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Syntactic and Positional Similarity Effects in the Processing of Japanese Embeddings*

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1 Introduction

This study addresses a fundamental issue in human language processing: the nature of limited working memory in comprehension. Our work is

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based on the hypothesis that similarity-based interference is a general principle that holds across all types of human working memory, including working memory for linguistic structure in parsing. The specific area of sentence processing that is most deeply related to working memory limitations is the difficulty of comprehending center-embeddings (Miller 1962, Miller and Chomsky 1963). Consider the well-known double center-embedded object relative clause in English:

(1) The salmon that the man that the dog chased smoked fell off the grill.

The problem faced by the parser in a center-embedding is that it must temporarily set aside the partial products of working on the initial part of a constituent while it parses another embedded constituent, then retrieve those earlier partial products to finish the parsing. The connection to computational theory is significant: one of Chomsky's earliest results was a formal proof that arbitrary center-embedding is precisely the property of a grammar that moves it outside the scope of any finite memory device (Chomsky 1959).

The original insights of Miller and Chomsky concerning center-embedding led to a rich line of work on resource-limited parsing, but it has been surprisingly difficult to produce models and metrics that are empirically adequate, particularly when considered against a broad range of cross-linguistic embeddings. Furthermore, there has been little independent psychological motivation for the proposed memory structures (e.g., stacks, lookahead buffers) and their associated limitations (Lewis 1996).

As an example of the kind of empirical hurdle faced by any theory of syntactic working memory, consider a fact established by Cowper (1976) and Gibson (1991) in their seminal work: a metric based purely on the amount of center-embedding does not account for many difficulty contrasts in English and other languages. Consider (2):

(2) a. That the food that John ordered tasted good pleased him.
    b. What the woman that John married likes is smoked salmon.

Though both constructions involve two levels of center-embedding of sentential structures (and (2b) even involves center-embedding of relative clauses), neither causes the dramatic difficulty associated with the classic structure in (1).

Although increasing center-embedding certainly increases difficulty, another important observation is that increasing the similarity of the embedded constituents increases difficulty, and making constituents more distinct or dissimilar in some way helps processing (e.g., Bever 1970, Miller and Chomsky 1963, Kuno 1974). Why is this observation significant? Similarity-based interference is a principle that holds of working memory in general. Lewis (1996) reviews evidence for a range of working memory types subject to selective, type-specific interference, including verbal, spatial, odor, kinesthetic, and sign language. The robust result across domains is that when to-be-remembered items are followed by stimuli that are similar along some dimensions, the original items are more quickly forgotten.

Building on these results, and the work cited earlier by Cowper (1976) and Gibson (1991), Lewis (1993, 1996) hypothesized that similarity-based interference is a principle that applies to syntactic working memory as well. Lewis described a computational model that embodies retroactive, type-specific syntactic interference, and accounts for a range of cross-linguistic data on difficult center-embeddings. The model posited a simple buffer that could index no more than two constituents under a particular syntactic relation (see also Stabler 1994).

The type specificity of the limitation is crucial to the empirical success of the model. To see why, consider the comprehensible Japanese construction in (3) below (Lewis 1993):

(3) Jon-wa Biru-ni Mari-ga Suu-ni Bobu-o syookaishita to itta.
John-Top Bill-Dat Mary-Nom Sue-Dat Bob-Acc introduced that said
'John said to Bill that Mary introduced Bob to Sue.'

Such sentences do not cause the difficulty associated with (1), despite stacking up five NPs. A crucial difference is that (3) requires buffering no more than two NPs of any particular syntactic function: at most two subjects, two indirect objects, and a direct object.

What this theory suggests is that we should add "syntactic" to the list of immediate memory types that exhibit type-specific interference and decreased performance with increased similarity. Just as there is the well-known phonological similarity effect, there is also a "syntactic similarity effect", and one way this effect manifests itself is difficulty with center-embedding. Lewis (1998) reformulates this theory to combine both retroactive and proactive interference into a measure of working memory load. The new theory increases the empirical coverage and yields moment-by-moment predictions of processing load. We discuss this model below in §2.

Assuming an interference based processing model raises a number of important questions, such as: What precisely are the features that contribute to similarity interference? For example, does semantic similarity or positional similarity count? Is interference alone sufficient to account for the data, or is there still some role for level of embedding or locality? We have begun a set of empirical studies to explore some of these issues, using embedded structures in Japanese. The head-final syntax and overt case-marking of Japanese make it particularly useful for teasing apart some of the factors contributing to processing complexity. (See Nakayama (1999) for an overview of Japanese syntactic characteristics and sentence processing.) In this paper, we report the results of several experiments using a difficulty rating task under different presentation modes. These experiments identify more precisely what makes complex syntactic embeddings difficult (or easy) to process, in particular, investigating syntactic and positional similarity interference. The first three experiments test the effects of positional similarity and stacking when controlling for level of embedding. The fourth and fifth experiments examine scrambling as a device for modulating positional similarity. The results of these experiments support the hypothesis that the *syntactic and positional similarity* of overt NP arguments contributes to the difficulty of sentence processing in Japanese.

The organization of this paper is as follows: The next section presents some background and discussion of Lewis's (1998) processing theory, and a pilot study to set the stage for the five experiments. Experiments I–III and IV–V will be discussed in Sections 3 and 4, respectively. Finally, concluding remarks will be provided in Section 5.

