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Chapter 3
Locality-based retrieval effects are dependent on dependency type: A case study of a negative polarity dependency in Japanese

1 Introduction

The human working memory capacity is limited (Daneman and Carpenter 1980; Just and Carpenter 1992; Osaka and Osaka 1992; Daneman and Merikle 1996; Engle et al. 1999; Conway et al. 2005). For example, the mean reading span score reported by Daneman and Carpenter (1980) (Experiment 1) was 3.15, meaning that, on average, participants were successful in storing and recalling slightly more than three words when a reading task interfered. Moreover, center-embedded structures such as (1a) are more challenging to understand than their right- or left-branching counterparts, such as (1b) (Yngve 1960; Chomsky and Miller 1963); furthermore, double center-embedding easily yields incomprehensible sentences, as illustrated in (2):

(1) a. The reporter who the senator attacked ignored the president.
  b. The senator attacked the reporter who ignored the president.

(2) The reporter who the senator who the congressman criticized attacked ignored the president.

Intuitively, it is obvious that the challenge in the processing of a doubly center-embedded structure stems from the difficulty in keeping track of who does what in the event depicted in the sentence. It is, thus, natural to assume that when multiple grammatical relations must be simultaneously tracked in incremental processing, the memory load will be greater. Such a structural situation is likely to be found

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when two words that constitute some grammatical relationships are separated, with other words intervening between them. The effect incurred by having a long-distance dependency is called a *locality effect* (Gibson 1998, 2000; Van Dyke and Lewis 2003; etc.). Locality effects are assumed to stem from an increase in the memory load because separating two words to be integrated adds to the number of incomplete dependencies that must be stored in memory (Gibson 1998), or it would make it more challenging to retrieve the antecedent at the tail of the dependency chain (Gibson 1998, 2000; Van Dyke and Lewis 2003), or both.

Despite this apparently straightforward logic, the evidence for locality effects has been relatively weak (Bartek et al. 2011; Levy and Keller 2013). Some have reported locality effects, while others have reported anti-locality effects (i.e., speedup effects for having long-distance dependencies). From Table 1, among 17 previous studies on the effects of long-distance dependencies, approximately half reported locality effects, while the rest reported anti-locality effects or null results. Furthermore, anti-locality effects have been found mostly in subject-object-verb (SOV) languages such as Hindi, German, and Japanese. Why is this the case?

Table 1: Summary of previous studies on locality effects (studies with an asterisk did not control for position effects).

	Language	Dependency type	Main findings
Safavi, Husain, and Vasishth (2016)*	Persian	Thematic	Locality effects
Bartek et al. (2011)*	English	Thematic / RC	Locality effects
Grodner and Gibson (2005)*	English	Thematic / RC	Locality effects
Levy, Fedorenko, and Gibson (2013)*	Russian	RC	Locality effects
Van Dyke and Lewis (2003)*	English	Reanalysis	Locality effects
Vasishth and Drenhaus (2011)	German	RC	Locality effects
Ono and Nakatani (2015)	Japanese	Wh-question	Locality effects
Nakatani (2021)	Japanese	Adverbial NPI	Locality effects
Phillips, Kazaninaa, and Abada (2005)	English	Wh-question	Lower ratings / Delayed P600
Nicenboim et al. (2016)	German, Spanish	RC	Locality effects (high-capacity readers) Anti-locality effects (low-capacity ones)
Vasishth and Lewis (2006)*	Hindi	Thematic / RC	Anti-locality effects
Husain, Vasishth, and Srinivasan. (2014)*	Hindi	RC / Thematic	Anti-locality effects
Konieczny (2000)*	German	Thematic	Anti-locality effects
Konieczny and Döring (2003)	German	Thematic	Anti-locality effects

Table 1 (continued)

	Language	Dependency type	Main findings
Levy and Keller (2013)	German	Thematic RC	Anti-locality effects Locality effects (with an adjunct)
Nakatani and Gibson (2008)*	Japanese	Thematic	Null results (trend toward speedup)
Nakatani and Gibson (2010)	Japanese	Thematic	Null results (slowdown at subject NPs)

(RC: relative clause, NPI: negative polarity item)

One non-trivial factor that may be partially responsible for the mixed results is the lack of control for potential position effects in some of the studies. It has been suggested that placing the critical word in different positions across the conditions would yield a so-called position effect because, generally, people tend to speed up as they proceed through a sentence (Ferreira and Henderson 1993). Thus, simply varying the distance of a dependency by putting more words in between and, thus, pushing the critical word to a later position is likely to facilitate the reading given the differences in the position in which the critical word is placed, independent of dependency length. This confound is often found in prior studies on locality effects (as pointed out by Nakatani and Gibson 2010 and Levy and Keller 2013; see also Table 1). Accordingly, this study's experimental designs employed scrambling operations in Japanese to control for this potential confound.

Another factor worth testing is the effect of dependency type. In SOV languages, the distance between a verb and its arguments, especially the subject, can easily be made greater because the subject is placed sentence-initially in canonical order, the verb is placed sentence-finally, and everything else comes in between. The situation surrounding the dependency length manipulation is different in subject-verb-object (SVO) languages because the verb is placed in the middle of the sentence, and adjuncts are usually placed in the right periphery, a non-interfering position in argument-predicate dependencies. This property seems to have induced the studies of locality effects in SVO languages to resort to the inclusion of extra grammatical dependencies such as a *wh*-gap relationship, where *wh* can be easily placed farther away from its original gap position. Indeed, in SOV languages, dependency length can be manipulated by varying a thematic dependency, whereas in SVO languages, the manipulation of dependency length often requires the inclusion of an extra dependency added to a thematic dependency.

