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An Eye-tracking Investigation of *Pre-head* and *Head-driven* Processing for Scrambled Japanese Sentences

Katsuo Tamaoka — *Nagoya University*
Michael P. Mansbridge — *Nagoya University*

Abstract: The syntactic movement of scrambled Japanese sentences is often attributed to *pre-head anticipatory processing* prior to reading the head verb. However, previous studies have not compared nouns within the same sentence position; furthermore, studies have compared different noun types, influencing processing via semantic activation. Thus, this study only presented highly frequent first names and maintained each noun in the same position by only manipulating the case markings. Under this strictly controlled condition, scrambling was investigated using two eye-tracking experiments. The results indicated that *pre-head processing* begins resolving the filler-gap dependency at the critical NP (noun phrase) containing the gap, as revealed by significantly longer go-past times for scrambled conditions. However, without additional semantic cues, case marking did not provide sufficient information, as seen by the difficulties under scrambled conditions during late-processing stages at the critical NP after reading the verb. Without semantic cues, Japanese speakers mostly used verb information to establish the structural properties of scrambled constituents. Consequently, the relative strength of *pre-head* and *head-driven* processing varies depending on the cues available.*

Key words: eye-tracking, head-driven processing, pre-head processing, scrambling

1. Introduction

Wh-movement and other long-distance dependencies occur in many of the world's languages. For example, *wh*-movement in English involves moving an NP to form a question or, in some cases, a relative clause (Chomsky 1977). Since *wh*-movement in English is obligatory, it can be difficult to directly compare its structure to a corresponding non-movement structure and to visualize syntactic movement experimentally. Here, scrambling comes into play. Many languages have a fundamental word order and sentence structure, termed the *canonical* word order. In

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addition to the canonical order, some languages exhibit a variety of non-canonical word orders (Ross 1967). Studies of theoretical linguistics (e.g., Saito 1985) have presented syntactic evidence for transformational accounts of free word order in Japanese. According to these accounts, canonical word order is reordered by a transformation called *scrambling*, which was originally proposed by Ross (1967).

Japanese is a head-final language with a canonical SOV (Subject-Object-Verb) word order with case particles, including the nominative *-ga* (NP-NOM), accusative *-o* (NP-ACC) and dative *-ni* (NP-DAT), which attach to the ends of nouns. Except for the verb, Japanese allows for flexible word order (e.g., Kondo and Yamashita 2011, Miyagawa 2003, Nakayama 1995, Saito 1992), partly because these particles mark the role of the NP within the clause. The syntactic movement of scrambled Japanese sentences has frequently been discussed as an attribution of *pre-head incremental processing* prior to reading the predicate (e.g., Aoshima el al. 2004, Aoshima et al. 2009, Kamide and Mitchell 1999, Mazuka et al. 2002, Miyamoto and Takahashi 2004). This processing is implemented *bit by bit* while reading a sentence from the beginning (Miyamoto 2006). However, a recent eye-tracking study by Tamaoka et al. (2014) indicated heavy *head-driven processing* (or *post-head processing* after seeing the verb) in Japanese scrambled sentences. Although native Japanese speakers read sentences incrementally as sequences of input, they still require the head verb information to complete the phrasal structure, especially when nouns do not provide sufficient information to construct a phrasal structure. With eye-tracking, we can investigate processing responses for both before and after the participant sees the verb; accordingly, this study aimed to clarify when the understanding of phrasal structures in scrambled word orders is resolved.