2 Theoretical Background

2.1 Syntactic Interference in Parsing

Lewis (1998) posited a metric that predicts processing load based on the combined effects of retroactive and proactive interference on syntactic attachments. Consider the abstract schema in (4) below:

(4) $\phi_1\ \phi_2 \ldots \phi_n\ X\ \rho_1\ \rho_2 \ldots \rho_m\ Y$

Suppose that Y is the current word, and that a syntactic relation must be established between a constituent projected from Y and a constituent headed by a prior word X. For example, Y might be a verb and X an argument of that verb. This attachment may suffer from retroactive interference from the intervening items $\rho_1 \ldots \rho_m$ and proactive interference from the prior items $\phi_1 \ldots \phi_n$ that are still active in the parse. The theory asserts that the critical factor determining the amount of interference is the similarity of the interfering items to the to-be-retrieved (to-be-attached) item X. This assumption follows considerable empirical work on multiple kinds of short-term and working memory (reviewed in Lewis 1996). We will operationalize similarity as syntactic similarity, determined by the structural role to be assigned element X. The focus on syntactic similarity is functionally motivated, assuming that an important task of the sentence processor is uncovering the structure of the input string. (In Lewis (1996), a standard ontology of X-bar structural positions was assumed, though that commitment is not critical for the studies presented here).

For example, if X is to be assigned the structural position of a subject, then we expect proactive interference from those items in $\phi_1 ... \phi_n$ that have not yet been attached and may also fill subject position.[1] And we expect retroactive interference from those items in $\rho_1 ... \rho_m$ that were potential subjects. As a simplifying first approximation, we will assume that the similarity metric is all-or-nothing, so that items with identical potential syntactic positions interfere with each other, and items with distinct positions do not.

Consider how to apply the metric to the two Japanese embedded structures in (5):

(5) a. [NP1-ga NP2-ni [NP3-ga NP4-o V1] V2]
1 1

b. [NP1-ga NP2-ni [NP3-ga NP4-ga V1] V2]
2 2

Focus on the subject attachment for the first (embedded) verb, V1. The item to be retrieved is the third noun phrase, marked with nominative *-ga* (NP3-*ga*). The set of items potentially contributing retroactive interference

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[1] To simplify the presentation, we will assume here that NP arguments are left unattached before the verbs are encountered. This assumption is probably incorrect in general for head-final constructions (e.g. Frazier 1987, Bader and Lasser 1994, Inoue and Fodor 1995, Koniecnzy, Hemforth, Scheepers, and Strube 1997). However, the processing account can be reformulated assuming a fully-connected structure is maintained throughout the parse with predicted categories. In that case, there is a choice of retrieval/attachment cues to use. Under one scheme, the syntactic features of the incoming lexical items are used to retrieve the matching predicted categories. For example, a verb would not directly set retrieval cues for its unattached subject and object, but would set cues for the matching predicted transitive category. In another scheme, the predicted categories are associated with exactly the same retrieval cues used in the more head-driven approach described in the text. In that case, the verb sets retrieval cues for a subject and object, which activates the predicted category. For present purposes, the two approaches can be taken as equivalent.

is only NP4-*o*, but since it is accusative marked and cannot appear in subject position, it should not cause interference.[2] The set of items potentially contributing proactive interference is NP1-*ga* NP2-*ni*. Of these, only NP1-ga should contribute interference, since its nominative marking indicates that it is a potential subject. The subject attachment of V2 is the symmetrical case: retrieving NP1-*ga* suffers no proactive interference, but is retroactively interfered with by NP3-*ga*. Thus, in both cases, there is one unit of interference for the subject attachments (indicated by the 1 below each verb).

Why should the attachment of V2 to NP1 suffer from retroactive interference from NP3, if NP3 has already been attached? While NP3 is not an active competitor for the subject role of V2 at the time V2 is encountered, the encoding of NP3 as a potential subject is assumed to interfere with the representation of NP1 as a potential subject. Even if NP3 is later retrieved and removed from active consideration as a subject before NP1 must be retrieved, the damage has been done at the time of encoding NP3. Thus (in these examples) retroactive interference results from *encoding* or *storage* interference, and proactive interference results from *retrieval* interference.[3] We will take RI and PI as descriptive terms that happen to map onto storage and retrieval interference respectively in these materials (though the mapping need not always be that straightforward).

The structure in (5b) is also a singly embedded structure with four stacked NPs, but now the embedded clause is a double nominative construction with a stative verb V1 taking a *-ga* marked subject and a *-ga* marked object. The potential subject-hood of NP4-ga increases the retroactive interference for the subject attachments of both V1 and V2.[4] Thus, V1 suffers from one unit of retroactive interference and one unit of proactive (total two), and V2 suffers from two units of retroactive interference (total two). We are adopting the initial simple assumptions that retroactive and

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2 Assuming that the embedded object NP-*o* contributes no interference seems to put the model at odds with the finding reported by Babyonyshev and Gibson (1999) that embedded transitive clauses are more difficult than embedded intransitives. However, the incorrect prediction follows from the simple all-or-nothing similarity metric. Under a more graded similarity metric, the object NP would contribute some retroactive interference and the transitive–intransitive contrast follows.

3 For example, retrieval interference is likely to be a function of overlapping retrieval cues, while storage interference will be a function of overlapping features of the item representation.

4 More precisely, we assume that it is the preferred interpretation of NP-*ga* as occupying subject position (e.g. Inoue and Fodor 1995) that contributes the interference. That is, if it was possible to change the interpretive bias for the NP to a nominative object, then the interference should be reduced. Our present materials do not distinguish between interference due to identical case marking, and interference due to preferred structural position.

proactive interference contribute equally to retrieval difficulty, and that the amount of interference increases linearly with the number interfering items. We expect that both assumptions will require modification; see Gibson (1998) for discussion of non-linear interference and decay functions.

Because this metric yields interference values for each word in a sentence, a natural and detailed behavioral correlate is on-line reading times. However, for the present set of studies, we are concerned with global judgments of processing difficulty, and, following Gibson (1998), we will assume that these global judgments reflect the *maximum* level of difficulty experienced in the sentence. That is, the word-by-word metric can be used to predict global acceptability by taking the maximum value over all the words in the sentence. Again, this is an initial simplifying assumption, and other plausible mappings are possible, including average difficulty, or, more likely, an averaged weighted by some non-linear recency function.