This contrast between SOV and SVO languages may have led to the contrast between the results of the studies of locality effects in SOV and SVO languages. This chapter hypothesizes that argument-predicate (and adjunct-predicate) dependencies (henceforth, *thematic dependencies*) are less prone to memory decay while other extra grammatical dependencies such as *wh*-gap dependencies may be more likely to decay. One possible memory-based explanation for the purported contrast between thematic dependencies and other grammatical dependencies may be provided by activation models, such as the CC READER model (Thibadeau, Just, and Carpenter 1982; King and Just 1991) and Vasishth and Lewis's (2006) activation decay model based on the ACT-R architecture (Anderson et al. 2004 and the references cited therein). According to these theories, information in working memory is assigned some activation level, and it decays from working memory as its activation level decreases. For example, Vasishth and Lewis (2006) hypothesize that the activation level is a function of recency and the number of reactivations triggered by the members of the dependency. The cost of integration at the tail of a dependency is inversely proportional to the activation level of the dependency.

We tentatively adopt Gibson's (2000) dependency integration theory, where dependencies are defined as relations between heads (rather than between a head and a phrase). We assume a head h_1 may trigger an initial expectation for another head ω, in which case an incomplete *dependency chain* $\langle h_1, \omega \rangle$ is set up in working memory; h_1 is the head of the dependency chain, and ω is its tail. If another head h_2 is encountered and is also expected to be integrated with ω, then the dependency chain $\langle h_1, \omega \rangle$ is reactivated and h_2 joins the chain, updating it as $\langle h_1, h_2, \omega \rangle$. If a head that is encountered is then qualified for fulfilling ω, the dependency relations are fully integrated and discharged from working memory. This process is found in a simple case of thematic integrations in SOV language, illustrated below, where the dependency chain dc_1, triggered by the subject *John-ga* with a predicted V head $_V$[ ], is stored in working memory and is incrementally joined by (integrated with) the other noun phrases (NPs), reactivated each time, and fully integrated when the verb is encountered:

(3)	dc_1	<***j***, *ω*>		<*j*, ***m***, *ω*>		<*j*, *m*, ***b***, *ω*>		<j, *m*, *b*, **introduced**>
		John	*ga*	*Mary*	*o*	*Bill*	*ni*	*syookaisita*
			NOM		ACC		DAT	introduced

Assumedly, if the ongoing processing of an incomplete dependency chain maintains its activation level in working memory, the members of this dependency chain can be accessed and recalled quickly.

From this perspective, the *wh*-gap dependency offers a different picture. Consider a case of object-extracted relative clauses in English, such as in (4) below.

Here, focusing on the dependencies within the relative clause, two dependency chains are involved: the filler-gap dependency chain triggered by *who* (dc_1) and the thematic dependency triggered by *John* (dc_2). The thematic dependency chain dc_2 is activated until the final participant of the chain, *t*, is set up because all the heads in between integrate into the same dependency chain. However, the filler-gap dc_1 is stored in working memory without “maintenance support” (King and Just 1991: 598) from intervening words, *John* and *criticized*, because they are independent of the A-bar chain formed by *wh* and *t*.

(4)

dc_1		<***wh***, ω_1>	→	→	<*wh*, ***t***>
dc_2			<***j***, ω_2>	<*j*, **criticized**, ω_3>	<*j*, criticized, ***t***>
	(*the nurse*)	*who*	*John*	*criticized*	*t*

Thus, unlike thematic dependencies, filler-gap dependencies are more likely (if not necessarily) prone to memory decay when the tail of the chain is distanced away from the head. This chapter is primarily concerned with this issue.

2 Negative polarity item dependency with *sika* in Japanese

This study utilizes a novel type of dependency between a negative-sensitive exceptive marker *sika* in Japanese and its obligatory licenser (i.e., verbal negative morpheme Neg), such as in (5) below, to test the hypothesis that locality effects are a function of dependency length and sensitive to the dependency type.

(5)

tentyoo	***sika***	*sore*	*o*	{ **sinzi-ta*	/ *sinzi-**nakat**-ta* }
store-manager	**SIKA**	it	ACC	{ *believe-PAST	/ believe-**NEG**-PAST }

“Nobody but the store manager believed it.”

This *sika*-marked element works like English negative polarity items (NPIs) such as *any*, but, unlike English NPIs, it can appear in the subject position of the negated predicate. Furthermore, unlike in English, where Neg precedes an NPI, the licenser Neg in Japanese always follows the *sika*-marked NPI in linear order because Neg in Japanese is a verbal suffix, and Japanese is strictly verb-final. This property makes the NPI-Neg dependency comparable with filler-gap dependencies in that an encounter with the NPI immediately opens a new incomplete dependency, triggering an expectation for Neg.[1]

Several different predictions can be made regarding the processing of a verb whose subject is marked with *sika* relative to the processing of the same verb preceded by a regular nominative-marked subject. First, because *sika* requires Neg, it may strengthen the expectation for the negated verb to come, speeding up the processing when the verb is encountered. However, from a retrieval perspective, adding an extra grammatical dependency may increase the cost of retrieving the *sika*-marked subject. In (5), the thematic relations between the verb root and the nominative and accusative arguments establish an affirmative proposition (*the manager believed it*), whereas the NPI relation between *sika* and Neg triggers an additional inference on exclusivity such that the proposition exclusively applies to *the manager*. These two dependencies should be of distinct types, and, thus, the activation level of the ongoing processing of the *sika*-Neg dependency should decrease in proportion to the distance between *sika* and Neg, under the assumption that the processing of the NPI-Neg dependency would not receive maintenance support from the intervening elements (King and Just 1991; Vasishth and Lewis 2006). This hypothesis predicts some locality effects at the negated verb when the subject is distant and *sika*-marked, relative to the cases where *sika* is not involved or the cases where the subject is local to the verb region. Hence, we conducted two self-paced reading experiments to test these predictions, controlling for the position factor.

3 Experiment 1

The main goal of Experiment 1 was to test the hypothesis that locality effects are a function of dependency length and dependency type, comparing the processing of a verb whose subject was *sika*-marked and that of a verb whose subject was not *sika*-marked.

1 Researchers such as Miyagawa, Nishioka, and Zeijlstra (2016) note that NP-*sika* is unlike NPIs in English in that the former obligatorily requires the presence of the Neg head and cannot be licensed semantically while the latter can be semantically licensed under a non-negative downward-entailing environment (Ladusaw 1979; Von Fintel 1999). They argue that NP-*sika* is better regarded as a negative concord item. Note that NP-*sika* is also different from negative concord expressions in English and other languages, such as *I don't have no money* in that Japanese *sika* obligatorily requires checking by Neg. Given that this study does not address the question of whether the *sika* marked element is a negative concord or polarity item, we tentatively stick to a more traditional term (negative polarity item) when referring to it.

