Eye-movement patterns of subject-predicate processing in Japanese nested structures

SAKI TSUMURA & YUKI HIROSE
The University of Tokyo

1 Introduction

In sentence comprehension, linguistic inputs are associated with each other to complete dependencies between them. Subject–predicate dependency is one of such dependencies, and the parser integrates a predicate with its subject to build the dependency. Previous studies have shown that when a sentence contains multiple embedded structures, it becomes difficult to understand, according to the number of the clauses as in (1) (e.g., Gibson, 1998, 2000; Grodner & Gibson, 2005).

(1) a. The reporter disliked the editor.
b. The reporter [who the senator attacked] disliked the editor.
c. #The reporter [who the senator [who John met] attacked] disliked the editor.

(Gibson, 2000)

Japanese/Korean Linguistics 27
Michael Barrie (ed.)

The difficulty caused by the presence of intervening elements in a dependency is called "locality effect".

This processing difficulty can be explained by cue-based parsing account (Lewis et al., 2005, 2006). Cue-based parsing accounts assume three stages: encoding, storage, and retrieval in memory. When a new linguistic input, such as a subject, arrives, its lexical and sematic information, including the expectation of its predicate, is encoded in the working memory along with the representation of the word, and it is stored there until the predicate is retrieved. In the retrieval process, retrieval cues are generated when the predicate arrives, and the stored information is retrieved using those cues. It is also suggested that when the syntactic and semantic similarity of the preceding or following items to the target item is increased, an interference occurs, resulting in increased reading times for the target item. This similarity-based interference could occur in both encoding and retrieval.

In Japanese, not all subject–predicate dependencies show the locality effect. For example, Nakatani (2009) examined nested structures in Japanese that contain the negative polarity item (NPI) *shika* 'only' or a referential noun phrase (NP) marked with the nominative case marker *-ga* in a matrix subject, as in (2).

(2) a. Distant/NPI condition:
*tenchoo-**shika*** [*uweitoresu-ga* *tennai-de* *joorenkyaku-o*
manager-**NPI** [waitress-NOM restaurant-at regular customer-ACC
nagutta-to] *shinjinakatta-node*...
hit-COMP] believe-NEG-PAST-CONJ ...
'Because nobody but the manager believed that the waitress had hit the regular customer in the restaurant...'

b. Distant/referential NP condition:
*tenchoo-**ga*** [*uweitoresu-ga* *tennai-de* *joorenkyaku-o*
manager-**NOM** [waitress-NOM restaurant-at regular customer-ACC
nagutta-to] *shinjinakatta-node*...
hit-COMP] believe-NEG-PAST-CONJ ...
'Because the manager did not believe that the waitress had hit the regular customer in the restaurant ...'

c. Local/NPI condition:
[*uweitoresu-ga tennai-de joorenkyaku-o nagutta-to*]
[waitress-NOM restaurant-at regular customer-ACC hit-COMP]
*tenchoo-**shika** shinjinakatta-node*...
manager-**NPI** believe-NEG-PAST-CONJ ...
'Because nobody but the manager believed that the waitress had hit the regular customer in the restaurant...'

d. Local/referential NP condition:
[*uweitoresu-ga tennai-de joorenkyaku-o nagutta-to*]
[waitress-NOM restaurant-at regular customer-ACC hit-COMP]
*tenchoo-**ga** shinjinakatta-node*...
manager-**NOM** believe-NEG-PAST-CONJ ...
'Because the manager did not believe that the waitress had hit the regular customer in the restaurant ...'

The results of a self-paced reading experiment showed that the reading time for the matrix predicate region, where the matrix subject and its predicate are integrated, as in (2c), was faster than that for (2a). That is, a locality effect was observed where the matrix subject contained an NPI in a nested structure, but there was no locality effect in Japanese when the matrix and embedded subjects are referential NPs in nested structures (see also, Nakatani, 2014). In cases where no locality effect is observed, it is assumed that both the matrix subject and the embedded subject are reactivated when the embedded verb is processed, which decreases the processing cost at the matrix verb because the matrix subject is reactivated just prior to the matrix verb position.

