundary in the Short Distance conditions. If this happened, the end of the sentence would surprise the reader, since there are not enough verbs. However, reading time data indicate no difference between the Long and Short Distance conditions at the end of the sentence. There is no indication of confusion in the comprehension accuracy of the Short Distance conditions either.

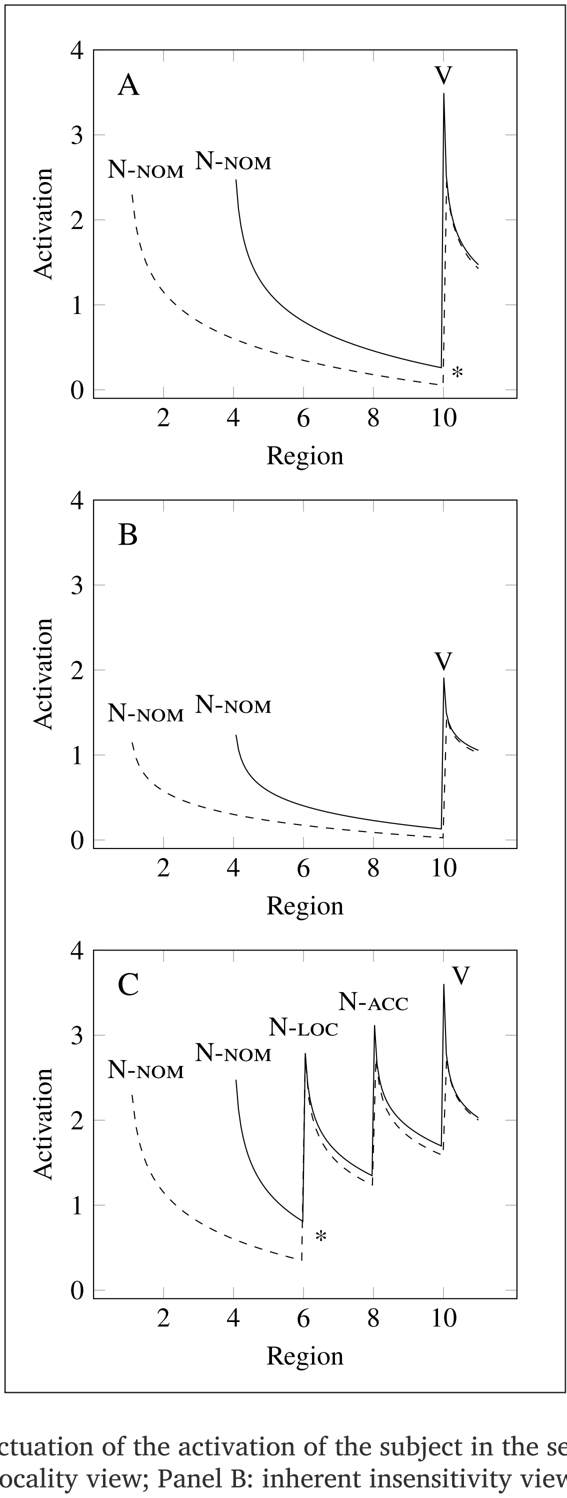



**Figure 2:** Simulated fluctuation of the activation of the subject in the sentences in Experiment 1. Panel A: underlying locality view; Panel B: inherent insensitivity view (one instantiation; see the main text); Panel C: pre-verb reactivation hypothesis. Solid line: Short Distance condition; Dashed line: Long Distance condition. The asterisks indicate where the locality effect is predicted.

The locality effect (the main effect of Distance) between the subject and the locative adverbial can also be due to the retrieval of the attachment site of the adverbial, however. When the adverbial phrase is completed by its head (*mae-de* in the above example), it has to be attached to a node in the matrix clause structure. If the attachment site is predicted when the subject is introduced, as would be assumed in the left-corner parsing strategy (Abney & Johnson, 1991), there would be a locality effect due to the retrieval of the attachment site. Therefore, a main effect of distance between the subject and the locative adverbial does not provide convincing evidence for the retrieval of the subject noun at the adverbial. Due to this consideration, the Distance factor was crossed with Interference. The idea is that higher similarity between the matrix subject and the RC noun would increase the retrieval difficulty of the matrix subject via encoding interference (see 1.1 for encoding interference). The Interference effect should be stronger in the Long Distance condition, because retroactive interference is stronger than proactive interference (Van Dyke & McElree, 2011). Thus, the pre-verb reactivation hypothesis predicts an interaction between Distance and Interference at the locative adverbial, such that the Long Distance, High Interference condition is the slowest. The underlying locality view predicts the same interaction at the verb.

Another possible source of the locality effect at the locative adverbial is the spillover from the RC. In SPR experiments, processing difficulty due to the material in a region can be reflected not only in the reading time of that region but also those of subsequent regions (*spillover;* Bartek et al., 2011; Mitchell, 1984). To separate out such spillover effects from effects inherent to the material of the current region, we included the reading time of the previous region in the statistical model (Vasishth, 2006) (see 3.1.4 for details). But this approach is only able to factor out the spillover as long as the effect caused by the material in the previous region surfaces both in the previous and the current regions. Given that the button can be pressed in principle once the visual encoding is done, effects of syntactic processing may start to show up only in subsequent regions. This is problematic in interpreting the data in two ways. Take the matrix locative adverbial at Region 6, for example. First, even if some effect is observed at Region 6, it is still possible that this is a delayed effect from the relativization process initiated by the RC head at Region 5 (in Japanese, the presence of an RC becomes evident only when the RC head appears). Second, the effect of the locative adverbial may only appear with delay, in subsequent regions. But it is also possible that the effect at Region 6 is a genuine effect of the locative adverbial. Due to these considerations, we look at the reading times of not only the locative adverbial itself (Region 6) but also the preceding Region 5 and the following Region 7. Effects in Region 7 are more likely to be due to the processing of the locative adverbial than effects in Region 6.

### 3.1.3 Method

**Participants.** 51 participants were assigned to Experiment 1. Their ages ranged from 19 to 53, with mean 22.3 and standard deviation (SD) 5.1.

**Materials.** We prepared 32 sets of target sentences, each consisting of the four conditions described above. Four lists were created in a Latin Square design, and each participant was assigned one of those lists. The target sentences were mixed with 64 fillers in a pseudo-random order generated for each participant, such that no two target sentences were presented consecutively.

**Procedure.** The moving-window, self-paced reading paradigm (Just et al., 1982) was employed and implemented using PCIbex (Zehr & Schwarz, 2018). Participants accessed the PCIbex Farm website (https://farm.pcibex.net/) from their own devices. A session took approximately 40 minutes.