3.1 Methods and materials

Participants

Participants comprised 51 native speakers of Japanese, mostly undergraduate students at a university in Japan. They received 800-yen compensation for their approximately 30-minute participation.

Design and materials

We prepared materials using a 2 × 4 factorial design, varying the Locality factor and the Dependency Type factor. Regarding the Locality factor, the distance was varied by scrambling. The Dependency Type factor was varied by different subject markers: NP *ga* "NP NOM," NP *dake ga* "NP only NOM," or NP *sika*. Neither case marker *ga* nor exclusivity marker *dake* "only" requires a negative context. Thus, only the *sika*-marked subjects were obligatorily negative-sensitive.[2] Note that, semantically speaking, *sika* is similar to *dake* in that both denote exclusivity. The non-negative-sensitive *dake* conditions were added to ascertain whether they were semantic exclusivity or expectation for an obligatory licensing dependency that would induce locality effects. All the target sentences were further embedded as adjunct clauses (using either *node* or *tame*, both of which are suffixal conjunctions heading "because" clauses) to avoid potential wrap-up effects. A sample set of materials is shown below, where regions for presentation are shown by slashes. The Locality factor did not alter the interpretations of the sentences; thus, English translations for the Local conditions are not given. The crucial dependencies in this experimental design are shown in boldface. The matrix clause in which the target clause was embedded is shown in (6a) but omitted in the other conditions for brevity.

2 When an NP is marked with *sika*, nominative and accusative case markers are obligatorily deleted, making the *sika* conditions slightly more ambiguous than others, but we assumed that sentence-initial *sika* phrases would likely be interpreted as subjects because of the canonical SOV order, especially when they referred to humans.

(6) a. Nom × Distant

tentyoo ga / *ueetoresu ga* / *zyoorenkyaku o*
manager NOM / waitress NOM / regular.customer ACC
/ *nagut-ta to* / ***sinzi-nakat-ta*** *node* / *hukutentyoo*
/ hit-PAST COMP / **believe-NEG-PAST** because / assistant.manager
wa / *doo* / *de-tara* / *yoi noka* / kangaeagune-ta.
TOP / how / deal-if / good Q / wonder-PAST
"Because the manager did not believe that the waitress hit the regular customer, the assistant manager wondered how to properly deal with it."

b. Only × Distant

tentyoo dake ga / *ueetoresu ga* / *zyoorenkyaku o*
manager only NOM / waitress NOM / regular.customer ACC
/ *nagut-ta to* / ***sinzi-nakat-ta*** *node* / . . .
/ hit-PAST COMP / **believe-NEG-PAST** because / . . .
"Because only the manager did not believe that the waitress hit the regular customer, . . ."

c. *sika* × Distant

tentyoo sika / *ueetoresu ga* / *zyoorenkyaku o*
manager SIKA / waitress NOM / regular.customer ACC
/ *nagut-ta to* / ***sinzi-nakat-ta*** *node* / . . .
/ hit-PAST COMP / **believe-NEG-PAST** because / . . .
"Because nobody but the manager believed that the waitress hit the regular customer, . . ."

d. Nom × Local

ueetoresu ga / *zyoorenkyaku o* / *nagut-ta to*
waitress NOM / regular.customer ACC / hit-PAST COMP
/ ***tentyoo ga*** / ***sinzi-nakat-ta*** *node* / . . .
/ **manager NOM** / **believe-NEG-PAST** because / . . .

e. Only × Local

ueetoresu ga / *zyoorenkyaku o* / *nagut-ta to*
waitress NOM / regular.customer ACC / hit-PAST COMP
/ ***tentyoo dake ga*** / ***sinzi-nakat-ta*** *node* / . . .
/ **manager only NOM** / **believe-NEG-PAST** because / . . .

f. *sika* × Local

ueetoresu ga / *zyoorenkyaku o* / *nagut-ta to*
waitress NOM / regular.customer ACC / hit-PAST COMP
/ ***tentyoo sika*** / ***sinzi-nakat-ta*** *node* / . . .
/ **manager SIKA** / **believe-NEG-PAST** because / . . .

Note that even though the meaning of *sika* is comparable to that of *dake* in exclusivity, it works in the opposite direction regarding truth conditions because NP *sika*, when properly licensed, creates an affirmative context for the *sika*-marked element (i.e., "nobody but X" is affirmative regarding X). Thus, (6c) means "only the manager believed," whereas (6b) means "only the manager did not believe." Although this study is concerned with the effects of negative polarity dependency and locality, not the effects of negation itself (cf. Yoshida 2002), affirmative versions of the *dake* conditions were also included as another type of grammatical relation for comparison.

(6) g. OnlyAff × Distant
tentyoo dake ga / *ueetoresu ga* / *zyoorenkyaku*
manager only NOM / waitress NOM / regular.customer
o / *nagut-ta to* / ***sinzi-ta*** *node* / . . .
ACC / hit-PAST COMP / **believe-PAST** because / . . .
"Because only the manager believed that the waitress hit the regular customer, . . ."

h. OnlyAff × Local
ueetoresu ga / *zyoorenkyaku o* / *nagut-ta to*
waitress NOM / regular.customer ACC / hit-PAST COMP
/ ***tentyoo dake ga*** / ***sinzi-ta*** *node* / . . .
/ **manager only NOM** / **believe -PAST** because / . . .