2.2 An Exploratory Pilot Study

The syntactic characteristics of Japanese make it possible to keep the level of embedding and amount of stacking constant, while changing the number of syntactically similar NP arguments, as in (5), repeated below as (6):

(6) a. [NP-ga NP-ni [NP-ga NP-o V] V]
(level of embedding=1, stacking=4, maximum interference=1)
b. [NP-ga NP-ni [NP-ga NP-ga V] V]
(level of embedding=1, stacking=4, maximum interference=2)

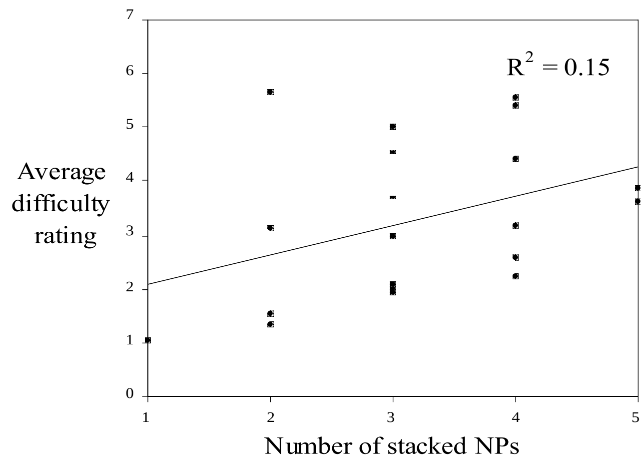
To explore the possible effects of stacking, embedding, and interference, we conducted a pilot questionnaire rating study with forty students from Kobe Shoin Women's University in Japan using a variety of sentential complement structures, along with single-clause controls. Subjects rated the difficulty of comprehending the sentences on a scale of 1 (easy) to 7 (very difficult) (e.g., see Uehara 1996, for similar designs). There were twenty different structural types, which varied along the three dimensions above. The level of embedding ranged from 0 (a single verb and its arguments) to 1 (a matrix verb taking a sentential complement, verb, and one embedded clause); the number of stacked NPs ranged from 1 to 5; and the level of maximum interference ranged from 0 to 2, according to the metric discussed above. A fully factorial design was impossible with this range of levels (e.g., it is impossible to stack five NPs in a single clause), but collapsing subranges of the levels into "high" and "low" permitted an ANOVA of these two factors. Table 1 shows the ratings as a function of NP stacking and syntactic similarity interference.

	Low stacking (1–3 NPs)	High stacking (4 and 5 NPs)
Low interference	1.3	2.3
High interference	4.5	4.2

Table 1. Difficulty ratings as a function of amount of syntactic similarity interference and NP stacking in the pilot study.

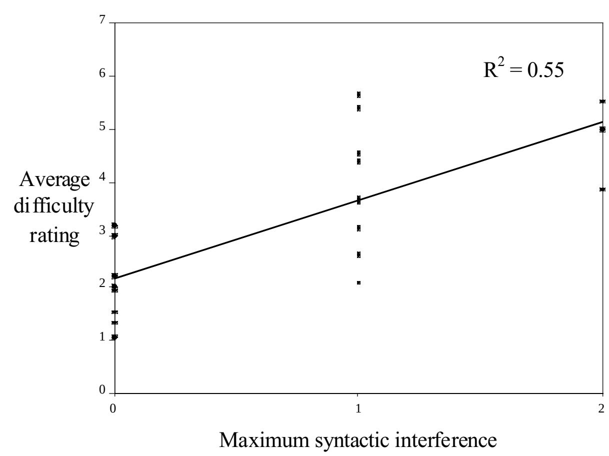
The predicted effect of interference was confirmed. Although interference appears to be more important than stacking as a determinant of difficulty in these materials, and there is a significant stacking × interference interaction ($p < 0.001$), the ordinal nature of the metric means that we should not take the interaction and the difference in the size of the stacking and interference effect too seriously. What the data do suggest is that both stacking and interference have independent effects on the difficulty ratings.

To gain a better understanding of the effects in this study, we performed a number of exploratory regressions, using level of embedding, amount of stacking, and interference as predictors of the average rated difficulty on the twenty different structures. Neither embedding level nor stacking were good predictors of difficulty alone (R^2=0.036 and R^2=0.15, respectively). Figure 1 shows the rated difficulty as a function of stacking. Interference was a much better predictor (R^2=0.55, see Figure 2). However, adding one more component to the similarity metric, *positional similarity*, improves the fit dramatically to R^2=0.73 (the regression equation is *difficulty* = 2.07 + 0.40*SyntacticInteference + 0.21*PositionalSimilarity, where positional similarity is simply the number of adjacent syntactically similar NPs). In other words, when syntactically similar NPs are closer together, there is a substantial increase in the perceived complexity of the structure. This replicates an effect noted by Uehara (1996, 1999).



(Twenty structures in the pilot experiment)

Figure 1. Rated difficulty as a function of number of stacked NPs



(Twenty structures in the pilot experiment)

Figure 2. Rated difficulty as a function of maximum similarity-based syntactic interference

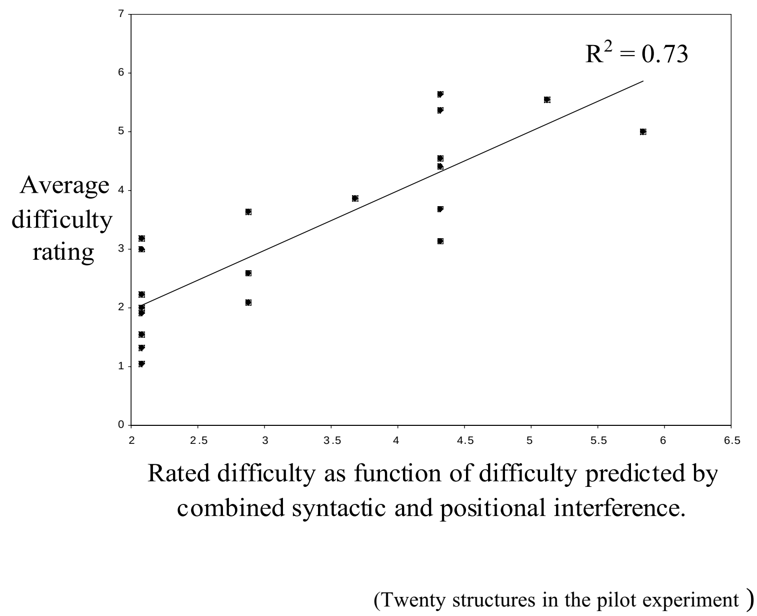


Figure 3: Rated difficulty vs. difficulty predicted from combined maximum syntactic and positional interference