Before the trials, written instructions were presented and the participant was told to make sure to understand the sentences. Two practice trials were included before the test trials. Each trial began with a fixation point '+' at the leftmost position, followed by dashes that mask the sentence. The participant pressed the space key to proceed to the next region. When a new region was revealed, the previous region was masked again. No backtracking was allowed. When the end of the sentence was reached, a true/false comprehension question was presented. The comprehension question was a cleft sentence like (12). The focus of the question was varied across sentences to prevent participants from focusing on a particular element of the sentence. The participants responded with the F key if they thought the sentence was true, and the J key if false.

| | | | | |
|---|---|---|---|---|
| (12) | Kanzya-o | nade-ta-no-wa | gekai | da. |
| | patient-ACC | stroke-PAST-NMLZ-TOP | surgeon | is |

'It is the surgeon that stroked the patient.'

### 3.1.4 Analysis

Analyses were conducted using the R programming language (R Core Team, 2021). First, participants and items whose mean comprehension accuracy was below 2.5 SDs from the mean were excluded. This resulted in exclusion of one participant with accuracy 66.7% and one target item with accuracy 37.3%. Individual reading times below 80 ms and above 5000 ms were also excluded.

Reading times were log-transformed and analyzed by linear mixed effects (LME) modeling (Baayen et al., 2008). For each region of interest, a maximal model was constructed that contained a fixed intercept and slopes of Distance, Interference, their interaction, and Spillover, as well as corresponding random intercepts and slopes for participants and items. Distance and Interference factors were coded using sum contrasts (Schad et al., 2020). Long Distance and High Interference were coded as 1, while Short Distance and Low Interference were coded as –1. The Spillover factor was the log-transformed, centered reading time of the previous region and was included to factor out the effect of spillover. The model fitting and simplification was done using the *buildmer* function from the *buildmer* package (Voeten, 2022). The *buildmer* function first finds the maximal model that converges, and then conducts a backward stepwise elimination of random effects that do not make a significant contribution to the log-likelihood (Bates et al., 2015). P-values were calculated using Satterthwaite's approximation for degrees of freedom provided by the *lmerTest* package (Kuznetsova et al., 2017). Comprehension accuracy was analyzed by generalized linear mixed effects (GLME) logistic regression, also using the *buildmer* package.

For each region, a model was fit in the manner specified above using all the data points, and then data points with an absolute standardized residual greater than 2.5 were excluded as outliers (Baayen et al., 2008). 2.5% of all data points were removed by this process. The final model was then fit using the remaining data points.

The data and code are available online as specified in the Data Accessibility Statement.

### 3.1.5 Results

**Comprehension accuracy.** The overall comprehension accuracy was 85.5% after the initial screening of participants and items, indicating that participants paid attention to the stimuli. **Table 3** shows comprehension accuracy for target sentences by condition after the screening. GLME modeling showed no significant effects.

**Table 3:** Comprehension accuracy by condition, Experiment 1.

| Condition | Mean (%) |
|---|---|
| Short Distance, Low Interference | 87.2 |
| Short Distance, High Interference | 85.3 |
| Long Distance, Low Interference | 86.8 |
| Long Distance, High Interference | 83.0 |

**Reading time. Figure 3** shows log-transformed reading times by region and condition after the outliers are removed. **Table 4** shows model estimates for the regions of interest.

Region 5 (the genitive noun modifying the locative adverbial; the head noun of the RC in the Long Distance conditions) showed a marginal effect of Distance, such that the Long Distance conditions were faster than the Short Distance conditions. Both Region 6 (the locative adverbial) and Region 7 showed a significant main effect of Distance, such that the Long Distance conditions were slower than the Short Distance conditions. Region 6 also showed a significant interaction of Distance and Interference. Nested analysis indicates that this is because the effect of Distance is larger in the High Interference condition. Region 10 (the matrix verb) showed a marginal effect of Interference, such that the High Interference conditions were faster than the Low Interference conditions.

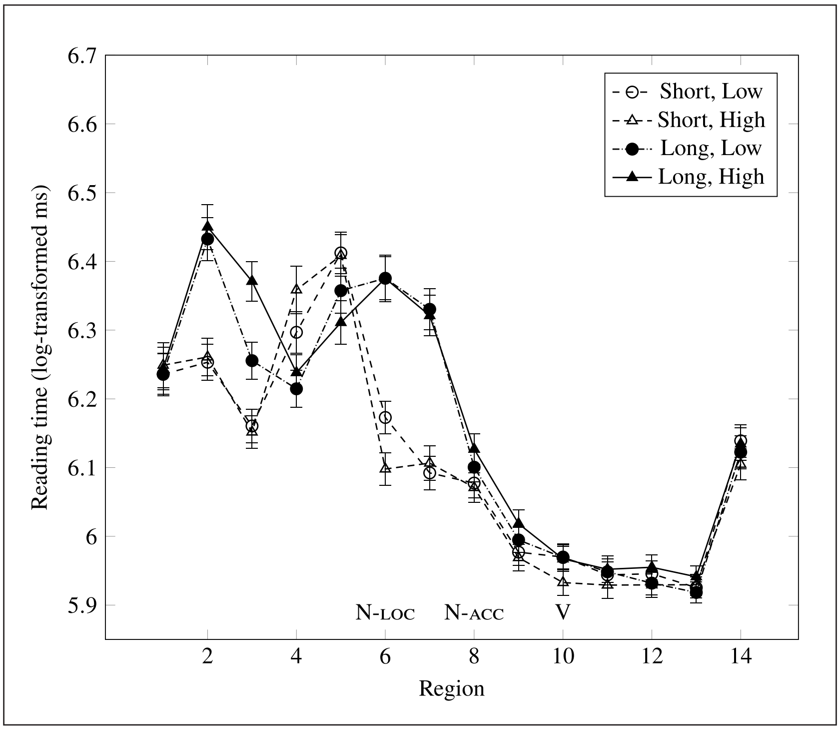



**Figure 3:** Reading times by region and condition, Experiment 1. Error bars indicate standard errors.

**Table 4:** Model estimates for selected regions of Experiment 1. Significance codes: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$, . for $p < 0.1$.

| **Region 5** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.3933 | 0.0546 | 54.92 | 117.118 | 0.0000 | *** |
| Distance | –0.0370 | 0.0187 | 46.22 | –1.978 | 0.0539 | . |
| Interference | –0.0163 | 0.0114 | 1362.03 | –1.438 | 0.1506 | |
| Spillover | 0.0941 | 0.0395 | 41.57 | 2.383 | 0.0218 | * |
| Distance:Interference | –0.0145 | 0.0114 | 1370.43 | –1.272 | 0.2035 | |
| **Region 6** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.2681 | 0.0459 | 54.70 | 136.669 | 0.0000 | *** |
| Distance | 0.1195 | 0.0171 | 46.63 | 6.969 | 0.0000 | *** |
| Interference | –0.0173 | 0.0106 | 1353.10 | –1.623 | 0.1049 | |
| Spillover | 0.1102 | 0.0372 | 44.69 | 2.966 | 0.0048 | ** |
| Distance:Interference | 0.0214 | 0.0107 | 1367.73 | 2.000 | 0.0458 | * |