The truth-conditional semantics of (6g, h) are comparable to those of (6c, f). These conditions were included to tease apart the effects of the Dependency Type factor and the truth-conditional semantics. In an ideal world, we could have prepared the affirmative conditions for the Only and other conditions, adopting a 2 × 3 × 2 factorial design ({Distant/Local} × {Nom/Only/*sika*} × {Neg/Aff}), though doing so would raise the number of conditions to 12, which is practically challenging to implement. Moreover, the combination of *sika* × Aff is ungrammatical in the first place. Thus, we included the affirmative versions of the Only conditions only, treating them as another level in the Dependency Type factor, labeled OnlyAff. Note that the critical verb region in the OnlyAff conditions lacked a negative morpheme, making this region shorter and less complex than the same region in the other Dependency Types, all of which involved Neg. Therefore, the interaction with the Locality factor would be the only target issue regarding OnlyAff. 32 sets of items as exemplified in (6a–h) were constructed and distributed into eight lists, using a Latin Square design, and 96 filler items were added to each list, among which 54 items were from three unrelated experiments, and 42 were pure fillers unrelated to any of the sub-experiments.

Procedure

The experiment was conducted with Linger 2.94 (https://tedlab.mit.edu/~dr/Linger/), a sentence-processing experimental presentation program written by Douglas Rohde, using Apple Mac mini computers on Mac OS X and 17-inch LCD monitors. The program presented one sentence at a time on the monitor, left to right and region by region in a noncumulative, moving-window manner as a participant pressed the space bar (Just, Carpenter, and Woolley 1982). Each region roughly corresponded to a unit containing one free morpheme plus suffixal-bound morphemes (e.g., case markers, postpositions, and conjunctions). The program presented the materials of one list in a different pseudo-random order for each participant such that no two target items were presented consecutively. The participants were asked to read the sentences as naturally as possible. The experiment was preceded by brief instructions and 10 practice items. Each stimulus sentence was immediately followed by a yes-no question regarding the content of the sentence, with visual feedback for wrong answers.

3.2 Results

Comprehension accuracy

The mean accuracy rate of all items (including fillers and excluding practice items) was 81.2%, and the mean accuracy rate of the target items for this experiment was 79.2%. The breakdown of the mean accuracy rate by conditions was as follows: (6a) Nom × Distant 79.4%; (6b) Only × Distant 76.5%; (6c) *sika* × Distant 71.1%; (6d) Nom × Local 82.8%; (6e) Only × Local 82.8%; (6f) *sika* × Local 77.0%; (6g) OnlyAff × Distant 78.9%; and (6h) OnlyAff × Local 85.3%. Numerically, the mean accuracy rate of the *sika* conditions was lower than that of the others (74.0% vs. 81.0%); that of the Distant conditions was lower than that of the others (76.5% vs. 82.0%); that of the Only conditions was slightly higher than that of the others (80.9% vs. 77.6%); and that of the OnlyAff conditions was higher than that of the others (82.1% vs. 78.3%). The fitted logistic regression model revealed neither the main effects of any of the factors nor significant interactions between them (all ps > .1).

Reading times

Data points beyond three standard deviations (SD) from the relevant condition × region cell mean were discarded to eliminate the outlier effects given noisy factors such as lack of attention and sleepiness. Wrongly answered trials were trimmed for initial analyses.

For statistical analyses, linear mixed effects (LME) models were fitted using the lmerTest package (which depends on lme4) in the statistical software R (version 3.6.2, 2019-12-12). We fitted the models with the Locality and dependency type factors as fixed effects. Deviation coding was used to code the main effects and interactions, with the Nom(inative) conditions and the Local conditions treated as baselines such that we could see, relative to the baselines, the effects of having dependencies with *sika*, *dake* (Only), or *dake* in an affirmative context (OnlyAff) and the effects of having long-distance dependencies (Locality).

We also included the reading times in the pre-critical region as a fixed effect (labeled "spillover") in the models (Vasishth and Lewis 2006) because the words in the region immediately preceding the critical region were not constant between the Local and Distant conditions, whose effects may have spilled over the response times (RTs) in the critical region. The values of this factor were centered and scaled before being built into the models because the values would, otherwise, be too different in scale from the other fixed factors. Though models without this spillover factor eventually showed essentially similar results, we report the results of the models with the spillover factor. Participant and item intercepts were included in the model as random effects, except for the random slopes, as the model had too many factors, and the inclusion of random slopes prevented the model from reaching convergence.

The results from the best-fitting LME model revealed the main effects of *sika* (t = 1.93, p = .054, with *sika* slower), Only (t = 4.35, p < .001, with Only slower), and OnlyAff (t = –7.75, p < .001, with OnlyAff faster) but no interactions (all $|t|$s < 0.6, all ps > .5). However, on dividing the participants into two groups per the comprehension accuracy (CA) rates of the filler items, a different picture emerged. The mean raw RTs for the critical verb region in the data from the upper group (n = 26), whose CA rates were equal to or above the median (83.2%), showed a tendency toward an interaction between the Locality and the *sika* factors (t = 1.87, p = .063) in such a direction that the distance did more harm to the *sika* than nominative conditions, whereas the lower group (n = 25) revealed an opposite tendency (t = –1.79, p = .074). No such effects were found in the comparison between the Nom conditions and the Only or OnlyAff conditions (all $|t|$s < 0.78, all ps > .43). Further, the lower group seems to have read the critical region much faster than the upper group (estimated intercepts: 784.5 [1137.3] ms for the lower [upper] group). Hence, good and poor readers (per the CA rates) may have had different strategies when processing the negative polarity dependencies.

We conducted post hoc analyses of the data including participants' comprehension performances (centered and scaled) on the 96 filler items as a fixed effect in the model to see if this tendency is statistically robust. We fitted an LME model to the data regardless of whether the trials were answered correctly because the data size would, otherwise, be skewed toward those of participants with higher accuracy rates. Table 2 shows a summary of the results from the best-fitting LME model.[3] The analyses showed the main effects of *sika* (t = 3.04, p = .002) and Only (t = 3.57, p < .001) relative to the baseline nominative conditions, showing that these markers incurred extra cost. A main effect of OnlyAff was also found (t = –8.49, p < .001), which is a trivial finding because the verb region of the OnlyAff conditions lacked a negative morpheme. There was a strong main effect of CA rates (t = 5.09, p < .001) such that higher comprehension rates correlated with greater reading times.