2. Scrambling in Japanese sentences and previous studies

Native Japanese speakers seem to use the canonical (or unmarked) word order as the base structure for sentence processing. An example of a canonical active (SOV) sentence with a transitive verb is *Sanae-ga banana-o tabe-ta* 'Sanae ate a banana'. This sentence can also be scrambled if the accusative noun phrase *banana-o* 'a banana' is moved to the initial position of the sentence, creating the scrambled OSV sentence *banana-o Sanae-ga tabe-ta*. The scrambled order requires a syntactic operation of phrasal movement from a gap (gap_1) in the canonical position to the sentence initial position (NP-ACC$_1$) as in $[_{IP'}\ \text{NP-ACC}_1\ [_{IP}\ \text{NP-}\mathit{ga}\ [_{VP}\ \mathit{gap}_1\ \text{V}]]]$. Because subjects NP-NOM(*-ga*) are often omitted in Japanese, native speakers will not expect scrambling order when initially seeing the NP-ACC(*-o*). However, since the NP-NOM follows the NP-ACC, the *gap* is usually expected. Thus, the sequential word order of NP-ACC and NP-NOM could create delays in reading time to establish a filler-gap dependency, while this order could also be a relative clause (Miyamoto 2006).

Tamaoka et al. (2005) found an inhibitory trend (i.e., a scrambling effect) in the processing speed (reaction times) for scrambled sentences across four different sentence types. This result suggests an extra cognitive cost for the scrambling operation. In psycholinguistic studies, the scrambling effect has frequently been offered as an explanation of *gap-filling parsing* (Frazier and Clifton 1989, Stowe 1986). This parsing mechanism is especially useful in identifying a *wh*-filler in English. A sentence-initial *wh*-phrase triggers a search for its gap to establish a filler-gap dependency. This mechanism was also supported by ERP and fMRI studies on the processing of German *wh*-questions (Fiebach et al. 2001). The strategy of *gap-filling parsing* has been applied to explain the processing of other types of scrambling in Japanese (e.g., Koizumi and Tamaoka 2004, 2010, Miyamoto and Takahashi 2004).

Some previous studies (e.g., Koizumi and Tamaoka 2004, 2010, Tamaoka et al. 2005) have used a sentence correctness decision task because the same nouns are not easily placed in the same phrasal position of the sentence. For example, the canonical SOV sentence *Sanae-ga banana-o tabe-ta* 'Sanae ate a banana' is scrambled as *banana-o Sanae-ga tabe-ta*. In the first phrasal position, the proper noun *Sanae*, a woman's name, is compared to the general (or common) noun *banana*. In the second phrasal position, the common noun *banana* is compared to the proper noun *Sanae*. Only the final verb is positioned in the same sentence-final position in both the canonical and scrambled sentences. The filler and gap share syntactic and semantic information essential for successful sentence interpretation. Sentence processing is a sequential operation, so a filler (*banana-o*) in the scrambled sentence cannot be assigned to its gap (after *Sanae-ga*) until sentence processing has occurred. Assuming that all possible factors equally influence the speed (reaction time) of sentence processing, reading times for the sentence correctness decision task were compared to judge the processing difference between canonical and scrambled sentences. However, as Miyamoto (2008), Miyamoto and Nakamura (2005), and Witzel and Witzel (2016) have stated, this task, strictly speaking, cannot provide detailed evidence at the crucial NP, where the gap-filling dependency occurs. Consequently, previous studies (e.g., Koizumi and Tamaoka 2004, 2010, Tamaoka et al. 2005) using this task could only assume that native Japanese speakers use *gap-filling parsing* for scrambled sentences, compared to canonical sentences. Although the sentential decision task is useful for comparing a minimal-paired condition at the sentence level, the explanatory limitation of the task is unavoidable once one attempts to describe the processing mechanism of scrambled order in detail.