(Contd.)

| Region 7 | Estimate | SE | *df* | *t* | *p* | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.2345 | 0.0466 | 58.96 | 133.8569 | 0.0000 | *** |
| Distance | 0.1071 | 0.0105 | 1410.00 | 10.1616 | 0.0000 | *** |
| Interference | 0.0002 | 0.0102 | 1398.59 | 0.0180 | 0.9857 | |
| Spillover | 0.1156 | 0.0301 | 43.33 | 3.8391 | 0.0004 | *** |
| Distance:Interference | –0.0023 | 0.0102 | 1399.32 | –0.2287 | 0.8191 | |
| **Region 8** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.1041 | 0.0299 | 47.29 | 203.9322 | 0.0000 | *** |
| Distance | 0.0072 | 0.0083 | 1426.41 | 0.8715 | 0.3836 | |
| Interference | 0.0026 | 0.0081 | 1411.27 | 0.3192 | 0.7496 | |
| Spillover | 0.1697 | 0.0298 | 46.05 | 5.7018 | 0.0000 | *** |
| Distance:Interference | 0.0081 | 0.0081 | 1410.60 | 1.0109 | 0.3122 | |
| **Region 9** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0051 | 0.0293 | 49.74 | 204.7173 | 0.0000 | *** |
| Distance | 0.0108 | 0.0068 | 1373.22 | 1.6045 | 0.1088 | |
| Interference | 0.0007 | 0.0079 | 46.52 | 0.0851 | 0.9325 | |
| Spillover | 0.2120 | 0.0322 | 51.44 | 6.5861 | 0.0000 | *** |
| Distance:Interference | 0.0069 | 0.0067 | 1371.05 | 1.0225 | 0.3067 | |
| **Region 10** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0057 | 0.0277 | 52.89 | 216.9538 | 0.0000 | *** |
| Distance | 0.0066 | 0.0077 | 29.59 | 0.8576 | 0.3980 | |
| Interference | –0.0143 | 0.0081 | 28.61 | –1.7623 | 0.0887 | . |
| Spillover | 0.3260 | 0.0400 | 49.58 | 8.1442 | 0.0000 | *** |
| Distance:Interference | 0.0054 | 0.0062 | 1374.50 | 0.8810 | 0.3785 | |
| **Region 11** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0100 | 0.0282 | 47.56 | 212.9729 | 0.0000 | *** |
| Distance | 0.0009 | 0.0065 | 1439.41 | 0.1425 | 0.8867 | |
| Interference | 0.0021 | 0.0065 | 1434.40 | 0.3221 | 0.7474 | |
| Spillover | 0.3713 | 0.0372 | 56.85 | 9.9802 | 0.0000 | *** |
| Distance:Interference | –0.0009 | 0.0064 | 1430.48 | –0.1339 | 0.8935 | |

### 3.1.6 Discussion

See **Table 2** to compare the predictions and the results.

First of all, there was no evidence for slowdown due to subject-verb distance. The current results thus fail to provide evidence for the underlying locality view. A null result must be interpreted with caution, especially given that this is a web-based experiment. It should be noted, however, that this experiment had sufficient statistical power to detect an effect of a reasonable size, and we did observe a locality effect before the verb, as described below.

The main effects of Distance at Regions 6 and 7, and the Distance-Interference interaction at Region 6, are consistent with the pre-verb reactivation hypothesis. These effects may be problematic for the inherent insensitivity view, which predicts certain kinds of dependencies in verb-final languages are insensitive to locality.

As stated in 3.1.2, there is a concern that the effect at Region 6 might be a result of spillover or delay of the processing load of the preceding RC. The statistical models control for spillover effects by including the reading time of the previous region, but this does not control for *delayed* effects. We address this concern below. In both the Short and Long Distance conditions, reading times increased at the RC head (Region 4 in the Short Distance condition and Region 5 in the Long Distance condition), as shown in **Figure 3**. This is consistent with the prediction that there is a reading slowdown at the RC head due to the processing of the RC. In the Short Distance conditions, the slowdown continues up to the next region, Region 5. This is corroborated by the marginal effect of Distance at Region 5, such that the Short Distance conditions were slower. If the effect of RC processing is confined to the head noun, then the Long Distance conditions should be slower here. Therefore, the main effect of Distance in Region 6 is likely due to the delayed effect of RC processing in the Long Distance conditions. Still, the effect in Region 7 is likely due to the retrieval of the subject rather than to RC processing, given that the effect of RC processing is apparently confined to one region after the RC head in the Short Distance conditions. The results of Experiment 2 further corroborate this view.

The marginal main effect of Interference at Region 10 (matrix verb) was unexpected. One possible account is that the active voice of the RC in the High Interference condition functioned as a prime and facilitated processing of the matrix verb, which was also active.

Overall, the results of Experiment 1 are consistent with the pre-verb reactivation hypothesis and are problematic for the underlying locality view and the inherent insensitivity view.

## 3.2 Experiment 2

### 3.2.1 Design

Like Experiment 1, Experiment 2 also manipulates the subject-object distance by insertion of an RC. Unlike in Experiment 1, the RCs in Experiment 2 are always in active voice. The interference between the the matrix subject and the RC noun is manipulated instead by the animacy of the RC noun. An example set of target sentences is shown in (13).

(13) a. (Short Distance, Low Interference)
Byooin-ga[1] itizitekini[2] yatot-ta[3] gekai-ga,[4] …
[$_{RC}$ hospital-NOM temporarily hire-PAST] surgeon-NOM

b. (Short Distance, High Interference)
Intyoo-ga[1] itizitekini[2] yatot-ta[3] gekai-ga,[4] …
[$_{RC}$ hospital.director-NOM temporarily hire-PAST] surgeon-NOM

c. (Long Distance, Low Interference)
Gekai-ga,[1] byooin-ga[2] itizitekini[3] yatot-ta[4] …
surgeon-NOM [$_{RC}$ hospital-NOM temporarily hire-PAST]

d. (Long Distance, High Interference)
Gekai-ga,[1] intyoo-ga[2] itizitekini[3] yatot-ta[4] …
surgeon-NOM [$_{RC}$ hospital.director-NOM temporarily hire-PAST]

kangosi-no[5] mae-de[6] kogarana[7] kanzya-o[8] yasasiku[9] nade-ta[10] kotode[11]
nurse-GEN front-at small patient-ACC gently stroke-PAST because
sonoba-no[12] hun'iki-ga[13] yawarai-da.[14]
that.place-GEN atmosphere-NOM soften-PAST
'As the surgeon {a. who the hospital hired temporarily / b. who the hospital director hired temporarily} gently stroked the small patient in front of the nurse {c. who the hospital hired temporarily / d. who the hospital director hired temporarily}, the atmosphere there softened.'