Despite no interaction of the Locality factor and the *sika* factor per se, there was a significant three-way interaction of Locality × *sika* × CA (t = 2.29, p = .022). Figure 1 presents a scatter plot of the locality effects (the differences in the log-transformed RTs between the Distant and Local conditions) for the NPI (*sika*) conditions at the critical region, relative to the baseline nominative conditions, overlaid by regression lines for the NPI conditions and the Nom conditions to visually see the interaction trend. Regression analyses showed a positive correlation between locality effects and CA rates for the *sika*-marked conditions (t = 3.20, p = .002, r = .423) but no such correlation for the nominative conditions (t = 0.05, p = .963, r = .007). Figure 2 illustrates the contrast between good and poor readers defined as the upper quartile group (CA rate 85.9% or higher) and the lower quartile (78.4% or lower) under an extreme-groups design (cf. Conway et al. 2005: 782–783) in a visual summary of the mean RTs of all conditions. Statistically, the good readers (n = 13) showed a significant locality effect for *sika* (t = 2.23, p = .027), whereas the poor readers (n = 13) showed no such effect (t = –0.34, p = .733). No other terms reached significance (all *p*s > .1), except for predicted (and irrelevant) main effects of OnlyAff (*t*s < –3, *p*s < .001).

There were also interactions between CA and Locality (t = 2.15, p = .032), suggesting that participants with higher CA rates were more careful in integrating long-distant dependencies, and between CA and *sika* (t = 2.20, p = .028), suggesting that those readers were more sensitive to the presence of the NPI marker and its retrieval. An interaction between CA and OnlyAff, which shows a reverse trend (t = –3.06, p = .002), indicates that the magnitude of the facilitation effect given the absence of the negative morpheme (in the OnlyAff conditions) relative to its presence (in the Nom conditions) was greater when the CA rate was higher, possibly because good readers were more careful when processing negated sentences than poor readers.

3 The model used was as follows: rt ~ Locality + *sika* + Only + OnlyAff + Locality:*sika* + Locality:Only + Locality:OnlyAff + CA + CA:Locality + CA:*sika* + CA:Only + CA:OnlyAff + CA:Locality:*sika* + CA:Locality:Only + CA:Locality:OnlyAff + spillover + (1|subj) + (1|item).

Table 2: Results of linear mixed effects model analysis for Experiment 1.

	Estimate	SE	*t*-value	Pr(>|t|)
(Intercept)	912.1	38.4	23.77	.000 ***
Locality	14.8	13.8	1.07	.285
sika	72.5	23.9	3.04	.002 **
Only	85.6	24.0	3.57	.000 ***
OnlyAff	−202.7	23.9	−8.49	.000 ***
CA	164.0	32.2	5.09	.000 ***
spillover	27.6	14.4	1.92	.055 .
Locality:*sika*	12.1	23.9	0.51	.613
Locality:Only	−13.8	24.0	−0.58	.565
Locality: OnlyAff	12.6	23.9	0.53	.597
Locality:CA	29.9	13.9	2.15	.032 *
sika:CA	53.6	24.4	2.20	.028 *
Only:CA	43.5	24.5	1.78	.076 .
OnlyAff:CA	−74.9	24.5	−3.06	.002 **
Locality:*sika*:CA	55.1	24.1	2.29	.022 *
Locality:Only:CA	−36.6	24.3	−1.51	.132
Locality:OnlyAff:CA	−4.7	24.3	−0.19	.848

Signif. codes: 0 “***” .001 “**” .01 “*” .05 “.” 0.1 “ ” 1

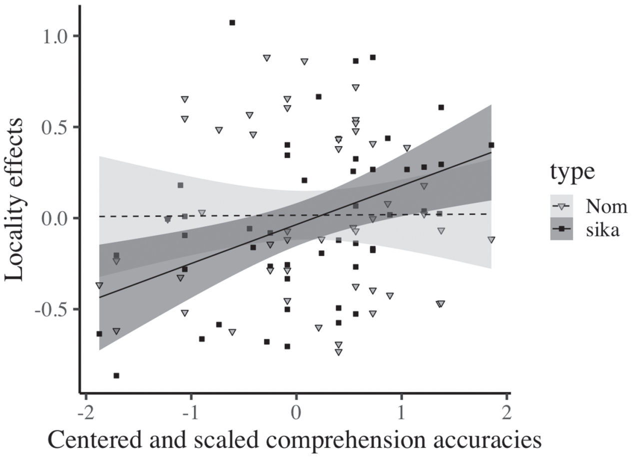

Figure 1: Differences between the log-transformed response times of the Distant conditions and those of the Local conditions at the critical verb region, as a function of centered and scaled comprehension accuracies.

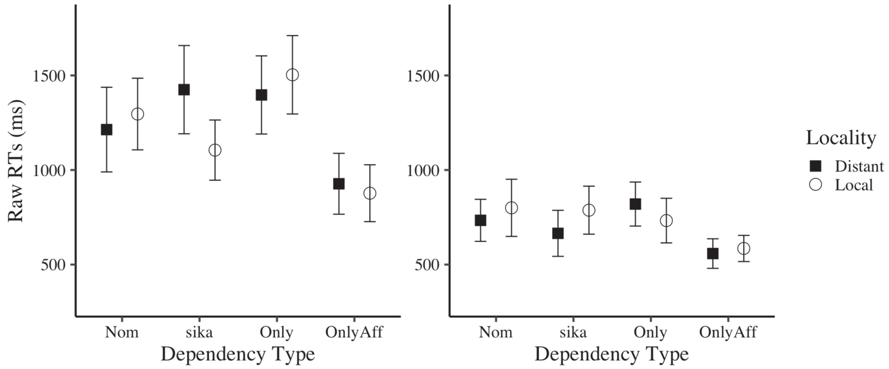

Figure 2: The mean raw response times of the critical region for the good readers (left) and the poor readers (right), with error bars representing 95% confidence intervals.