Using eye-tracking, Mazuka et al. (2002) examined phrase-by-phrase parsing of Japanese canonical and scrambled sentences. These authors reported that an extra cognitive load was required to process simple transitive SOV-structured sentences with scrambled word order. This result was found in both the first-pass and re-reading time at the crucial NP of the second argument position immediately before the verb. Mazuka et al. (2002) created paired sentences, as in *Mariko-ga otooto-o yon-da* [$_{IP}$ NP(Mariko)-NOM [$_{VP}$ NP(brother)-ACC V-PAST]], meaning 'Marito called [her] younger brother', and its OSV scrambled minimal pair *Otooto-o Mariko-ga yon-da* [$_{IP'}$ NP(brother)-ACC$_1$ [$_{IP}$ (Mariko)-NOM [$_{VP}$ t_1 V-PAST]]]. In this pair, the second NP of the scrambled sentence (i.e., NP(Mariko)-NOM) is crucial to establishing a filler-gap dependency. However, when a different NP was placed in the same position in the baseline canonical sentence, it resulted in comparing a common noun to a proper noun.

Similarly, the eye-tracking study by Mazuka et al. (2002) also created a noun-type mismatch issue. Common nouns (e.g., *banana*) denote general conceptual characteristics, while proper nouns (e.g., *Sanae*) refer to individual entities. As Kripke (1980) and Searle (1958) discussed, proper nouns seem to occupy a unique linguistic status distinguished from common nouns. In relation to this position, multiple experimental studies (e.g., Semenza 2009, Van Lancker and Ohnesorge 2002) have suggested that proper nouns possess a special neuropsychological status different from common nouns. The difference in processing speed could be the result of comparing different noun types (proper noun vs. common noun). Consequently, unless a study directly compares the same noun in an NP and possibly its collocational frequencies, the mechanism for establishing a filler-gap dependency remains unclear. It is also possible that a contrast in noun types prior to the reading of the predicate could act as a semantic expectation cue for the predicate and its argument relationship, which would also account for pre-head processing. In addition, the contrast of a proper noun (e.g., *Sanae* <agent>) and a common noun (e.g., *banana* <theme>) often provides a relation of agent and theme (i.e., spreading activation, Collins and Loftus 1975), such as *Sanae* acting on *banana*, resulting in raised activation levels of possible following verbs, such as *muku* (peal), *taberu* (eat), and *kiru* (cut), which would come at the end of a Japanese sentence.

Tamaoka et al. (2014) also used eye-tracking to investigate how scrambled sentences are processed. Three paired, simple types of Japanese active sentences with ditransitive verbs were used: (1) SO_1O_2V [$_{IP}$ NP-NOM [$_{VP}$ NP-DAT [$_{VP'}$ NP-ACC V]]] canonical; (2) SO_2O_1V single-scrambled; and (3) O_1O_2SV double-scrambled order. First-pass reading times indicated that the third noun phrase immediately before the verb in both single- and double-scrambled sentences required longer reading times than canonical sentences. Tamaoka et al. (2014) proposed the possibility that a single filler-gap dependency could be resolved via *pre-head processing* by enabling language users to incrementally construct syntactic structures without seeing the head verb (e.g., Kamide and Mitchell 1999, Miyamoto and Takahashi 2004). However, like Mazuka et al. (2002), Tamaoka et al. (2014) also compared different types of nouns (proper noun vs. common noun) at the crucial NP position before the verb; the nouns in NPs before the final verb were common nouns for the canonical order but proper nouns for short- and long-distance scrambling. Therefore, although both Mazuka et al. (2002) and Tamaoka et al. (2014) revealed a similar result, this claim should be investigated further with consistent noun types in the crucial position.