### 3.2.2 Predictions

The predictions for Experiment 2 are essentially the same as Experiment 1. Namely, the underlying locality view predicts a main effect of Distance and a Distance-Interference interaction at the verb; the inherent insensitivity view predicts no Distance effect; the pre-verb reactivation hypothesis predicts a main effect of Distance and a Distance-Interference interaction at the locative adverbial.

### 3.2.3 Method

49 participants were assigned to Experiment 2. Their ages ranged from 19 to 33, with mean 21.7 and SD 2.4.

### 3.2.4 Analysis

The data were analyzed using the same method as Experiment 1. Initial screening by comprehension accuracy excluded one participant with accuracy 52.1% and one target item with accuracy 30.1%. Screening by individual reading times removed 2.5% of all the data points as outliers.

### 3.2.5 Results

**Comprehension accuracy.** The overall comprehension accuracy was 84.5% after the initial screening of participants and items, indicating that participants paid attention to the stimuli. **Table 5** shows comprehension accuracy for target sentences by condition after the screening. GLME modeling showed no significant effects.

**Table 5:** Comprehension accuracy by condition, Experiment 2.

| Condition | Mean (%) |
|---|---|
| Short Distance, Low Interference | 85.1 |
| Short Distance, High Interference | 86.3 |
| Long Distance, Low Interference | 84.1 |
| Long Distance, High Interference | 82.6 |

**Reading time. Figure 4** shows log-transformed reading times by region and condition after the outliers are removed. **Table 6** shows model estimates for regions of interest.

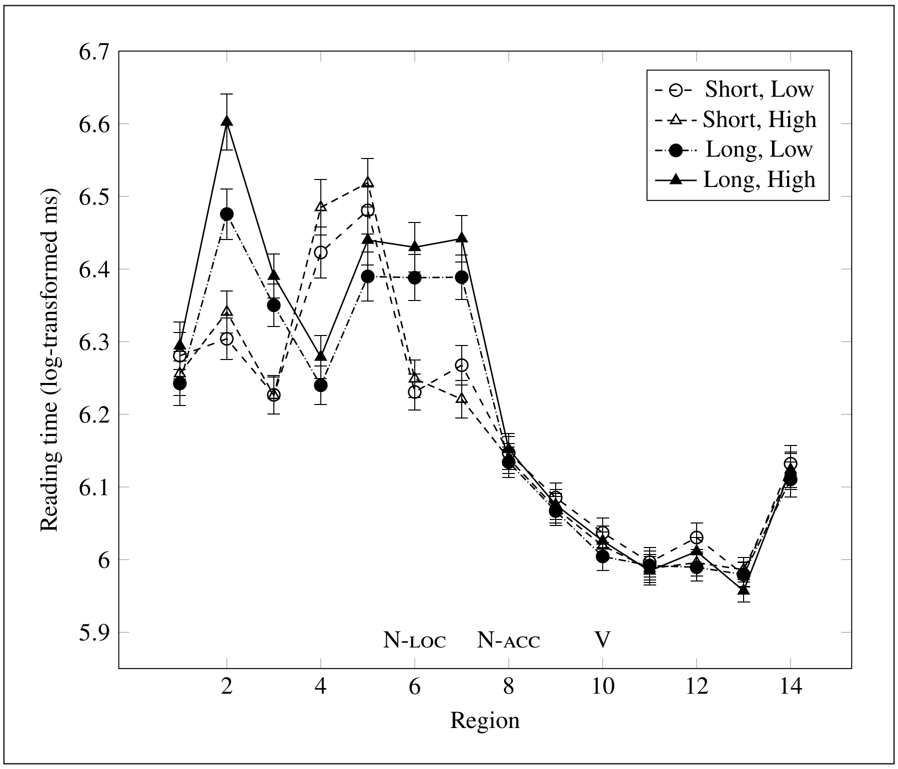



**Figure 4:** Reading times by region and condition, Experiment 2. Error bars indicate standard errors.

**Table 6:** Model estimates for selected regions of Experiment 2. Significance codes: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$, . for $p < 0.1$.

| **Region 5** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.4797 | 0.0553 | 54.04 | 117.0711 | 0.0000 | *** |
| Distance | –0.0348 | 0.0131 | 1345.36 | –2.6561 | 0.0080 | ** |
| Animacy | 0.0205 | 0.0128 | 1328.31 | 1.5994 | 0.1100 | |
| Spillover | 0.1310 | 0.0446 | 43.35 | 2.9387 | 0.0053 | ** |
| Distance:Animacy | 0.0016 | 0.0128 | 1323.85 | 0.1238 | 0.9015 | |
| **Region 6** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.3590 | 0.0495 | 44.62 | 128.4793 | 0.0000 | *** |
| Distance | 0.0983 | 0.0182 | 44.34 | 5.3939 | 0.0000 | *** |
| Animacy | 0.0174 | 0.0113 | 1290.09 | 1.5469 | 0.1221 | |
| Spillover | 0.0727 | 0.0423 | 43.55 | 1.7206 | 0.0924 | . |
| Distance:Animacy | 0.0091 | 0.0112 | 1276.36 | 0.8096 | 0.4183 | |
| **Region 7** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.3427 | 0.0455 | 52.11 | 139.3374 | 0.0000 | *** |
| Distance | 0.0914 | 0.0166 | 44.58 | 5.5038 | 0.0000 | *** |
| Animacy | –0.0011 | 0.0112 | 1297.20 | –0.0953 | 0.9241 | |
| Spillover | 0.1285 | 0.0417 | 40.49 | 3.0802 | 0.0037 | ** |
| Distance:Animacy | 0.0232 | 0.0112 | 1291.42 | 2.0779 | 0.0379 | * |
| **Region 8** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.1585 | 0.0335 | 45.52 | 183.8979 | 0.0000 | *** |
| Distance | –0.0084 | 0.0081 | 1350.57 | –1.0342 | 0.3012 | |
| Animacy | –0.0009 | 0.0080 | 1346.04 | –0.1177 | 0.9063 | |
| Spillover | 0.1319 | 0.0311 | 39.88 | 4.2360 | 0.0001 | *** |
| Distance:Animacy | 0.0007 | 0.0080 | 1343.02 | 0.0904 | 0.9280 | |
| **Region 9** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0983 | 0.0247 | 54.57 | 247.0476 | 0.0000 | *** |
| Distance | –0.0010 | 0.0096 | 28.80 | –0.1004 | 0.9208 | |
| Animacy | –0.0006 | 0.0086 | 42.77 | –0.0741 | 0.9413 | |
| Spillover | 0.2693 | 0.0431 | 51.07 | 6.2510 | 0.0000 | *** |
| Distance:Animacy | 0.0008 | 0.0074 | 1290.34 | 0.1013 | 0.9194 | |