2.3 Interference due to Positional Similarity

To see why positional similarity may exert a strong effect on processing difficulty, consider again the NP1–V2 attachment required in (5) above. Both NP1 and NP3 are syntactically marked as potential subjects. In the absence of any further basis on which to discriminate the NPs, the only way that the parser knows that NP1, and not NP3, is to be attached to V2 (and similarly, that NP3, and not NP1, is to be attached to V1) is the relative *serial positions* of the two candidate NPs. (Japanese disallows crossed embeddings, so the alternative attachments are not syntactically viable.)

A substantial body of on memory for serial order has established that positional confusions arise as a function of distance: the closer together two items are, the more likely their serial positions will be confused (e.g. Estes 1972, see Henson 1998 for a recent review). If we adopt this principle as a property of working memory for parsing, then it follows that placing otherwise syntactically indiscriminable NPs adjacent to one another will increase processing difficulty, just in those cases where the correct attachment of the NPs depends on their relative positions. We call this the *positional similarity* effect.

Positional similarity can be understood to be another kind of similarity-based retrieval interference. At the point of attachment, the correct NP must be retrieved on the basis of positional information as well as item information (the syntactic features associated with the item.) Just as retrieval interference arises as a function of the syntactic similarity of candidate items, interference also arises as a function of the positional similarity of candidate items. Furthermore, serial position itself provides a natural, graded, similarity metric for positional interference, and one that receives considerable empirical support from existing work in verbal short term memory. Our initial results from the pilot study suggest that positional similarity plays an important role in working memory for parsing as well.

3 Experiments I–III: Testing the Effects of Positional Similarity and Amount of Stacking

To test the new processing metric in which positional similarity plays an important role, we designed the following experiment. Level of embedding was kept constant at one embedded clause. We independently varied the amount of stacking (STACK) and the number of syntactically and positionally similar NP arguments (POS). Consider the schematic sentences below.

(7) a. *Type DI*
[NP-ga NP-ni [NP-ga V-to] V] (POS 0, STACK 3)
b. *Type TT*
[NP-ga [NP-ga NP-o V-to] V] (POS 2, STACK 3)
c. *Type DT*
[NP-ga NP-ni [NP-ga NP-o V-to] V] (POS 0, STACK 4)
d. *Type TD*
[NP-ga [NP-ga NP-ni NP-o V-to] V] (POS 2, STACK 4)

Sentence type (7a) contains a ditransitive verb in the matrix clause and an intransitive verb in the embedded, complement clause (DI). Sentence type (7b) has a matrix transitive verb and an embedded transitive verb in the complement clause (TT). Sentence type (7c) is similar to (7a) in that it also includes a matrix ditransitive verb, but it is different from (7a) in that it has a transitive verb in the complement clause. Sentence type (7d) is similar to

(7b) in that it contains a matrix transitive verb, but different in that its complement clause includes a ditransitive verb. Thus, sentence types (7a)–(7d) all have the same level of embedding, and sentence types (7a) and (7b) have three NPs, and (7c) and (7d) four NPs. Only (7b) and (7d) contain two adjacent overt subject NPs with the same case marker *-ga*.

Experiments I–III all contained the sentence types described above.[5] They were all 2×2 designs with two levels of stacking (3 NP and 4 NP) and two levels of positional similarity (adjacent subject NPs and non-adjacent subject NPs), holding constant level of embedding. Each subject saw four versions of the four experimental types (sixteen total experimental sentences) interspersed with thirty-four fillers, for a total of fifty sentences.

3.1 Design and Procedure

Experiment I was a paper-and-pencil questionnaire study, where participants were asked to rate the difficulty of a sentence on a seven point scale, as in the pilot study. Experiment II employed the same test material as in Experiment I, but was an on-line non-cumulative moving window study implemented in Psyscope (Cohen, MacWhinney, Flatt, and Provost 1993) on a Macintosh Powerbook G3. The participants were asked to rate the difficulty of a sentence on a seven point scale as in Experiment I. Participants read the sentences one word (or *bunsetsu,* i.e., NP-*ga/o/ni*) at a time by pressing the space bar. Each time the subject hit the space bar, the next word was uncovered on the screen and the previous word was hidden with a string of dashes. At the end of the sentence there was a period, and as soon as the participant hit the space bar, the period disappeared and the screen presented the instruction to rate the difficulty of the sentence just read. Then, the subject typed in a number from one to seven. Experiment III used the same on-line moving window task as in Experiment II, but, as explained below, the test sentences were slightly different from those in Experiments I and II. The same number of test sentence types and filler sentences were included in all three experiments.