3.3 Discussion

Although locality effects per se were not found for *sika*, Only, or OnlyAff relative to the baseline nominative conditions, there was an interaction between the locality effects for the *sika*-marked conditions and the participants' CA rates: participants who scored better on comprehension questions showed stronger locality effects. CA rates also showed a strong main effect such that better readers tended to be slower, indicating that better readers were more careful in processing sentences. Further, there were no interactions between CA and Locality effects with the Only or OnlyAff conditions, even though these conditions were semantically comparable to the *sika* conditions. As noted, *dake* "only" does not call for a syntactic licenser. The presence of locality effects for *sika* and their absence for *dake* suggests that it was not the semantic computation of exclusivity but the setup of an extra dependency chain that incurred locality effects.

One might be skeptical about all these conclusions because the results did not reveal straightforward locality effects for *sika*—we only found an interaction between locality effects and CA rates. Under this hypothesis, the processing of *sika* involves two kinds of effects that counter each other: the processing load for retrieving distant *sika* and the facilitation by an expectation for Neg. Thus, locality effects at the critical region would be observed only when the retrieval of the antecedent *sika* is costly enough to override the expectation-based facilitation effect (cf. Levy and Keller 2013). Hence, perhaps, we did not find straightforward locality effects because the distant-based retrieval cost was not large enough. In Experiment 2, we augment the retrieval cost at the critical region by making the distance between NP-*sika* and Neg greater by adding a word. We may detect locality effects across all the participants if the distance-based cost was large enough.

4 Experiment 2

Experiment 2 was essentially identical to Experiment 1, except that the dependency distance in the Distant conditions was made one region greater by adding a locative adjunct to find more robust locality effects.

4.1 Methods and materials

Participants

The participants comprised 77 native speakers of Japanese, mostly undergraduate students at the same university as in Experiment 1. None had participated in Experiment 1. They were paid 800 yen for their participation, which lasted approximately 30 minutes.

Design and materials

We adopted the same design, target and filler materials, and procedures as in Experiment 1, except that a locative adjunct was added to the embedded clause of each target item, making the distance between the subject and the critical verb in the Distant conditions (6a-c, g) greater by one region. For example, the *sika* × Distant condition (6c) was transformed into (7) below, with a locative adjunct (underlined) added immediately after the embedded subject:

(7) *sik*a × Distant

tentyoo sika / *ueetoresu ga* / *tennai de* / *zyoorenkyaku o*
manager SIKA / waitress NOM / inside.shop at / regular.customer ACC
/ *nagut-ta to* / ***sinzi-nakat-ta*** *node* / . . .
/ hit-PAST COMP / **believe-NEG-PAST** because / . . .
"Because nobody but the manager believed that the waitress hit the regular customer in the restaurant, . . ."

Unlike most English prepositions, Japanese postpositions have no adnominal/adverbial ambiguity; the locative phrases used in this experiment were always unambiguously adverbial. This extra phrase was added in the same position (i.e., immediately after the embedded subject) in all the other seven conditions.

Procedure

The procedure and filler items of Experiment 2 were identical to that of Experiment 1.

4.2 Results

Comprehension accuracy

The mean accuracy rate of all items (including fillers and excluding practice items) was 78.2%, and the mean accuracy rate of the items for this experiment was 74.4%. The breakdown of the mean accuracy rate by conditions was as follows: Nom × Distant 71.8%; Only × Distant 69.5%; *sika* × Distant 66.9%; Nom × Local 75.0%; Only × Local 78.6%; *sika* × Local 75.6%; OnlyAff × Distant 79.9%; and OnlyAff × Local 78.6%. The fitted logistic regression model did not reveal any main effects or interactions (all ps > .2).

Reading times

The statistical analyses for Experiment 2 followed those of Experiment 1. When we analyzed the correctly answered data points (within 3 SDs of the relevant condition × region cell mean) without considering participants' comprehension performances, we found the main effects of Only (t = 2.89, p = .0039, with Only slower), and OnlyAff (t = –7.13, p < .001, with OnlyAff faster) but no main effect of *sika* (t = 1.30, p = .196); there was a weak tendency toward a locality effect with *sika* (t = 1.77, p = .077) but not with Only or OnlyAff ($|t|$s < 1.2, ps > .2). As in Experiment 1, we found a similar contrast between the two groups divided by the CA rates for filler items at the median (79.2%): the upper group (n = 41) showed a locality effect for *sika* (t = 3.17, p = .002), while the lower group (n = 36) showed an opposite tendency (t = –1.70, p = .090). Thus, we re-fitted the model with participants' centered and scaled CA rates and relevant interactions to the data (irrespective of whether they were correctly answered). Table 3 summarizes the results from the best-fitting LME model. The analyses showed main effects of Only (t = 3.00, p = .003), OnlyAff (t = –7.63, p < .001), CA (t = 4.19, p < .001), and spillover (t = 6.70, p < .001). There was also an interaction of CA and OnlyAff (t = –2.79, p = .005).

There was a strong main effect of CA such that participants with higher CA rates were slower at reading the critical region (t = 4.19, p < .001). More importantly, we found a significant three-way interaction of CA × Locality × *sika* (t = 2.60, p = .009). Figure 3 shows the scatter plot of the locality effects for the NPI (*sika*) conditions at the critical region, relative to the baseline nominative conditions. Regression analyses revealed a positive correlation between locality effects and CA for the *sika*-marked conditions (t = 3.96, p < .001, r = .423) but no such correlation for the nominative conditions (t = 0.50, p = .619, r = .059). As for good and poor readers defined as the upper (CA rate 84.4% or higher) and lower (75.8% or lower) quartile groups, the good readers (n = 22) showed a significant locality effect for *sika* (t = 3.64, p < .001), and the poor readers (n = 20) showed no such effect (t = -0.25, p = .801). Figure 4 summarizes the contrast between good and poor readers regarding the mean RTs at the critical region.

Table 3: Results of linear mixed effects model analysis for Experiment 2.