(Contd.)

| Region 10 | Estimate | SE | *df* | *t* | *p* | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.0693 | 0.0262 | 48.21 | 231.3166 | 0.0000 | *** |
| Distance | –0.0038 | 0.0068 | 1351.45 | –0.5639 | 0.5729 | |
| Animacy | –0.0006 | 0.0067 | 1348.90 | –0.0942 | 0.9250 | |
| Spillover | 0.3040 | 0.0393 | 41.33 | 7.7305 | 0.0000 | *** |
| Distance:Animacy | 0.0042 | 0.0067 | 1342.87 | 0.6207 | 0.5349 | |
| **Region 11** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0742 | 0.0274 | 46.97 | 221.6915 | 0.0000 | *** |
| Distance | 0.0053 | 0.0061 | 1343.70 | 0.8758 | 0.3813 | |
| Animacy | –0.0027 | 0.0060 | 1333.68 | –0.4442 | 0.6570 | |
| Spillover | 0.4029 | 0.0429 | 57.77 | 9.3859 | 0.0000 | *** |
| Distance:Animacy | –0.0032 | 0.0060 | 1330.30 | –0.5239 | 0.6004 | |

Region 5 (the genitive noun modifying the locative adverbial; the head noun of the RC in the Long Distance conditions) showed a significant effect of Distance, such that the Long Distance conditions were faster than the Short Distance conditions. Both Region 6 (the locative adverbial) and Region 7 showed a main effect of Distance, such that the Long Distance conditions were slower than the Short Distance conditions. Region 7 also showed a significant interaction between Distance and Interference. The nested model indicates that this is because the effect of Distance is larger in the High Interference condition.

### 3.2.6 Discussion

Overall, the results were similar to that of Experiment 1 and consistent with the pre-verb reactivation hypothesis. In particular, the significant interaction between Distance and Interference in the region following the locative adverbial (Region 7) provides evidence for pre-verb reactivation of the subject rather than some functional head, since the Interference factor is manipulated by animacy in this experiment.[10]

[10] A reviewer pointed out that the Distance-Interference interaction could be an effect of similarity-based interference of the Voice head (see 4.2), rather than the subject noun. For this to be the case, the flavor of Voice must be different depending on the animacy of the subject, probably due to difference in intentionality. We consider this unlikely, given that most verbs used in the RCs of the target sentences do not allow non-intentional subjects. According to the judgments of one of the authors, who is a native speaker of Japanese, only five out of 32 RC verbs in the experimental stimuli allow non-intentional subjects. They were *sodateru* 'grow', *hogosuru* 'protect', and *kunrensuru* 'train' (the first two were used twice). Even in these cases, the inanimate subjects in all the RCs can be metaphorically understood as agents. When these items were removed, the Distance-Interference interaction remained marginally significant ($p$ = 0.0740). We therefore conclude that the interaction cannot be entirely attributed to difference in Voice.

## 3.3 Between-experiment comparison

Half of the target sentences used in Experiments 1 and 2 were the same. Namely, the Low Interference conditions in Experiment 2 are the same as the High Interference conditions in Experiment 1. We noticed that the same sentences were read slightly differently in these experiments. Specifically, Experiment 2 was generally slower, especially around Region 6, where we observed the subject-adverbial locality effect. This is unlikely to be due to any systematic difference in the participant groups. They were recruited from the same communities and assigned one experiment randomly. The mean age of the participants were close (Experiment 1: 22.3 (SD: 5.1) / Experiment 2: 21.7 (SD: 2.4)). The experimental method was exactly the same in both experiments. The only difference was the other half of the target sentences.

One possible account for this difference is that the pre-verb retrieval of the subject is a reflection of the parser's *strategic* effort to have a better understanding of the event, rather than a syntactically required operation. If so, whether a pre-verb retrieval takes place may be affected by various linguistic and extralinguistic factors, including task difficulty. In the current case, specifically, the matrix subject nouns were subject to more interference in Experiment 2 than in Experiment 1. This may have changed the participants' perception of the difficulty of maintaining and remembering the subject, and encouraged them to perform strategic retrieval of the subject more often. This would result in an interaction between Distance and Experiment at the locative adverbial, and main effects of Experiment at the object and the verb. To investigate this possibility, we additionally conducted a between-experiment analysis of the reading time data.

The relevant target sentences are repeated in (14) below. The difference between the two conditions is the distance between the subject and the other matrix elements.

(14) a. (Short Distance)

| | | | | | |
|---|---|---|---|---|---|
| | Byooin-ga$^{1}$ | itizitekini$^{2}$ | yatot-ta$^{3}$ | gekai-ga,$^{4}$ | … |
| [$_{RC}$ | hospital-NOM | temporarily | hire-PAST] | surgeon-NOM | |

b. (Long Distance)

| | | | | |
|---|---|---|---|---|
| Gekai-ga,$^{1}$ | byooin-ga$^{2}$ | itizitekini$^{3}$ | yatot-ta$^{4}$ | … |
| surgeon-NOM | [$_{RC}$ hospital-NOM | temporarily | hire-PAST] | |

| | | | | | | |
|---|---|---|---|---|---|---|
| kangosi-no$^{5}$ | mae-de$^{6}$ | kogarana$^{7}$ | kanzya-o$^{8}$ | yasasiku$^{9}$ | nade-ta$^{10}$ | kotode$^{11}$ |
| nurse-GEN | front-at | small | patient-ACC | gently | stroke-PAST | because |

| | | |
|---|---|---|
| sonoba-no$^{12}$ | hun'iki-ga$^{13}$ | yawarai-da.$^{14}$ |
| that.place-GEN | atmosphere-NOM | soften-PAST |

'As the surgeon (a. who the hospital hired temporarily) gently stroked the small patient in front of the nurse (b. who the hospital hired temporarily), the atmosphere there softened.'

To compare the by-region reading times in the two experiments, LME models were constructed. The full model included the fixed intercept and slopes of Distance, Experiment, their interaction, and Spillover, as well as corresponding random intercepts and slopes for participants and items. Experiment 1 was coded as –1 and Experiment 2 as 1. Coding of other factors and model fitting were done in the same way as in Experiments 1 and 2.

**Figure 5** shows the reading times by region, condition, and experiment. **Table 7** shows model estimates for the regions of interest. The modeling results indicate that Experiment 2 was generally read more slowly. Such a trend persisted from Region 5 to 11, was significant at Regions 9 and 10, and was marginally significant in Region 7. In addition, Region 6 showed a significant interaction of Distance and Experiment. A nested model indicates that there were simple effects of Distance in both experiments, such that the Long Distance condition was slower, but the effect was larger in Experiment 1.