Another example of a study of nested structures in Japanese is found in Ono & Nakatani (2010). They examined the locality effect of the case where the wh-phrase subject *dare-ga* 'who-NOM' and its predicate with/without the Q-particle *shinjiteiru-ka*/*shinjiteiru-to* 'believe-Q/believe-C' are contained in the matrix clause. The results of a self-paced reading experiment demonstrated that the wh-phrase is also sensitive to distance, showing a locality effect (see also, Ono & Nakatani, 2013).

Previous studies on nested structures in Japanese have shown that when the matrix subject is a referential NP, no locality effect is observed, while in the NPI phrase case and the wh- and Q-particle case, a locality effect was observed. In the present study, we examined the locality effect between universal quantifiers (either + or – wh) in Japanese and their predicate, including whether the similarity-based interference is observed in the encoding and retrieval process. One possibility is that universal quantifiers are generally sensitive to the distance between the subject and its predicate. Universal quanti-

fiers, such as *minna* and *daremo* 'everyone,' may require additional processing costs. Another possibility is that *minna* and *daremo* behave in different ways. *Minna* does not contain a wh-phrase, while *daremo* 'who-*mo*' does contain the wh-phrase 'who', although both mean 'everyone'. Previous studies have shown that wh-phrase with Q-particle is sensitive to distance as mentioned above, so it might be a case where a locality effect occurs when the intervened element contains a wh-phrase itself. If dependencies between +wh subjects and their predicates are more sensitive to locality compared to those between –wh subjects and their prediates, there would be locality effects only in the wh case *daremo*. The third possibility is that those two universal quantifiers do not show locality effects. The expressions *minna* and *daremo* can be followed by the nominative case maker, *-ga*. When these expressions are included in nested sentences (e.g., *minna-**ga*** [*uweitoresu-**ga** tennai-de*... 'everyone-**NOM** (matrix subject) [waitress-**NOM** (embedded subject) restaurant-at...'), the similarity-based interference effects could arise, because both the matrix subject and the embedded subject have a nominative case marker.

2 Present Study

To investigate whether the processing of the two types of universal quantifiers is sensitive to the distance between subject and predicate, that is, whether the similarity status between two NPs modulates in relation to the presence or absence of a wh-phrase, we conducted an eye-tracking experiment.

2.1. Stimuli

Twenty-four sets of the sentences like (3) are used in the experiment.

(3) a. Distant/Wh Condition:
daremo-ga *sono-uweitoresu-ga* *tennai-de*
wh+*'mo'*-NOM [the waitress-NOM restaurant-LOC
jourenkyaku-wo *nagu-tta-to* *sinji-nakatta-node*
regular customer-ACC hit-past-comp] believe-not-past-because …
'Everyone did not believe that the waitress hit the regular customer at the restaurant, so...' / 'Not everyone believed that...'

b. Distant/Non-Wh Condition:
minna-ga *sono-uweitoresu-ga* *tennai-de*
Everyone-NOM [the waitress-NOM restaurant-LOC
jourenkyaku-wo *nagu-tta-to* *sinji-nakatta-node*
regular customer-ACC hit-past-comp] believe-not-past-because …
'Everyone did not believe that the waitress hit the regular customer at the restaurant, so...' / 'Not everyone believed that...'

c. Local/Wh Condition:
sono-uweitoresu-ga *tennai-de* *jourenkyaku-wo*
[the waitress-NOM restaurant-LOC regular customer-ACC
nagu-tta-to ***daremo-ga*** *sinji-nakatta-node*
hit-past-comp] **Wh+'*mo'*-NOM** believe-not-past-because …
'Everyone did not believe that the waitress hit the regular customer at the restaurant, so...' / 'Not everyone believed that...'

d. Local/Non-Wh Condition:
sono-uweitoresu-ga *tennai-de* *jourenkyaku-wo*
[the waitress-NOM restaurant-LOC regular customer-ACC
nagu-tta-to ***minna-ga*** *sinji-nakatta-node*
hit-past-comp] **Everyone-NOM** believe-not-past-because …
'Everyone did not believe that the waitress hit the regular customer at the restaurant, so...' / 'Not everyone believed that...'