	Estimate	SE	*t*-value	Pr(>|t|)
(Intercept)	705.2	24.3	29.07	.000 ***
Locality	3.6	7.7	0.47	.637
sika	18.7	13.2	1.41	.158
Only	39.8	13.2	3.00	.003 **
OnlyAff	−101.2	13.3	−7.63	.000 ***
CA	93.2	22.2	4.19	.000 ***
spillover	62.8	9.4	6.70	.000 ***
Locality:*sika*	17.9	13.2	1.36	.175
Locality:Only	−13.6	13.3	−1.02	.307
Locality:OnlyAff	−10.5	13.3	−0.79	.431
Locality:CA	13.6	7.7	1.76	.078
sika:CA	−0.8	13.4	−0.06	.954
Only:CA	9.8	13.4	0.73	.465
OnlyAff:CA	−37.5	13.4	−2.79	.005 **
Locality:*sika*:CA	34.9	13.4	2.60	.009 **
Locality:Only:CA	−9.5	13.4	−0.72	.475
Locality:OnlyAff:CA	−15.4	13.4	−1.15	.251

Signif. codes: 0 "***" .001 "**" .01 "*" .05 "." 0.1 " " 1

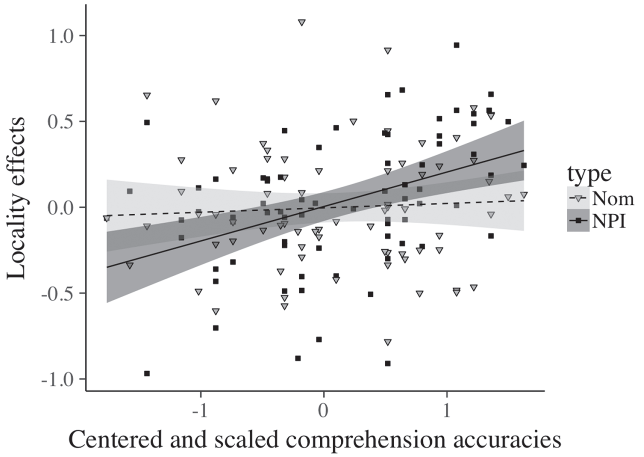

Figure 3: Differences between the log-transformed response times of the Distant conditions and those of the Local conditions at the critical verb region, as a function of centered and scaled comprehension accuracies.

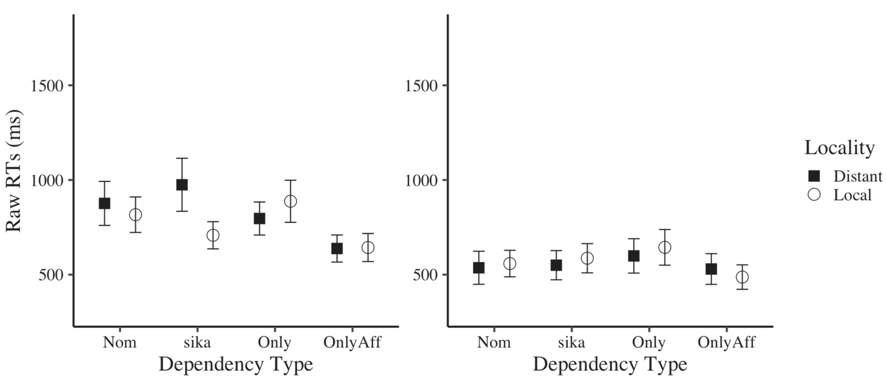

Figure 4: The mean raw response times of the critical region for the good readers (left) and the poor readers (right), with error bars representing 95% confidence intervals.

4.3 Discussion

Experiment 2 yielded similar results to Experiment 1, except for a weak indication of locality effects for *sika*. However, as in Experiment 1, there was a significant interaction between locality effects in the *sika* conditions and CA rates in such a direction that locality effects tended to be stronger when CA rates were higher. It suggests the possibility that the processing of NP-*sika* may be a function of reading comprehension skills because NPI-marker *sika* introduces an extra dependency that adds to memory load. The finding that the semantically comparable conditions with *dake* (Only / OnlyAff) did not match the *sika* conditions suggests that the obligatory setup of a new grammatical relation, not the semantic exclusivity per se, invoked a decay-based locality effect.

Although Experiments 1 and 2 yielded similar results, there was one clear contrast: the critical verb region was read faster in Experiment 2 than in Experiment 1 (703 ms vs. 909 ms), a strong indication of position effects (Ferreira and Henderson 1993). Recall that the target items in Experiments 1 and 2 were identical, except that the latter had one extra element (locative PP), which pushed the critical region one region away in the latter. The filler items were identical. We conducted a between-participants meta-analysis of the results of Experiments 1 and 2 combined (128 participants), using a model including the Experiment factor as a fixed effect to all the relevant factors. Table 4 summarizes the results, revealing a significant facilitation effect of the Experiment factor (t = –5.36, p < .001). Thus, as per several studies, varying the dependency distance by simply adding an intervening word is not appropriate for testing memory-based locality effects. The results confirmed a robust CA × Locality × *sika* interaction (t = 3.41, p = .001); no such interaction was found with other Dependency Types.

Table 4: Results of the meta-analysis of the combined results of Experiments 1 and 2 using a linear mixed effects model.

	Estimate	SE	*t*-value	Pr(>|t|)
(Intercept)	807.5	23.0	35.14	.000 ***
Experiment	−101.9	19.0	−5.36	.000 ***
Locality	7.5	7.2	1.04	.298
sika	41.0	12.5	3.28	.001 **
Only	58.1	12.5	4.64	.000 ***
OnlyAff	−141.7	12.5	11.32	.000 ***
CA	121.5	18.8	6.46	.000 ***
spillover	46.4	8.2	5.65	.000 ***
Locality:*sika*	16.4	12.5	1.31	.190
Locality:Only	−14.4	12.5	−1.15	.252
Locality:OnlyAff	−0.8	12.5	−0.06	.950
Locality:CA	21.0	7.3	2.88	.004 **
sika:CA	20.1	12.7	1.59	.112
Only:CA	24.6	12.6	1.95	.051 .
OnlyAff:CA	−52.3	12.7	−4.13	.000 ***
Locality:*sika*:CA	43.1	12.6	3.41	.001 ***
Locality:Only:CA	−20.6	12.6	−1.63	.102
Locality:OnlyAff:CA	−12.6	12.7	−1.00	.320