The focus of Tamaoka et al. (2014) mainly centered on *head-driven processing* (Pritchett 1988, 1991). They investigated how participants analyze the structure after seeing a sentence-final verb. Their claim was that *pre-head processing* is not sufficient to process a double-scrambled sentence. Instead, a sentence involving multiple scrambling requires the information encoded in the head-final verb to resolve double scrambling (two movements). In fact, Tamaoka et al. (2014) directly compared single-scrambled sentences with SO_2O_1V orders (e.g., $[_{IP}$ NP-NOM $[_{VP'}$ NP-ACC$_1$ $[_{VP'}$ NP-DAT $[_{VP}$ t_1V]]]) with double-scrambled sentences with O_1O_2SV orders (e.g., $[_{IP''}$ NP-DAT$_1$ $[_{IP'}$ NP-ACC$_2$ $[_{IP}$ NP-NOM $[_{VP'}$ t_1 $[_{VP}$ t_2V]]]). Because both sentence types have the same nouns in the same region (e.g., *Satoo-san-ga kaban-o Suzuki-san-ni azuke-ta* 'Mr. Satoo left (his) bag to Mr. Suzuki' vs. *Satoo-san-ni kaban-o Suzuki-san-ga azuke-ta* 'Mr. Suzuki left (his) bag to Mr. Satoo'), they could directly compare noun phrases of two single- and double-scrambled orders. Re-reading times showed that all noun phrases, including the crucial phrase before the verb in double-scrambled sentences, required longer re-reading times than noun phrases in the same regions in single-scrambled sentences.

Head-driven processing (Pritchett 1988, 1991) suggests that syntactic phrasal structures are established by the head verb with argument information. To explain scrambling effects, Tamaoka et al. (2005) proposed that neither thematic roles nor case particles can provide fully satisfactory information for phrase order: only grammatical functions offer satisfactory information in canonical orders for active, passive, potential, and causative sentences. Because grammatical functions basically imply the agreement information provided by the sentence-final verb, head-driven processing might better explain the processing of scrambling in head-final languages, such as Japanese. Also using eye-tracking, Tamaoka et al. (2014) suggested that a sentence with two filler-gap dependencies in Japanese was likely solved using verb information via head-driven processing. Evidence for this head-driven model was also found in Ikuta et al. (2009), in which functional magnetic resonance imaging (fMRI) showed activation differences between canonical and scrambled Japanese sentences at the head verb in brain areas related to syntactic processing. Similarly, a study using event-related potentials (ERPs) (Woff et al. 2008) indicated processing difficulty in scrambling sentences at the sentence-final verb.

Witzel and Witzel (2016), using the *Maze Task* (Forster 2010), controlled the noun types to be proper first names. Their results supported the pre-head processing account; however, their items included an adverb region that might have acted as a cue that could elicit the anticipation of a verbal head based on collocation (e.g., Ellis et al. 2009). Thus, the information provided by this cue might initiate the filler-gap integration mechanism in combination with case-marking cues. Accordingly, it is unclear which cues were responsible for the pre-verbal difficulties.

3. Eye-tracking measurements and possible indices for movement

During reading, there are two basic components of eye movements: *saccades* and *fixations* (Rayner 2009). Eye-tracking provides a detailed method to observe the complex cognitive activity of reading. This method has been frequently used in experiments that involve the processing of complex phrasal structures, such as ambiguous sentences (e.g., Binder et al. 2001, Clifton et al. 2007, Frazier and

Rayner 1982, Rayner et al. 1983, Rayner and Frazier 1987, 1989).

Reading time measures in eye-tracking can be collected for each phrase of the sentence. The measurements for early processing are *first-fixation time* and *first-pass time*. These early measurements generally are sensitive to the early stages of sentence processing, such as lexical access and early integration of information. First-fixation time refers to the very first fixation made in an interest region from which the region was first visually entered. First-pass reading time is composed of all fixations made within an interest region from when an eye movement first entered from the left until it exits in either direction. First-pass times are the essential index for the early stage of sentence processing. The late processing measurements of eye-fixation durations are *re-reading time* and *go-past time* (or *regression-path duration*). The late measurements are the late stages of sentence processing, such as structural re-analysis, recovery from processing difficulties and discourse integration (Rayner 2009). Go-past time is the total reading time for an interest region before it is exited to the right for the first time; it also includes any regressive readings out of the region to the left before going right.