All test sentences in Experiments I and II were constructed using common nouns with familiarity rating from 1.14 to 2.5 (SD .11) and verbs from 1.29 to 2.36 (SD .22) (where 1=very familiar (see/hear very frequently) and 7=very unfamiliar (not see/hear at all) in the 1–7 scale). These ratings were the average ratings of the word familiarity test independently given to fourteen native speakers of Japanese in Columbus, Ohio, and Tokyo, Japan, prior to conducting this experiment. Each individual test sentence was balanced as much as possible with the noun and verb ratings so

[5] Experiment I was first presented in Lewis and Nakayama (1999).

that a particular sentence did not contain only less familiar words: The mean ratings for the nouns in DI, TT, DT, and TD were 2.06, 2.06, 2.15, and 2.15, the mean ratings for the verbs were 1.6, 1.87, 1.76, and 1.76, and the mean ratings for all items (i.e., nouns and verbs; SD .10) were 1.89, 1.98, 2.02, and 2.02, respectively. Although the familiarity was controlled, the number of mora and letters were not controlled. Appropriate characters (i.e., *hiragana*, *katakana*, *kanji* and *romaji*) were used in order to avoid reading difficulties. All nouns used in the test sentences were human common nouns, but those in the filler sentences contained inanimate and proper nouns. Test sentences in Experiment III contained proper nouns (names) instead of common nouns. These proper nouns were not controlled in terms of the familiarity ratings because of the unavailability of their ratings, but they were judged to be familiar names by one of the authors (Nakayama), a native speaker of Japanese. They were either 3 or 4 morae long, but represented by two *kanji*s. The verbs used in the test sentences included both native Japanese and Sino-Japanese verbs (i.e. Verbal Noun+*suru*). Matrix verbs were all past-tense while the embedded verbs had a counter-balanced number of present and past tenses (i.e. two non-past and two past tense sentences). Five matrix verbs in Experiment III were different from those used in Experiments I and II in order to avoid the unnaturalness resulting from the uses of the individual names. Verbs with familiarity rating from 1.29 to 2.36 were used in Experiment III: The mean ratings for DI, TT, DT, and TD were 1.6, 1.94, 1.78, and 1.84 (SD.24). The mean familiarity ratings of the four types were not significantly different from one another. Examples are shown below. For instance, the DI sentence contained three NPs with a matrix ditransitive verb and an intransitive embedded verb, i.e., zero similar consecutive NPs (POS 0) with three stacked NPs (STACK 3).

(8) a. DI (POS 0, STACK 3)

Experiments I and II

Ani-ga sensei-ni onna-no-ko-ga asondeiru-to
elder brother-Nom teacher-Dat girl-Nom playing that

renrakushita.
Notified

'My older brother notified the teacher that a girl was playing.'

Experiment III

Yamada-ga Uehara-ni Fukuzawa-ga asondeiru-to renrakushita.
'Yamada notified Uehara that Fukuzawa was playing.'

b. TT (POS 2, STACK 3)
Experiments I and II
Haisha-ga daitooryoo-ga tsuuyaku-o yonda-to
dentist-Nom president-Nom interpreter-Acc called that

oboeteita.
remembered

'The dentist remembered that the President called the interpreter.'

Experiment III
Koyama-ga Miyamoto-ga Takeuchi-o yonda-to oboeteita.
'Koyama remembered that Miyamoto called Takeuchi.'

c. DT (POS 0, STACK 4)
Experiments I and II
Kyooju-ga shachoo-ni daihyoo-ga kookoosei-o
professor-Nom president-Dat representative-Nom h.s. student-Acc

shinsasuru-to yakusokushita.
examine that promised

'The professor promised the company president that the representative would examine the high school student.'

Experiment III
Kosaka-ga Ogihara-ni Miyazawa-ga Morita-o shinsasuru-to yakusokushita.
'Kosaka promised Ogihara that Miyazawa would examine Morita.'

d. TD (POS 2, STACK 4)
Experiments I and II
Seito-ga kooshi-ga repootaa-ni sakka-o
student-Nom lecturer-Nom reporter-Dat author-Acc

shookaishita-to kizuita
introduced that noticed

'The student noticed that the lecturer introduced the author to the reporter.'

Experiment III
Misawa-ga Hagimoto-ga Watanabe-ni Matsui-o
shookaishita-to kizuita.
'Misawa noticed that Hagimoto introduced Matsui to Watanabe.'

According to the interference theory outlined in §2 above, the POS 0 sentences should be easier than those with POS 2. Furthermore, if there is some encoding or storage interference from any NP regardless of case-marking, then STACK 3 sentences should be easier than those with STACK 4. That is, if STACK is an independent determinant of processing complexity, (8a) and (8b) should be easier than (8c) and (8d). If POS is an independent determinant of processing complexity, then (8a) and (8c) should be easier than (8b) and (8d). If both are contributing factors, (8d) should be the most difficult sentence type.

Sixty female participants (between 19–22 years old) from Kobe Shoin Women's University participated in Experiment I. Each participant was given a questionnaire and asked to rate the sentences in class. They were also asked to make the sentences easier with slight changes if they found them to be difficult. Because of this rewriting, the experiment took about thirty to forty minutes. In Experiment II, thirty-five female subjects with normal vision or corrected vision (between 19–39 years old) from Kobe Shoin Women's University participated. They were all different from those who participated in Experiment I. In Experiment III, thirty male and female Japanese native speakers with normal vision or corrected vision (25–40 years old) participated. Half of them were Japanese elementary and junior high school teachers who had just arrived from Japan to observe elementary and junior high school classes in Ohio, and the other half were the Ohio State University students or students' spouses. In both Experiments II and III, all participants were paid volunteers and tested individually. The experiments took about twenty to thirty minutes per person.

3.2 Results

Results show that the DI sentences evoked the easiest and the TD sentence the most difficult ratings among the four sentence types in all three experiments. Table 2 shows the summary of the average ratings of the four sentence types in Experiment I.

STACK	POS 0	POS 2
3	3.02 ± 0.26 (DI)	5.07 ± 0.24 (TT)
4	4.2 ± 0.25 (DT)	5.22 ± 0.24 (TD)

Table 2. Mean ratings of the four sentence types in Experiment I (paper-and-pencil questionnaire), with 95% confidence intervals.