Signif. codes: 0 “***” .001 “**” .01 “*” .05 “.” 0.1 “ ” 1

5 General discussion

This study tested the hypothesis that locality effects are a function of dependency length and type. Adopting activation-based working memory retrieval models (Thibadeau, Just, and Carpenter 1982; King and Just 1991; Vasishth and Lewis 2006), we assumed that non-thematic dependencies are more prone to memory decay when dependency lengths are greater because they tend to be linearly discontinuous and, thus, do not receive maintenance support from intervening elements in working memory. We conducted two self-paced reading experiments to test whether NPI-marker *sika* would invoke a locality effect relative to its nominative control. In Experiment 1, there was no interaction of *sika* and Locality; in Experiment 2, the dependency length in the distance conditions was greater by one word, though we only found a marginal tendency toward an interaction. However, when we included participants' CA rates in the models, both experiments yielded a significant three-way interaction of *sika*, Locality, and participants' CA rates, such that better readers tended to show greater locality effects (i.e., longer reading times when *sika* was distant). Such an interaction was not found with semantically comparable *dake* "only," suggesting that the requirement for polarity triggered by *sika* incurred an extra complexity that selectively affected good readers. However, why was the locality effect with *sika* a function of comprehension performance?

Prior findings suggest interactions between working memory capacities and reading behaviors. It is known that individual differences in working memory capacity induce differences in reading times and CAs, interacting with structural factors (Just and Carpenter 1992; King and Just 1991; MacDonald, Just, and Carpenter 1992). Nicenboim et al. (2016) find an interaction between locality effects and individual working memory capacities such that locality effects were greater with high-capacity readers, while an anti-locality trend was found with readers with lower working capacity. They conjecture that this interaction is an indication of forgetting effects (Gibson and Thomas 1999): low-capacity readers tended to lose track of longer dependencies, failing to integrate them, thus failing to show locality effects. MacDonald, Just, and Carpenter (1992) probe the processing complexity of ambiguous sentences and report that high-span readers showed longer reading times than low-span readers. They also find an interaction of the capacity factor and the ambiguity factor such that the slowdown effects of temporal ambiguity were greater with high-span readers. They conclude that high-span readers could maintain multiple structural analyses for a longer period than low-span readers.[4]

4 King and Just (1991) probe the interaction between working memory capacity and the processing complexity of relative clauses (subject- vs. object-extraction) and report seemingly opposite

Many previous studies report that the working memory measure is highly correlated with general reading skill measures, including CAs.

Thus, we conjecture that poor readers likely to have lower working memory capacity are more likely to lose track of multiple dependencies (cf. MacDonald et al. 1992). Note the hypothesis that the presence of NPI-marker *sika* would introduce an extra dependency. Assumedly, the distance-based retrieval cost for *sika* was found only with good readers because they could successfully keep multiple dependencies in working memory. These findings are highly compatible with Nicenboim et al. (2016), where low working memory capacity readers tended to show anti-locality effects, while high-capacity readers tended to show locality effects. The results are also compatible with MacDonald et al. (1992), where high-capacity readers could track multiple analyses of locally ambiguous sentences and, thus, were slower than low-capacity readers. Although comprehension question accuracy cannot be considered directly reflective of working memory capacity, working memory capacity is highly correlated with various reading skills (Just and Carpenter 1992; King and Just 1991; MacDonald et al. 1992). It is measured by complex tasks (see Conway et al. 2005 for review) and, thus, is regarded as an attention-inhibition component and a storage component (Conway and Engle 1994; Engle et al. 1999). Keeping track of multiple distinct dependencies may be comparable to complex memory tasks. We assume individual working memory capacities and individual comprehension performances affect reading behaviors in the same direction, but the validity of this claim needs further examination, which is left open for future research.

One final issue that should be addressed is the question of what type of expectation for a dependency would incur a decay-driven retrieval cost. For example, Husain, Vasishth, and Srinivasan (2014) tested the interaction of locality effects and the strength of expectation in Hindi. They employed idiomatic noun-verb combinations, such as *khayaal rakhnaa* "(lit.) care keep" = "take care of," against non-idiomatic combinations, such as *gitaar rakhnaa* "guitar keep," to vary the expectation factor. They found anti-locality effects when the noun triggered a strong expectation for a specific verb (*khayaal . . . rakhe*) but not when it did not (*gitaar . . . rakhe*). Thus, the strong expectation for a specific verb worked in the opposite direction to the grammatical expectation for a Neg triggered by an NPI in our experiments. It indicates that the expectation based on a fixed complex expression is qualitatively different from the expectation for Neg triggered by an NPI. In the former

results to those of Nicemboim et al. (2016) and MacDonald et al. (1992), such that low-span readers showed greater reading times with object-extracted relative clauses, assumed to be structurally more complex than subject-extracted ones. Interestingly, King and Just (1991) also reported that this effect was absent with "non-readers" whose CA rates were at chance levels.

case, the expectation is thematic: when *khayaal* "care" is encountered, the thematic interpretation "take care of" is immediately established; in this sense, this "expectation" is part of the already present thematic chain. However, the computation of the NPI-Neg dependency hinges upon the completion of the thematic computation of the proposition. It may explain why the latter type of dependency, not the former, poses some working memory load and may incur locality effects.

One may conclude that the qualitative difference between the expectation based on idiomatic noun-verb complex expressions on the one hand and that based on NPI-Neg dependencies as well as *wh*-gap dependencies on the other hinges on the presence (absence) of a syntactic feature (i.e., the latter dependencies incur locality effects because they involve formal syntactic checking operations). However, Nakatani (2021) reports locality effects of maximally positive adverbials marked with contrastive marker *wa* (e.g., *hakkirito-wa* "clearly"), which behave like a negative polarity item. It is not very plausible to assume that these adverbial "pseudo-NPIs" involve a formal syntactic NPI feature that must be checked because it is not completely ungrammatical for them to appear in an affirmative context without Neg (see Nakatani 2021 for details). Therefore, the type of dependency that counts as an extra dependency is not exclusively limited to formal syntactic feature-checking relations. Further research is needed to explicate what type of expectation for a head to come leads to the establishment of "multiple" dependencies that may incur locality effects.

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