Conditions (3a) and (3b) are the Distant conditions, in which the matrix subject and its predicate were intervened by the embedded clause, while in conditions (3c) and (3d), which is the Local conditions, the matrix subject is next to its predicate. Conditions (3a) and (3c) are the Wh conditions, where the matrix subject is *dare-mo-ga* (wh + *mo* + nominative case marker (NOM) *-ga* 'everyone'), while conditions (3b) and (3d) are the Non-Wh conditions, in which the matrix subject is *minna-ga* ('everyone'+ NOM -ga 'everyone'). Both *dare-mo-ga* and *minna-ga* are universal quantifiers, but the former contains the wh-element, and the latter does not. In the Distant conditions, the first NP and the second NP are followed by nominative case marker *-ga*.

Forty-eight filler sentences were also included in the experiment. Filler sentences had structures unrelated to the target sentences (e.g., '*The stylist talked to the newscaster who was wearing a skirt with a floral print on it.*' or *'The president went to a restaurant, but he didn't like the food.'*)

Predictions

The critical region is the matrix predicate region, where the integration occurs between matrix subject and matrix predicate. If universal quantifiers are sensitive to distance, the duration of the fixation in the Distant conditions (3a) and (3b) would be longer than for the Local conditions (3c) and (3d), and the locality effects would be observed. If the universal quantifiers are not sensitive to distance, the fixation times would not be different across the four conditions.

On the other hand, if the wh-status of the subject matters, the locality effect would be observed only in the Wh condition, but not in the Non-Wh condition. In this case, it could be expected that the similarity status between

the first two NPs modulates with the presence/absence of a wh-feature and, the similarity-based interference would occur only in (3b), but not (3a). Therefore, the fixation time in the embedded subject-encoding position (second NP) and embedded verb-retrieval position in the Non-Wh condition (3b) would be longer than that of the Wh condition (3a). However, if similarity-based interference does not occur, the RTs would not differ from each other in the encoding and retrieval position.

2.2. Procedure

The eye movements that occur during the participants' reading were recorded with *Eyelink 1000* (SR Research, Mississauga, Ontario, Canada). The readers' eyes were 80 cm away from the screen. A chinrest was provided to prevent the participants from moving their head during the reading. Calibrations were conducted before recording the eye movements.

The sentences were presented in Yu Mincho Demibold in black letters on a white background. The size of the computer screen was 378.3 mm × 303.1 mm. A small black square was shown up on the left of the screen to signal where the sentence began. When the participants' eye was fixated on the black square, each experimental sentence was presented. All experimental items were shown in one line. The participants pressed a button on a game pad when they finished reading each sentence. For the one-third of the items, comprehension questions were presented following the sentence. The participants answered to the comprehension questions by pressing another button on a game pad. The participants were asked to read the sentences carefully and to answer the comprehension questions as correctly as possible. Before the main experiment, the participants performed four practice trials to become familiar with the experimental procedure. The experiment took approximately 20 minutes, including the practice part.

2.3. Participants

Thirty-seven students from the University of Tokyo participated in the eye-tracking experiment. All participants were native Japanese speakers.

2.4. Statistical Analysis

Statistical analyses of linear mixed-effects models (Baayen et al., 2008) were conducted with R (R Core Team, 2019) by submitting eye-movement data to the lmer function in the *lme4* package (Bates et al., 2015). The models included DISTANCE (Distant/Local) and WH-STATE (Wh/Non-Wh) as fixed factors. Both the participants and the sets of experimental sentences were treated as random factors. The dependent variable was the fixation duration or the number of fixations for each measure. The final models were selected using the backward stepwise method. After the final models were selected, the data

points above 2.5 standard deviations from the residual between the estimated data points and the actual reading times were excluded, and then the very final models were calculated (Baayen, 2008). *P*-values were calculated by submitting the final model to the lmer function of the *lmerTest* (Kuznetsova et al., 2017). A negative value for the coefficient of DISTANCE indicates that the Distant conditions were read more slowly than the Local conditions, and a positive value indicates the opposite pattern. A negative value for the coefficient of the WH-STATE indicates that the Wh conditions were read more slowly than the Non-Wh conditions, and a positive value indicates the opposite pattern.