The STACK 3 sentences (DI and TT) were significantly easier to understand than the STACK 4 sentences (DT and TD) (F1(1, 59)=31.68, p<.001; F2(1, 12)=10.20, p<.008) and the POS 0 sentences (DI and DT) were significantly easier than the POS 2 sentences (TT and TD) (F1(1, 59)=106.89, p<.001; F2(1, 12)=54.94, p<.001). There is a significant interaction of STACK and POS (F1(1, 59)=25.35, p<.001; F2(1, 12)=6.10, p<.029). However, because the difficulty scale used here is ordinal (and may not be interval), this interaction may not be meaningful. Sentence type DI is significantly easier than DT, TT, and TD, and DT is significantly easier than TT and TD (by a post-hoc Tukey HSD test at family α=0.05, for both item and subject means).

Table 3 shows the summary of the average ratings of the four sentence types in Experiment II.

STACK	POS 0	POS 2
3	2.77 ± 0.28 (DI)	3.89 ± 0.28 (TT)
4	3.91 ± 0.30 (DT)	4.43 ± 0.28 (TD)

Table 3. Mean ratings of the four sentence types in Experiment II (moving-window), with 95% confidence intervals.

Again, the STACK 3 sentences were significantly easier to understand than the STACK 4 sentences (F1(1, 34)=37.49 p<.001; F2(1, 12)=12.38, p<.004) and the POS 0 sentences were significantly easier than the POS 2 sentences (F1(1, 34)= 27.47, p<.001; F2(1,12)=11.76, p<.005). There was no significant interaction of STACK and POS. Sentence type DI is significantly easier than DT, TT, and TD at the .05 level (by a post-hoc Tukey HSD test at family α=0.05, for both item and subject means).

Table 4 shows the summary of the average ratings of the four sentence types in Experiment III.

	POS	
STACK	0	2
3	3.16 ± 0.30 (DI)	4.19 ± 0.30 (TT)
4	4.05 ± 0.33 (DT)	5.23 ± 0.29 (TD)

Table 4. Mean ratings of the four sentence types in Experiment III (moving window, with proper nouns), with 95% confidence intervals

The same patterns holds with sentences using proper nouns: the STACK 3 sentences were significantly easier to understand than the STACK 4 sentences ($F1(1, 29)=81.32$, $p < .001$; $F2(1, 12)=13.75$, $p<.003$) and the POS 0 sentences were significantly easier than the POS 2 sentences ($F1(1, 29)=44.42$, $p<.001$; $F2(1, 12)=18.09$, $p<.001$). There is no significant interaction of STACK and POS. Sentence types DI and DT are significantly easier than TD (by a post-hoc Tukey HSD test at family $\alpha=0.05$, for both item and subject means).

The results of these three experiments demonstrate that the number of argument NPs and their positional and syntactic similarity contribute to the difficulty of the sentences across quite different presentation paradigms and across different sentences with common and proper nouns. Increasing the discriminability (decreasing the similarity) of the NP arguments clearly makes processing easier. If this finding is correct, scrambling should also in some cases reduce the difficulty of processing. We will look at the effect of scrambling below.

4 Experiments IV and V: Using Scrambling to Reduce Interference Due to Positional Similarity

The experiments above suggest that the difficulty of comprehending sentences is a function, in part, of similarity-based syntactic and positional interference. This section examines the similarity interference hypothesis in scrambled sentences. According to the simplest hypothesis in which scrambling per se introduces no additional cost (Yamashita 1997, see also Nakayama 1995), scrambling that reduces positional similarity should make sentences easier to process. Japanese is a language that allows us to test this prediction.

Two experiments were conducted testing the following sentence types. Level of embedding was kept constant at one embedded clause and both matrix and embedded verbs were transitive verbs (i.e., three NP arguments for the entire sentence). Consider the following examples.

(9) a. *Type Sso* (STACK 3, POS 2)
Keikan-ga ryooshin-ga kodomo-o sagasu-to kangaeta
policeman-Nom parents-Nom child-Acc look for that thought
'The policeman thought that the parents would look for their child.'

b. *Type soS* (STACK 2, POS 0)
Ryooshin-ga kodomo-o sagasu-to keikan-ga kangaeta.

c. *Type Sos* (STACK 3, POS 0)
Keikan-ga kodomo-o ryooshin-ga sagasu-to kangaeta.

All three sentences in (9) contain the same number of words and the same nouns and verbs, but word orders are different. Sentence (9a) is the canonical word order while both (9b) and (9c) contain scrambled constituents. In (9b), the entire complement clause is scrambled while in (9c) the object is scrambled in the complement clause. Because of the different word orders, the positional similarity (POS) levels are different: only the Sso type has POS 2, because there are consecutive overt subject NPs with the same case marker *–ga*. If scrambling per se carries no processing cost, i.e., the processing cost is determined only by the effects that scrambling has on interference, it should be possible to scramble NPs or complement clauses and actually reduce working memory costs. Therefore, (9b) and (9c) are predicted to be easier than (9a).

4.1 Design and Procedure

Experiments IV and V both contained the same test material as described above. However, they were different in that Experiment IV was a paper-and-pencil questionnaire study while Experiment V was a moving window study, as in Experiments I and II, respectively.[6] Similar to the experiments above, all test sentences were constructed using nouns and verbs with similar familiarity ratings. Nouns with familiarity rating from 1.14 to 2.43 (mean 1.98, SD .10) and the verbs from 1.36 to 2.36 (mean 1.88, SD .24) were used (the mean item rating = 1.94, SD .12). Three versions of each sentence (corresponding to the three conditions) were constructed from each set of nouns and verbs, so there was no lexical variability across conditions.

[6] Experiment IV was reported in Nakayama and Lewis (2000).

Appropriate characters (*hiragana*, *katakana*, *kanji* and *romaji*) were used in order to avoid reading difficulties. All nouns used in the test sentences were human common nouns, but the filler sentences contained inanimate and proper nouns. The verbs used in the test sentences included both native Japanese and Sino-Japanese verbs (i.e., Verbal Noun+*suru*). Matrix verbs were all past-tense. In the test material, each sentence type was represented by four sentence tokens, and there were thirty-eight filler sentences, for a total of fifty sentences in the experiment. Three different lists of experiments were prepared so that each subject saw only one version of each sentence. Each list was given to the same number of the subjects in each experiment.