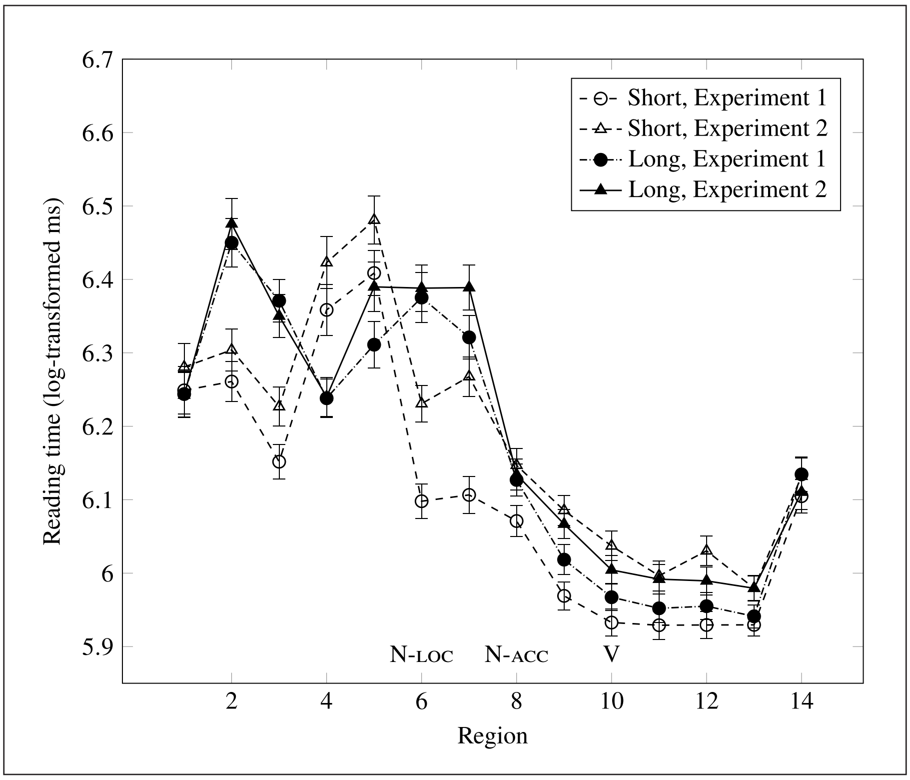



**Figure 5:** Reading times by region, condition, and experiment. Error bars indicate standard errors.

Although this analysis is exploratory, the results are striking in that they demonstrate that participants changed the way they read the sentences in response to a slight change in other experimental sentences. Specifically, stronger interference between the matrix subject and the RC subject led to a slowdown in a number of regions. This observation suggests that participants strategically commit to more retrieval of the subject when faced with more interference.

**Table 7:** Model estimates for selected regions of the between-experiment analysis. Significance codes: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$, . for $p < 0.1$.

| **Region 5** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.4193 | 0.0404 | 95.04 | 159.0276 | 0.0000 | *** |
| Distance | –0.0417 | 0.0150 | 90.74 | –2.7847 | 0.0065 | ** |
| Experiment | 0.0512 | 0.0337 | 86.59 | 1.5201 | 0.1321 | |
| Spillover | 0.1250 | 0.0364 | 88.77 | 3.4350 | 0.0009 | *** |
| Distance:Experiment | 0.0038 | 0.0146 | 93.33 | 0.2575 | 0.7974 | |
| **Region 6** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.2768 | 0.0308 | 77.84 | 203.639 | 0.0000 | *** |
| Distance | 0.1174 | 0.0168 | 86.82 | 7.006 | 0.0000 | *** |
| Experiment | 0.0427 | 0.0267 | 82.74 | 1.600 | 0.1135 | |
| Spillover | 0.1636 | 0.0369 | 76.15 | 4.436 | 0.0000 | *** |
| Distance:Experiment | –0.0328 | 0.0164 | 84.94 | –2.001 | 0.0486 | * |
| **Region 7** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.2832 | 0.0342 | 95.44 | 183.739 | 0.0000 | *** |
| Distance | 0.0814 | 0.0139 | 89.64 | 5.869 | 0.0000 | *** |
| Experiment | 0.0533 | 0.0290 | 87.20 | 1.836 | 0.0698 | . |
| Spillover | 0.1398 | 0.0363 | 63.94 | 3.852 | 0.0003 | *** |
| Distance:Experiment | –0.0159 | 0.0120 | 90.28 | –1.328 | 0.1876 | |
| **Region 8** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.1317 | 0.0248 | 82.55 | 246.9725 | 0.0000 | *** |
| Distance | 0.0048 | 0.0084 | 1339.30 | 0.5766 | 0.5643 | |
| Experiment | 0.0184 | 0.0224 | 86.03 | 0.8196 | 0.4147 | |
| Spillover | 0.1376 | 0.0248 | 76.64 | 5.5492 | 0.0000 | *** |
| Distance:Experiment | –0.0144 | 0.0083 | 1327.12 | –1.7270 | 0.0844 | . |
| **Region 9** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0433 | 0.0229 | 96.28 | 264.270 | 0.0000 | *** |
| Distance | 0.0088 | 0.0071 | 1328.32 | 1.253 | 0.2104 | |
| Experiment | 0.0510 | 0.0196 | 78.88 | 2.602 | 0.0111 | * |
| Spillover | 0.2344 | 0.0319 | 63.39 | 7.342 | 0.0000 | *** |
| Distance:Experiment | –0.0093 | 0.0071 | 1325.63 | –1.316 | 0.1883 | |

(Contd.)

| Region 10 | Estimate | SE | *df* | *t* | *p* | |
|---|---|---|---|---|---|---|
| (Intercept) | 6.0352 | 0.0201 | 89.31 | 299.5886 | 0.0000 | *** |
| Distance | 0.0013 | 0.0065 | 1324.12 | 0.1927 | 0.8473 | |
| Experiment | 0.0357 | 0.0159 | 72.58 | 2.2509 | 0.0274 | * |
| Spillover | 0.3528 | 0.0336 | 75.28 | 10.4950 | 0.0000 | *** |
| Distance:Experiment | –0.0101 | 0.0065 | 1325.90 | –1.5476 | 0.1220 | |
| **Region 11** | **Estimate** | **SE** | ***df*** | ***t*** | ***p*** | |
| (Intercept) | 6.0543 | 0.0196 | 90.07 | 308.8083 | 0.0000 | *** |
| Distance | 0.0042 | 0.0063 | 1332.62 | 0.6592 | 0.5099 | |
| Experiment | 0.0263 | 0.0167 | 74.53 | 1.5763 | 0.1192 | |
| Spillover | 0.4600 | 0.0332 | 87.56 | 13.8436 | 0.0000 | *** |
| Distance:Experiment | 0.0060 | 0.0063 | 1331.47 | 0.9503 | 0.3421 | |