2.5. Results

We report the results of the five eye-tracking measures (mentioned in Clifton et al., 2007). First fixation is the duration of the very first fixation in the region. First-pass reading time represents the sum of the fixation durations in the region from first entering the region until leaving the region. Regression path duration is the sum of all fixations in the region from first entering the region until moving to its right of the region. Second-pass reading time is the sum of all fixations in a region following the initial first-pass time. Total reading time is the sum of all fixations in a region, including both forward and regressive movement. All measures were statistically analyzed (Table 1).

Table 1. Parameters from the final linear mixed-effects model for each value at the critical region. (*: p <.05, +: p <.01)

		Estimated β	SE	df	t/z	p-value
First Fixation	(Intercept)	219.63	4.91	35.91	44.78	< .0001
	distance	-1.52	5.40	812.81	-0.28	0.78
	wh-state	8.26	5.40	812.79	1.53	0.13
	distance × wh-state	5.11	10.80	812.73	0.47	0.64
First Pass Reading Time	(Intercept)	473.14	25.05	48.83	18.89	< .0001
	distance	-1.25	15.10	778.46	-0.08	0.93
	wh-state	4.05	15.10	778.91	0.27	0.79
	distance × wh-state	-35.12	30.22	779.01	-1.16	0.25
Regression Path Duration	(Intercept)	1927.32	152.90	41.19	12.61	< .0001
	distance	50.86	99.66	784.33	0.51	0.61
	wh-state	-50.66	99.69	784.64	-0.51	0.61
	distance × wh-state	-265.47	199.32	784.30	-1.33	0.18
Second Pass Reading Time	(Intercept)	601.44	41.27	43.29	14.57	< .0001
	distance	-9.73	29.73	522.93	-0.33	0.74
	wh-state	-0.94	32.28	30.79	-0.03	0.98
	distance × wh-state	197.69	59.48	522.21	3.32	< .001 *
Total Time	(Intercept)	925.20	60.24	51.38	15.36	< .0001
	distance	44.59	26.56	792.59	1.68	0.09 +
	wh-state	7.70	26.55	792.47	0.29	0.77
	distance × wh-state	106.83	53.12	792.63	2.01	0.045 *

Matrix predicate region

The results showed that at the matrix verb position, where the matrix subject and matrix predicate are integrated, and the locality effect could potentially be observed ("believe-not-past-because" region), there were no significant effects for early measures, such as the first pass reading time or first fixation duration. However, in the second pass reading time, the interaction between DISTANCE and WH-STATE was significant (p <.01). The post-hoc analysis showed that in the Wh conditions, the Distant condition (3a) was read slower than the Local condition (3c) (i.e., locality effect), while in the Non-Wh conditions, the reading time in the Local condition (3d) was longer than in the Distant condition (3b) (i.e., anti-locality effect) (Figure 1).

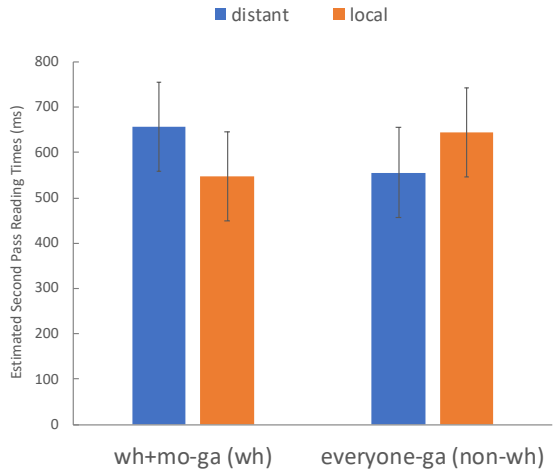

Figure 1. Estimated second pass reading times at matrix predicate region.

In the total reading time, the interaction between DISTANCE and WH-STATE was also significant, showing the anti-locality effect in the Non-Wh condition (p <.05) (Figure 2).