For example, in a three-phrase sentence with SOV or OSV order (S or O as in Region 1 and/or Region 2 and V as in Region 3), although there is no region to the right of a verb in Region 3, go-past time at the end of a sentence (a verb in Japanese) would be a useful index for understanding total reading time, including the time spent within and moving out of that region (i.e., the sentence wrap-up effect). Thus, the difference in go-past time with null difference in first-pass time in Region 2 could be an important index (or measurement) to judge *pre-head anticipatory processing*, used for processing scrambled OSV ordered sentences. Re-reading time is the sum of all fixations after the first-pass for an interest region. Re-reading time in Region 2 is especially important for identifying post-head processing (after participants see the verb). The total measurement in each region is *dwell time*, which is the sum of all fixations made in an interest region. Accordingly, dwell time is composed of both early and late measurements. Regressions are saccades that move backward. Two important regression measurements are *regression-in* and *regression-out*. Regression-in expresses whether the participant regresses back into the region. Regression-out indicates whether there is an eye movement out of a region into a region to its left during the first-pass through a region.

4. The present investigation

While scrambling effects were observed in the aforementioned studies, they used *gap-filling* as the assumed mechanism for various types of sentences with a scrambled word order, which is resolved chiefly via the so-called *pre-head anticipation processing*. This anticipation processing is often used for interpreting various movement operations, including processing scrambled sentences and subject/object relative clauses. However, these studies did not precisely investigate detailed phrasal processing by keeping all noun phrases of the same type in the same sequential position by altering case markers and/or allowing participants to read back when necessary. By not doing so, the filler-gap dependency model has remained a hypothetical explanation. Therefore, we investigated, using two eye-tracking experiments, the detailed processing of OSV single-scrambled simple sentences in Experiment 1, and short-distance and long-distance scrambling in complex sentences in Experiment 2. Using ditransitive verbs, which allow all arguments to be proper nouns, all nouns were kept the same across NP positions in stimulus sentences, with only case marking varying between NP pairs. While this condition would change the meaning between sentences, it is only a subtle change since the noun type is the same. Experiment 1 used simple SOV and OSV sentences with two high-frequency first name proper nouns (e.g., *Kenta*, *Naoko*) and a verb. Although some degree of the pre-head processing is involved in the processing of scrambled sentences in Japanese, the agreement information from the head verb will play an important role in forming the final syntactic structure. Because the sentences in the present experiments no longer contain strong anticipatory cues, the verb argument information might be necessary for the correct interpretation of the phrasal relation. In such a case, the indices of re-reading times and possibly regression-in/-out frequencies will provide evidence for head-driven processing.

Experiment 2 used scrambled sentences embedded in complex sentences in the three conditions of canonical [S [SOV] V], short-distance scrambling within an embedded sentence [S [O_1 S gap_1 V] V], and long-distance scrambling beyond an embedded sentence [O_1 S [S gap_1V] V]. For the processing of complex sentences with short- and long-distance scrambling, we predict that, despite the complex sentence structure, the general processing pattern will be similar to that of the simple sentence.

5. Experiment 1

5.1. Methods

5.1.1. Participants

Forty-two native Japanese speakers were recruited from Nagoya University in Japan. Four participants were excluded due to excessive eye-tracking errors, leaving 38 participants (N = 38; Female = 24). The ages ranged from 18 years and 3 months old to 23 years and 3 months old. The mean age of the participants was 19 years and 3 months old. All participants received monetary compensation in exchange for their participation and provided written informed consent. All collected information was stored in a secure location, and the participants were given numerical pseudonyms to ensure privacy.

5.1.2. Materials

Thirty-six canonical and scrambled experimental item pairs were created. Each item contained two NPs and a verb, and each item came in two variants: a canonical SOV order and a corresponding scrambled OSV counterpart. The nouns of two NPs were chosen from a list of the top ten most frequently used first names given to newborn babies between 1980 and 2014 (http://www.tonsuke.com/nebin.html retrieved on April 15, 2015, Web accessibility checked in March 2019). An example set of SOV- and OSV-ordered sentence pairs is presented below.