Sixty male and female Japanese natives (20–25 years old) from Tohoku Gakuin University participated in Experiment IV and 30 female subjects with normal vision or corrected vision (18–28 years old) from Kobe Shoin Women's University and University of Shizuoka participated in Experiment V. They were asked to rate the difficulty of each of these sentence types on a 7 point scale in the questionnaire (Experiment IV) or in the moving window presentation (Experiment V). The subjects in Experiment V were tested individually and paid nominal fees. Experiment IV took about thirty minutes while Experiment V took about twenty to thirty minutes.

4.2 Results

Results show that the soS sentences (with a scrambled clause) evoked the easiest and the Sos sentence (with a scrambled object in the complement clause) the most difficult ratings among the three sentence types in both experiments. Table 5 shows the summary of the average ratings of the three test sentences in Experiments IV and V.

Structure type	Experiment IV *(paper questionnaire)*	Experiment V *(moving window)*
Sso, STACK 3, POS 2 (no scrambling)	4.53 ± 0.19	3.90 ± 0.35
soS, STACK 2, POS 0 (scrambled clause)	3.59 ± 0.22	3.05 ± 0.35
Sos, STACK 3, POS 0 (scrambled object in complement clause)	5.20 ± 0.17	4.38 ± 0.37

Table 5. Mean ratings of the three sentence types in Experiments IV and V (scrambling), with 95% confidence intervals.

As predicted by the similarity interference theory, the soS type sentences like (9b) are the easiest.[7] The soS type sentences are significantly easier than the Sso and the Sos ((9a) and (9c) respectively) sentences in (by a post-hoc Tukey HSD test at α=0.05, for both item and subject means). However, the Sos (9c) sentences are not easier than the Sso (9a) sentences, contrary to the theory's predictions. Why? One explanation is that it is unnatural to have scrambling within the complement clauses in the sentences with the overt matrix subjects. Because the complement clauses were not direct quotes, it is odd to prepose the object within the complement clause. This unnaturalness might have overcome the reduced positional similarity and evoked the high score in the difficulty rating. Another possibility is that there is a kind of garden path effect in (9c) resulting from the initial subject NP and object NP being structured together in the same clause. There is considerable independent evidence that such structuring takes place before the verb in head-final languages (e.g. Bader and Lasser 1994, Inoue and Fodor 1995). Thus, the Sos sentences may incur the additional processing cost of reanalyzing the second NP from object of the main clause to object of the embedded clause (see Mazuka, Itoh, and Kondo 2001, Miyamoto and Takahashi 2001, and Nakano, Felser, and Clahsen, 2000; cf. Yamashita 1997). Either of these possibilities provides an independent reason for the difficulty of the Sos structure. Thus, we believe that the results of the experiments are consistent with the prediction of the theory that positional similarity of NP arguments will be a significant determinant of processing difficulty. What clearly remains to be done is to integrate this metric with a comprehensive processing model that includes reanalysis from garden paths.

5 Conclusion

The results of all the studies confirm the prediction of the similarity-based interference theory (Lewis 1996, 1998) that syntactic similarity of NP arguments will be a significant determinant of processing difficulty in unambiguous embedded constructions, even when controlling for level of embedding and amount of stacking. We have furthermore extended this account to include positional interference. All five experiments confirm the

[7] There is also a difference in level of center-embedding between the soS sentences and Sso sentences (9a); i.e., level of embedding is confounded with interference. Thus, a theory based only on level of center-embedding could also account for this difference. However, such a theory could not account for the results of Experiments I–III, which controlled level of embedding while varying amount of interference.

prediction that increasing the positional similarity of syntactically indiscriminable NPs will increase processing difficulty. Our results are similar to Uehara's (1999), who came to the conclusion that it is repetitive nominativeness that causes the difficulty in parsing (but see below); we are interpreting this result in the theoretical framework of similarity-based interference. Thus, we continue to have empirical support for the idea that working memory for syntactic processing is governed by the same processing principles that govern other kinds of working memory, even if the underlying representational codes used are different across different tasks.

Are there viable alternative explanations for the positional similarity effects? The evidence we have presented here comes exclusively from repeated NP-*ga* sequences, and therefore the difficulty could have arisen from a number of sources not related to positional similarity. Let's consider briefly three such possibilities:

a) Is the difficulty due to the functional ambiguity of the *–ga* marker—perhaps a kind of garden path effect? Independent evidence suggests that the multiple functions of *–ga* (focus, subject marker, and object marker of the statives) do not account for the processing difficulty. Such sequences are effectively taken as two subjects belonging to two separate clauses (Uehara 1999, Uehara and Bradley 2001), which is the correct interpretation for all five of our experiments.

b) Is the difficulty due to the phonological repetition of the *–ga* marker? Apparently not: similar findings are reported in Korean using phonologically distinct nominative markers (Uehara and Bradley 1996).

c) Is the difficulty due to repetitive nominative marking, as Uehara (1999) suggests? Apparently not: Vasishth (2000) reports studies in Hindi that show that adjacent NPs marked by the dative *–ko* also lead to difficulty.

Although much works remains to be done, we believe the studies to date point to the need to include some effect of positional similarity in models of parsing.[8] This is a natural extension to a model already based on similarity-modulated interference, and receives support from the fact that positional similarity (or temporal distinctiveness; Neath and Crowder 1990, Neath and Knoedler 1994) is known to affect recognition and recall in a variety of verbal short-term memory paradigms. More generally, we believe

[8] The item separating the two *ga*-marked NPs was a dative-marked NP in Experiments I-III. Apparently, it does not have to be the argument NP. We have tested the sequences separating two *ga*-marked NPs with a dative-marked NP and an adjunct locative PP (NP-*de*) in another experiment. Both sentence types evoked similar difficulty ratings.

the theoretical framework and studies reported here will pave the way to a better understanding of how serial position information is encoded in sentence comprehension, and provides the opportunity to establish close ties between sentence processing theory and accounts of serial order in other more general theories of memory.