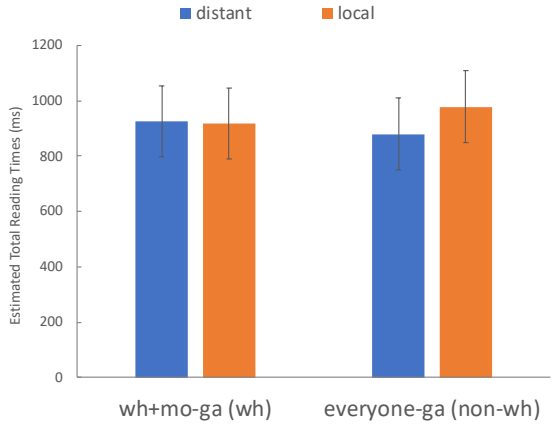

Figure 2. Estimated second pass reading times at matrix predicate region.

In the regressions out measure, the main effect of DISTANCE was significant(p <.05), revealing that the probability of regression to earlier regions was higher in the Local conditions than in the Distant conditions. The interaction between DISTANCE and WH-STATE was marginally significant (p <.10).

Second NP (embedded subject) region
In the encoding of the second NP in the Distant conditions, the first pass reading time for the Non-Wh condition (3b) was significantly longer than that of the Wh-condition (3a) (β = 48.98, SE = 22.43, t = 2.18, p = .0297). This trend was also found for the total reading times (β = 153.77, SE = 56.61, t = 2.72, p = .0069). However, there were no significant effects for other measures, such as first pass reading time and second pass reading time.

Embedded predicate region (retrieval of embedded subject region)
For the second pass reading time and total reading time, the main effects of DISTANCE were marginally significant (β = -82.33, SE = 42.58, t = -1.93, p = .054; β = -60.44, SE = 34.42, t = -1.756, p = 0.0799). For both measures, the RT in the Wh condition (3a) was slightly longer than in the Non-Wh condition (3b).

3 Discussion

This eye-tracking experiment on nested structures in Japanese showed that when the matrix subject contained *daremo-ga* 'wh+*mo*+NOM,' which is a universal quantifier with a wh-phrase, a locality effect was found in the matrix predicate position. On the other hand, when the matrix subject included

minna-ga 'everyone-NOM,' which is a universal quantifier without a wh-feature, an anti-locality effect was found. It is assumed that anti-locality effect is observed where the distance increases the anticipation of the upcoming input (e.g., Levy & Keller, 2013), and the greater distance makes the integration process easier. That is, when the matrix subject had a wh-universal quantifier in a nested structure, the integration was difficult because of the greater distance between the subject and its predicate. However, when the matrix subject was a non-wh-universal quantifier, the integration was easier due to the longer distance. Further, these effects were found only in late measures, such as second pass reading time and total reading time. It can be assumed that these measures reflect the integration costs in processing. Thus, these results support the integration difficulty/easiness in the matrix predicate region.

Similarity-based interference

We also looked at similarity-based interference effects in the nested structures. At the second NP region in the Distant conditions, where the second nominative-case-marked phrase was encoded, the first pass reading time of the non-wh-universal quantifier condition was longer than the wh-universal quantifier condition. This can be regarded as similarity-based encoding interference in the second NP region. Although both expressions were marked by the nominative case marker *-ga*, the non-wh-quantifier phrase was the same as the referential NP (second NP) noun, in terms of the wh-state (i.e., both *minna* and referential NPs were 'non-wh'). When the second NP was encountered, in the wh-quantifier case, the similarity between the first NP phrase (i.e., the matrix subject, the wh-quantifier) and the second NP (referential NP) phrase was low, compared to the non-wh-quainter case. Given the wh-state, this difference affected the encoding of the second NPs.

In the embedded-verb position, where it is possible that reactivation of both matrix subject and embedded subject occurred, no statistical difference was observed between conditions for early measures. However, marginally significant effects were found for late measures, such as second pass reading time and total reading time, showing that the wh-quantifier condition was read more slowly than the non-wh-quantifier condition. The second pass reading time is the sum of the durations for the region after regressions/go-past to the other regions, and the total reading time is the total fixation duration of the region. Considering that those measures reflect processing costs after readers reached to the other words/information in the sentence, the numerical difference between the wh-quantifier condition and the non-wh-quantifier condition could not be considered as strong evidence for similarity-based retrieval interference.