The Distance-Experiment interaction at Region 6 is particularly important, since it implies the strategic nature of the pre-verb reactivation of the subject at the adverbial, but it should be interpreted with caution. First, the interaction was found in Region 6 but not in Region 7. An effect that appears in Region 6 alone may be due to the processing of the preceding RC, for reasons discussed earlier with regard to Experiment 1. More specifically, it may be a delayed effect of the retrieval of the RC subject triggered by the RC verb. Even so, the interaction with Experiment still constitutes evidence that the retrieval of the argument is strategic, since it means that the same sentences are processed differently between the two experiments. Another caution concerns the way Distance and Experiment interact. If strategic retrieval was simply more frequent in Experiment 2, we should observe it as a larger locality effect, i.e., longer reading times in the Long Distance condition of Experiment 2. However, the actual interaction was driven by the Short Distance condition in Experiment 2 being read more slowly than the same condition in Experiment 1. This interaction can be attributed to a ceiling effect. Suppose that strategic retrieval is affected not only by other sentences in the experiment but also by the *current* sentence being processed. This can make the Long Distance conditions in both experiments “hit the ceiling,” i.e., the parser always commits to strategic retrieval to save the subject from degradation. Then, a difference from other experimental sentences should exist only in the Short Distance condition. In sum, the results of the between-experiment comparison are consistent with the idea that the retrieval of the subject is strategic. In 4.2 we will discuss why this is the case.

# 4. General discussion

## 4.1 Summary of the results

Overall, the current results were consistent with the pre-verb reactivation hypothesis. To recapitulate, the pre-verb reactivation hypothesis states that arguments are often reactivated before the verb, and that counteracts their degradation. We argued that this hypothesis accounts for the mixed results regarding the argument-verb locality effect in previous studies. In two experiments, we manipulated the distance between the matrix subject and the following locative adverbial, and the similarity of an intervening noun to the matrix subject. The results of both experiments are consistent with the hypothesis that the subject is retrieved at the adverbial. Both Experiments 1 and 2 showed a main effect of distance and an interaction between distance and similarity.

In contrast, the current results do not provide evidence for the underlying locality view, which states that the argument-verb locality effect is masked by confounding factors. The current experiment controlled for such factors, but revealed no argument-verb locality effect. We also ensured that the experiments had sufficient statistical power to detect locality effects of a reasonable size. Admittedly, it is still possible that the size of the argument-verb locality effect in Japanese is very small, and can be observed with a larger sample size and/or in a lab experiment with less noise in the data. We leave this possibility for future research.

The results are also problematic for the inherent insensitivity view, which assumes that verb-final languages and/or thematic dependencies are generally insensitive to locality effects. We did observe a locality effect between the subject and the subsequent locative adverbial in a verb-final language.

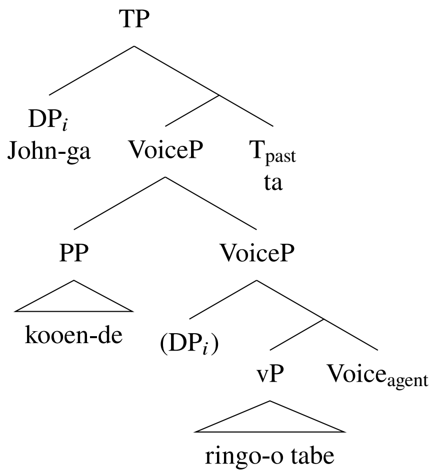
## 4.2 An account of pre-verb reactivation based on constructivism

We now return to the question that we left unanswered in 2.1: what is the underlying structural representation that motivates the pre-verb reactivation? Isono and Hirose (2022) briefly suggest that the *constructivist* analysis of argument structure, which has been developed in generative syntax, can be an answer. As a possible theoretical implementation of pre-verb reactivation, we elaborate on this idea below.

According to the constructivist view, often couched in terms of Distributed Morphology (Halle & Marantz, 1993), some or all thematic arguments are introduced by functional heads rather than the lexical argument structure of the verb (Borer, 2005a, 2005b; Folli & Harley, 2005, 2007; Hale & Keyser, 1993; Harley, 2011; Kratzer, 1996; Lohndal, 2012; Marantz, 1997, 2013, among many others). This contrasts with what is called the *projectionist* view, which assumes that all arguments are licensed in the verb phrase that projects the lexical argument structure of the verb (see Borer, 2005a; Harley, 2011; Marantz, 2013, for discussions on constructivism vs. projectionism).

The precise structural analysis of argument structure is still hotly debated within constructivism. For current purposes, it is sufficient to adopt the assumption that there is a functional head (a particular type of 'Voice' head) that introduces an agent argument in a position that is external to the lexical verb (Borer, 2005b; Hale & Keyser, 1993; Kratzer, 1996; Marantz, 1997, among many others). Under this view, the structure for the transitive sentence (8a) would be as in (15) below. The subject *John* is base-generated as the specifier of the VoiceP, where it receives the agent role, and then raises to the specifier of the TP. We remain agnostic about the structure below Voice, represented as vP.

(15)




The separation of the external argument is supported by the observation (due to A. Marantz) that external arguments rarely trigger a special interpretation of the verb, while internal arguments often do (Kratzer, 1996). Kratzer argues that this is because the interpretation of the external argument is determined fully compositionally, as formulated in (16), which is the Neo-Davidsonian logical form that corresponds to (15).[11] Here, *e* denotes the event described by the sentence, and the predicates *past, agent, eat,* and *in_the_park* all take *e* as an argument, meaning that they describe aspects of the event *e*. Notably, the agent *John* is described as the agent of the event, and only indirectly associated with the verb *eat* via *e*.

(16) $\lambda i.\exists e.$past($e,i$) ∧ agent(John, $e$) ∧ eat(the_apple,$e$) ∧ in_the_park($e$)

Although such constructivist analyses have developed in theoretical linguistics, which is concerned with competence and based on offline judgments, it is reasonable from the perspective of theoretical parsimony to assume that these structures are also relevant for online processing (Bresnan & Kaplan, 1982; Chomsky, 1965; S. Lewis & Phillips, 2015; Phillips, 2012; Steedman, 2000). If constructivist structures underlie online processing, we must reconsider the view that the verb's lexical content is the sole pivot of argument structure that specifies the thematic roles of the arguments all at once, although such an idea seems to tacitly underlie existing processing models. At the same time, given previous experimental results that show similarity-based interference with subjects (Van Dyke, 2007; Van Dyke & McElree, 2006, 2011), we cannot

[11] We follow Harley (2012) in assuming that the tense existentially quantifies the event *e* and introduces a variable *i* over time intervals. We thank an anonymous reviewer for suggesting this.

deny that agent arguments can be retrieved at the verb. Precisely speaking, those studies do not explicitly control for the thematic role of the subject, but the critical verbs used for illustration in the papers (*complain, sail, fix, compromise*) seem compatible with the agent role. The trigger of the retrieval of the agent at the verb is probably the indirect association between the verb and the agent argument via the event variable. Then, it further follows that the adverbial should also be able to trigger a retrieval of the preceding agent, since the adverbial and the agent are indirectly associated with the event variable in the same fashion as the verb and the agent.