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Appendix A

Instructions for the questionnaire:

I am investigating how Japanese natives perceive Japanese sentences while hearing/reading them. Please read the following sentences and rate how easy they are to understand. If the sentence is very easy to understand, write numeral 1, if it is average, 4, if it is very difficult to understand, write 7 in ( ). If the sentence is difficult to understand, please write under the sentence how you would say it. Thank you very much for your cooperation.

Examples:

a) Zaisei-koozoo-ga kawaru.
economic structure-Nom change
'The economic structure will change.'
(1) (= very easy to understand)

b) Keeki-o jon-ni biru-ga inu-ga daidokoro-de tabeteiru-to itta.
cake-Acc John-Dat Bill-Nom dog-Nom kitchen at eating that said
'Bill told John that the dog was eating the cake in the kitchen.'

(7) (= very difficult to understand)

(These examples were the same in both experiments.)

Appendix B

Experiments I & II: Test Sentences

The number before each sentence indicates the order of presentation in the experiments.

DI 3. Ani-ga sensei-ni onna-no-ko-ga asondeiru-to renrakushita.
17. Kantoku-ga josei-ni picchaa-ga ganbatta-to kotaeta.
36. Shoogakusei-ga otoosan-ni hito-ga ita-to shiraseta.
45. Oya-ga kyaku-ni musume-ga neteiru-to chuuishita.
TT 12. Haisha-ga daitooryoo-ga tsuuyaku-o yonda-to oboeteirta.
21. Untenshu-ga kyokan-ga tomodachi-o korosu-to shinjiteita.
28. Suponsaa-ga buchoo-ga shijo-o shootaisuru-to kimeta.
38. Haha-ga chichi-ga tsuma-o mushishita-to nayandeita.
DT 9. Ryooshin-ga hitobito-ni puro-ga satsujinhan-o sagasu-to happyooshita.
24. Anaunsaa-ga juumin-ni keikan-ga daigakusei-o shirabeta-to hoosooshita.
30. Chuugakusei-ga OL-ni seijika-ga otooto-o tsukatta-to itta.
42. Kyooju-ga shachoo-ni daihyoo-ga kookoosei-o shinsasuru-to yakusokushita.
TD 6. Seito-ga kooshi-ga repootaa-ni sakka-o shookaishita-to kizuita.
15. Ashisutanto-ga kakari-ga hannin-ni kodomo-o watasu-to shitteita.
33. Keisatsukan-ga gakusei-ga yuujin-ni imooto-o uru-to kangaeta.
48. Otoko-no-ko-ga hahaoya-ga isha-ni akachan-o miseta-to omoidashita.

Appendix C

Experiment III: Test Sentences

DI 3. Yamada-ga Uehara-ni Fukuzawa-ga asondeiru-to renrakushita.
17. Nonaka-ga Matsuyama-ni Nagashima-ga ganbatta-to kotaeta.
36. Natsume-ga Ootsuka-ni Miyazaki-ga ita-to shiraseta.
45. Nizuno-ga Yamanaka-ni shindoo-ga neteiru-to chuuishita.
TT 12. Koyama-ga Miyamoto-ga Takeuchi-o yonda-to oboeteita.
21. Ogawa-ga Fujiwara-ga Nishimura-o korosu-to shinjiteita.
28. Shiono-ga Kobayashi-ga Moriyama-o shootaisuru-to kanjita.

38. Tanaka-ga Shimamoto-ga Yamaguchi-o mushishita-to nayandeita.

DT 9. Suzuki-ga Nakamura-ni Nishiyama-ga Tanabe-o sagasu-to tsu-taeta.

24. Shimada-ga Nakazawa-ni Nishimoto-ga Takano-o shirabeta-to henjishita.

30. Nakata-ga Shinohara-ni Miyashita-ga Takei-o tsukatta-to itta.

42. Kosaka-ga Ogihara-ni Miyazawa-ga Morita-o shinsasuru-to yakusokushita.

TD 6. Misawa-ga Hagimoto-ga Watanabe-ni Matsui-o shookaishita-to kizuita.

15. Shimoda-ga Yoshimoto-ga Morisawa-ni Satoo-o watasu-to handanshita.

33. Yoshino-ga Nishizawa-ga Yoneyama-ni Sakata-o uru-to kangaeta.

48. Ueda-ga Yoshimura-ga Kurosawa-ni Komiya-o miseta-to omoikonda.

Appendix D

Experiments IV & V: Test Sentences (unscrambled version)

3. Sensei-ga otooto-ga hahaoya-o shinsasuru-to kimeta.
6. Koshi-ga gakusei-ga ashisutanto-o tsukatta-to kookaishita.
10. Untenshu-ga kyooshi-ga tomodachi-o korosu-to shinjiteita.
15. Haha-ga chichi-ga tsuma-o mushishita-to nayandeita.
18. Keikan-ga ryooshin-ga kodomo-o sagasu-to kangaeta.
21. OL-ga otoosan-ga isha-o hihanshita-to kanashinda.
24. Oya-ga kyooju-ga musume-o otosu-to kanjita.
29. Repootaa-ga seito-ga hito-o mitsuketa-to omotta.
33. Daigakusei-ga keisatsukan-ga bujinesuman-o shiraberu-to shitteita.
38. Josei-ga puro-ga yuujin-o kangeishiteita-to kizuita.
43. Haisha-ga daitooryoo-ga tsuuyaku-o yobu-to omoidashita.
48. Suponsaa-ga buchoo-ga shijo-o shootaishita-to oboeteita.