(1) a. SOV canonical order

Region 1	Region 2	Region 3
Kenta-ga	*Naoko-o*	*sasot-ta*
NP-NOM	NP-ACC	V-PAST

‘Kenta invited Naoko.’

b. OSV scrambled order

Region 1	Region 2		Region 3
Kenta-o	*Naoko-ga*		*sasot-ta*
NP-ACC$_1$	NP-NOM	gap_1	V-PAST

‘Naoko invited Kenta.’

The Regions in (1a) and (1b) refer to the visual area where the eye-tracker measures eye-fixations and movements. Based on the SOV canonical ordered sentence in (1a), a scrambled ordered sentence was created by moving the accusative-marked (-*o*) NP to the front of sentence (1b), resulting in OSV scrambled order [$_{IP'}$ NP-ACC$_1$ [$_{IP}$ NP-NOM [$_{VP}$ gap_1 V]]] with a single gap. As shown in the example set (1a–b), the names *Kenta* and *Naoko* were kept in the same position (i.e., region). With this manipulation, each region of the two NPs can be directly compared using multiple indices of eye-tracking. In the OSV scrambled sentence, the gap is placed between Region 2 and Region 3. The experimental items (36 canonical sentences and 36 scrambled sentences; stimulus items in Appendix 1) were counterbalanced with an additional 112 filler items to ensure that participants would only see one condition of each item per experimental session. All experimental sentences for Experiment 1 are downloadable from the web site http://tamaoka.org/en/scholarly/ under article #169 [accessed March 2019]. The 112 filler items include various sentences: those with manner or resultative adverbs, numerical classifiers, and subject/object-modified relative clauses.

5.1.3 Procedure

The present study employed a verification task. A participant was instructed to read the target sentence at his or her natural pace, such as *Tomoko-ga Tatoo-o hometa* ‘Tomoko praised Taro’. Once they finished reading and comprehending the sentence (within a time limit of 8,000 ms), the participants were instructed to press any button on a gamepad to replace the sentence with a verification question, such as ‘Did Taro praise?’ The participant answered the question by pressing either a TRUE- or FALSE-marked button on the gamepad. In this case, the correct answer is FALSE because Taro was the person praised. All questions were constructed in canonical order. The participant’s right eye was periodically calibrated to the eye-tracker camera using a 9-point calibration and validation method.

Before the display of an experimental trial, a drift-checking mask was presented on the far-left center of the screen, indicated by ‘◎’. Once a participant accurately fixated on the mask, the experimenter then accepted the fixation to allow the presentation of a trial item that replaced the mask. Stimulus sentences were displayed horizontally on the center-left of a 17-inch LCD monitor. All characters were displayed in Japanese (MS Gothic 30 pt). Eye movements were recorded using an EyeLink 1000 Core System (SR Research Ltd., Ontario, Canada). Eight practice items were given prior to the experiment proper to ensure that the participants understood the task.

5.2. Results

5.2.1. Data and analysis

All fixations shorter than 80 ms were merged into a neighboring fixation within a one-radian distance, and the remaining fixations shorter than 80 ms and fixations exceeding 1,000 ms were removed (796 fixation points or 6.83% of all fixations). This adjustment was performed to remove points representing eye-tracker loss, blinks or moments of non-reading. Data outliers (reading time data only) were trimmed based upon ± 2.5 standard deviations of the predicted model, which resulted in the elimination of 1.54% of the data; see below for data analyses. The means and standard errors of the reading times and the regression-out/-in ratios are reported in Table 1.