An advantage of the account of pre-verb reactivation based on constructivism is that it naturally predicts the strategic nature of the retrieval that we observed in the between-experiment analysis. Under this account, the pre-verb reactivation is triggered by the indirect association between clausemates via the event variable. This is not required to build a grammatical syntactic structure, unlike the thematic role assignment from the verb to the arguments under a projectionist structural assumption. Rather, it is an optional operation that can be performed to have a better understanding of the event described by the relevant predicates.

In short, the constructivist analysis of argument structure can provide theoretical motivation for the pre-verb reactivation of an argument (or an adjunct) by a subsequent clausemate, which is a plausible account of the previous and current experimental results.

A more general implication of this *constructivist processing hypothesis* is that a structural analysis that has been developed in the study of competence grammar can derive a reasonable hypothesis for real-time performance. This is a desirable direction, since having a single generative system is conceptually more plausible than having two or three, and there is evidence that other aspects of competence grammar, such as island constraints, are actively used in real-time processing (S. Lewis & Phillips, 2015). Ultimately, this approach will have to face the issue of how to formulate the grammar in a way that allows left-to-right structure building (cf. Bresnan & Kaplan, 1982; Phillips, 2003; Sag & Wasow, 2011; Stabler, 2013; Steedman, 2000). Currently, constructivism is primarily formulated in Distributed Morphology (Halle & Marantz, 1993) and Minimalism (Chomsky, 1995), which describe syntactic structures as built in a bottom-up manner, especially in formulating principles such as the phase and Late Insertion. Bottom-up structure building is not problematic as far as competence grammar is concerned, and confining one's interest to competence grammar is a valid research strategy. Still, given the theoretical and empirical plausibility of integrating competence grammar and performance, we should ask how constructivist structures can be built in a left-to-right manner. We leave this issue for future research.

## 4.3 Remaining issues

There are several other remaining issues for future research. First, the timing of strategic retrieval of arguments needs further investigation. The current study found evidence for two factors that affect strategic retrieval: addition of a clausemate, and difficulty of other sentences in the same experiment. But this does not have to be an exhaustive list. The effect of other experimental sentences points to the more general possibility that the experimental task affects retrieval strategy. There may also be individual differences. Individuals with low working memory capacity may resort to more retrievals to compensate for the low capacity, or may avoid the computational cost with additional retrieval. Indeed, interactions of working memory capacity and memory effects in reading have been reported, but their results vary as to whether low capacity individuals are more prone to memory effects or less prone to them (Nicenboim et al., 2016; Tan et al., 2017). Taking into account the strategic aspect of retrieval in sentence processing may shed light on this issue.

A related issue is whether retrieval of arguments takes place at the verb. The constructivist approach suggests that verbs do not necessarily trigger the retrieval of arguments, since verbs are not the sole pivot of argument structure. If thematic roles can be assigned by functional heads such as Voice before the verb is revealed, retrieval of arguments for thematic role assignment at the verb would be required only when the predicted role mismatches the verb (putting aside strategic retrieval based on association with the event variable). Thus, it is possible that whether arguments are retrieved at a given verb depends on the argument structure of the verb.[12] The current study is unable to directly speak to this issue. Even if some verbs in the experiments trigger the retrieval of the subject, we would not be able to observe that as an effect of Distance (or any other factor), since the distance between the verb and the last reactivation of the subject, i.e., the object, is constant across conditions. Studies using the cross-modal priming and visual world paradigms have found differences in the activation profile of subjects in sentences with unergative and unaccusative verbs (Burkhardt et al., 2003; Friedmann et al., 2008; Koring et al., 2012). A comparable contrast between unergatives and unaccusatives is also reported in sentence production (Momma et al., 2018). Future study may investigate if an unergative-unaccusative contrast can also be observed in reading times, and whether transitive verbs also show contrasts between verb types, such as agent, causer, and experiencer verbs (Belletti & Rizzi, 1988; Folli & Harley, 2005).

The processing of functional heads must also be further investigated. In the current study, we did not work out how functional heads are generated and reactivated during incremental processing. This is because the hypothesis space is too large. Indeterminacy resides both in the syntactic structure, which is still hotly debated in theoretical linguistics, and in how the structure is built incrementally. There could be locality effects between non-adjacent clausemates due to retrieval of some functional heads that are predicted in advance, such as T and Voice. However, we did not observe such effects. One possible reason for the lack of such effects is that functional

[12] We thank the anonymous reviewers for pointing out the need to discuss this possibility.

heads are conflated into a single chunk by head movement. In that case, the single chunk is retrieved every time an argument or an adjunct is added to the clause, so there would be locality effects only between adjacent clausemates. Future research may investigate particular aspects of the processing of functional heads by experiments specifically designed for that purpose. We believe this is where collaboration of psycholinguistics and theoretical linguistics would be particularly fruitful.

## 5. Conclusion

In two Japanese self-paced reading experiments, we found a processing slowdown that can be attributed to the distance between the subject and the head of a following adverbial. These results are consistent with the hypothesis that pre-verb clausemates can reactivate each other to cancel out their degradation, which is proposed to account for previous mixed results regarding the argument-verb locality effect. We further argued that the constructivist analysis of argument structure, which has been developed in generative syntax, can explain why such pre-verb reactivation takes place. This hypothesis has a broad range of implications, since it involves how thematic relations, a fundamental component in human language, are processed in real-time processing, and points to the possibility of a tight integration between competence grammar and performance theory.

## Abbreviations

ACC = accusative, DAT = dative, EZ = ezafe (possessive marker in Persian), GEN = genitive, INDEF = indefinite, NEG = negation, NMLZ = nominalizer, NOM = nominative, PASS = passive, SG = singular, TOP = topic

## Data accessibility statement

The stimuli, data, and code for the analysis are available at https://osf.io/5bcnd/

## Ethics and consent

The experiments were approved by the Ethical Review Committee for Experimental Research involving Human Subjects of the Graduate School of Arts and Sciences, the University of Tokyo (No. 582). Participants in both experiments provided informed consent before the session.

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## Competing interests

The authors have no competing interests to declare.

## Authors' contributions

SI: Conceptualization, methodology, investigation, formal analysis, writing – original draft. YH: Conceptualization, funding acquisition, writing – review & editing.

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