Difference between the wh-quantifuer and the non-wh-quantifier
Although *daremo-ga* 'wh+*mo*+NOM' and *minna-ga* 'everyone+NOM' are both universal quantifiers, we found processing differences for the nested structures. One possible reason for this is that the wh-state causes such differences. Our results showed a slowdown for the non-wh-quantifier in the embedded subject phrase, which can be considered to be encoding interference due to the similarity between the non-wh phrase and the embedded subject NP phrase. This could also mean that the presence of the wh-feature makes a difference, i.e., the information for the embedded NP phrase is encoded into the working memory in a different way from the way the wh-quantifier matrix subject is in real-time processing. Locality effects and anti-locality effects in the matrix predicate position also reflect that when the matrix subject contains a wh-phrase, integration costs become higher, while the integration of a matrix subject and a matrix predicate is facilitated when the matrix subject has non-wh-phrase. This facilitation comes from an increased anticipation of the appearance of the matrix predicate. When there are two subjects in a sentence in Japanese are marked with a nominative case marker, it is obvious that the sentence contains multiple clauses. This also could facilitate the anticipation of the upcoming predicate. In the case of a wh-quantifier, this facilitation may not function as strongly as the non-wh-quantifier case, because the processing of wh-phrase itself could cause additional costs due to the markedness of the phrase.

4 Conclusion

The eye-tracking experiment reported here showed greater integration difficulties in nested sentences as determined in late measures of eye-movement patterns. We found that universal quantifiers are sensitive to distance in that locality effects were observed when the matrix subject contained a wh-quantifier, while an anti-locality effect was observed when the matrix subject contained a non-wh-quantifier. The processing difficulty that was observed in subsequent second NPs in early measures may reflect the interference in the information on the encoding of the new input.

Acknowledgements We thank the reviewers and the audience of the poster session at the 27th Japanese/Korean Linguistics conference for the comments and discussions. We also would like to thank our lab members for the comments and suggestions.

References

Baayen, H., D. Davidson and D. Bates. 2008. Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language* 59: 390–412.

Clifton, C., A. Staub and K. Rayner. 2007. Eye movements in reading words and sentences. In R.P.G. van Gompel, M.H. Fischer, W.S. Murray, and R.L. Hill (Eds.), *Eye movements: A window on mind and brain*: 341–371. New York: Elsevier.

Bates, D., M. Maechler, B. Bolker, S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* 67(1): 1–48.

Gibson, E. 1998. Linguistic complexity: Locality of syntactic dependencies. *Cognition* 68: 1–76.

Gibson, E. 2000. The dependency locality theory: A distance-based theory

of linguistic complexity. In Y. Miyashita, A. Marantz, and W. O'Neil (Eds.), *Image, language, brain*: 95–126. Cambridge, MA: MIT Press.

Grodner, D. and E. Gibson. 2005. Consequences of the serial nature of linguistic input. *Cognitive Science* 29: 261–290.

Kuznetsova A., P. Brockhoff, R. Christensen. 2017. lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software* 82(13): 1–26.

Lewis, R., and S. Vasishth. 2005. An activation-based theory of sentence processing as skilled memory retrieval. *Cognitive Science* 29: 375–419.

Lewis, R., S. Vasishth, and J. Van Dyke. 2006. Computational principles of working memory in sentence comprehension. *Trends in Cognitive Sciences* 10: 447–454.

Levy, R., and Keller, F. 2013. Expectation and Locality Effects in German Verb-final Structures. *Journal of memory and language* 68(2): 199–222.

Nakatani, K. 2009. Is the nesting effect caused by structural complexity or structural frequency? A case study of Japanese NPI processing. *The 22nd Annual CUNY Conference on Human Sentence Processing*.

Nakatani, K. 2014. Locality and anti-locality effects in the processing of expected and unexpected inputs: A study of NPI dependencies in Japanese. *Thee 27nd Annual CUNY Conference on Human Sentence Processing*.

Ono, H., and K. Nakatani. 2010. Integration of Wh-phrases and predicates in Japanese sentence processing, *Technical report of IECIE* 110(163: 99–104.

Ono, H., and K. Nakatani. 2013. Integration costs in the processing of Japanese wh-interrogative sentences. *Studies in Language Sciences* 13: 13–31, Kurosio Publishers, Tokyo, Japan.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.