The collected reading times and binomial data (i.e., accuracy and regression-out/-in) were analyzed using a linear mixed effect model (Baayen et al. 2008) and the *lme4* package (Bates et al. 2014) within R (R Core Team 2014). For every analysis, the fixed effect was sentence type (canonical SOV word order vs. scrambled OSV word order). The random effects were participants and items (random intercept and slopes). In addition to accuracy, all other analyses were performed only using data from trials with correct judgments. Reading times were transformed using natural logarithms and analyzed with the *lmer* function with maximum likelihoods. Satterthwaite's approximations were used via the *lmerTest* package to generate p values for each model (Kuznetsova et al. 2014). For binomial data, the *glmer* function (logit link function) was used to calculate the z distribution using maximum likelihoods and Laplace approximations. The detailed results of the linear mixed effect modeling are shown in Table 2.

5.2.2. Overall sentence processing

The total reading time for whole sentences revealed that SOV canonical sentences were read faster than scrambled OSV sentences ($p < .001$). Additionally, SOV sentences had significantly higher judgment accuracies than OSV scrambled sentences ($p < .001$).

Region 1 (NP-NOM vs. *NP-ACC)*

In the first region of the sentence, there were no significant differences between conditions in first-fixation time ($p = .45$), first-pass ($p = .76$), re-reading time ($p = .39$), dwell time ($p = .84$), or regression-in ratio ($p = .67$).

Region 2 (NP-NOM vs. *NP-ACC) – Crucial NP for OSV Scrambled Sentences*

There were no significant differences between SOV and OSV sentences in first-fixation duration ($p = .30$) or first-pass time ($p = .96$). However, the go-past time ($p < .01$) between the two sentence types was significant, suggesting that participants were likely to spend longer in Regions 1 and 2 before going beyond Region 2 in scrambled sentences. Re-reading time ($p < .001$) in Region 2 showed a significant difference; OSV scrambled sentences had longer re-reading times than SOV canonical sentences. In addition, eye movements (or saccades) were significant in their frequency ratios for regression-in ($p < .001$) into Region 2 from the verb of Region 3, showing that OSV scrambled sentences more frequently involved looking back to Region 2 than SOV canonical sentences. Because the verb is the only sentence element that follows the NP in Region 2, this regression-in is only possible from the sentence-ending verb into the NP in Region 2. The dwell time ($p < .001$) in Region 2 was also significant, reflecting the significant re-reading time result.

Table 1. Means and standard errors for SVO and OSV ordered sentences

Eye-tracking indexes	Canonical SOV		Scrambled OSV		*p*
	M	*SE*	*M*	*SE*	
Whole sentence					
Total time	1,819	25	2,035	32	**8.45E-08**
Accuracy	90.6%	1.1%	72.5%	1.7%	**6.63E-07**
Region 1: NP-NOM or NP-ACC					
First-fixation time	200	3	205	4	.454
First-pass time	410	8	412	10	.758
Re-reading time	546	14	568	18	.386
Dwell time	896	17	910	20	.836
Regression-in	0.89	0.01	0.86	0.02	.665
Region 2: NP-NOM or NP-ACC					
First-fixation time	223	3	220	3	.297
First-pass time	325	8	331	10	.960
Go-past time	651	20	780	26	**.005**
Re-reading time	489	14	636	19	**6.56E-06**
Dwell time	653	20	780	26	**1.57E-08**
Regression-out	0.43	0.02	0.49	0.02	.081
Regression-in	0.19	0.02	0.32	0.02	**1.43E-05**
Region 3: Verb					
First-fixation time	228	5	234	5	.087
First-pass time	271	7	273	7	.221
Go-past time	1,061	26	1,201	35	**.002**
Re-reading time	294	14	322	18	.316
Dwell time	345	10	373	12	**.021**
Regression-out	0.91	0.01	0.88	0.02	.213

Note: N=38. *SE*=standard errors. Bold numbered p values indicate significance.

Region 3 (Verb)

There were no significant differences in the reading of the head verb between SOV and OSV sentences in first-fixation duration ($p = .09$), first-pass time ($p = .22$), and re-reading time ($p = .32$); however, dwell time was significant ($p < .05$), showing that OSV sentences were read for a longer time than SOV sentences. Additionally, go-past time (since nothing comes after the verb, this time is composed of first-pass reading time at the verb plus any fixation duration after leaving the verb for all regions) was also significant ($p < .01$), indicating that OSV sentences were longer than SOV sentences. Nevertheless, regression out ($p = .23$) was not significant.

Table 2. Results of linear mixed effect (LME) modeling

Eye-tracking Indexes	Estimate	*SE*	*DF*	*t/z* value	*p*
Whole sentence					
Total reading time	0.11	0.02	39	6.59	***
Accuracy	-1.99	0.40	1,368	–4.97	***
Region 1: NP-NOM or NP-ACC					
First-fixation time	0.02	0.02	36	0.76	
First-pass time	0.01	0.03	32	0.31	
Re-reading time	-0.04	0.05	37	-0.88	
Dwell time	-0.01	0.04	38	-0.21	
Regression-in	-0.17	0.40	1,112	-0.43	
Region 2: NP-NOM or NP-ACC					
First-fixation time	-0.03	0.02	34	-1.06	
First-pass time	0.00	0.04	39	0.05	
Go-past time	0.15	0.05	23	3.12	**
Re-reading time	0.24	0.05	38	5.22	***
Dwell time	0.24	0.03	40	7.06	***
Regression-out	0.30	0.17	1,108	1.74	
Regression-in	0.72	0.17	1,108	4.34	***
Region 3: Verb					
First-fixation time	0.06	0.03	30	1.77	
First-pass time	0.05	0.04	38	1.25	
Go-past time	0.11	0.03	34	3.35	**
Re-reading time	0.08	0.07	31	1.02	
Dwell time	0.11	0.05	27	2.45	*
Regression-out	-0.43	0.34	838	-1.25	

Note: N=38. * p<.05. *** p<.001. *SE*=standard error. *DF*=degree of freedom.

5.3. Discussion

Experiment 1 indicated a clear difference in processing between SOV canonical and OSV scrambled sentences. As indicated by previous studies (e.g., Koizumi and Tamaoka 2004, 2010, Mazuka et al. 2002, Miyamoto and Takahashi 2004, Tamaoka et al. 2005, 2014), SOV canonical sentences were processed more quickly and accurately than their OSV counterparts. The involvement of pre-head incremental processing (e.g., Aoshima et al. 2004, Aoshima et al. 2009, Kamide et al. 2003, Kamide and Mitchell 1999, Miyamoto 2006, Mazuka et al. 2002, Witzel and Witzel 2016) was indicated by the go-past time in the crucial NP of Region 2. However, we consider this processing to be minimal since multiple indices have clearly indicated heavy head-driven processing (Ikuta et al. 2009, Woff et al. 2008). The re-reading time for the crucial NP (NP-NOM) in OSV scrambled sentences in Region 2 was significantly longer than for the NP (NP-ACC) with the same noun in SOV canonical sentences. Since the gap in OSV scrambled sentences is placed between the crucial NP in Region 2 and the head verb in Region 3, the re-

reading time suggested that the participants read back to the crucial NP in Region 2 after seeing the head verb. This trend was further supported by the significantly higher regression-in frequency for OSV scrambled sentences in Region 2 from the verb. In summary, although the word order of NP-ACC(*-o*) and NP-NOM(*-ga*) will trigger, to an extent, pre-head processing for preparing to establish the dependency between the NP-ACC filler and its gap located close to NP-NOM, the OSV sentence with a single instance of scrambling was basically read up to the head verb and then read back to the crucial NP closest to the gap. We suggest that this step of reading backwards resolved the filler-gap dependency.

6. Experiment 2

6.1. Methods

6.1.1. Participants

Fifty-four native Japanese speakers were recruited from a university in Japan; none participated in Experiment 1. Due to eye-tracking errors, eight participants were removed (*N* = 46; Female = 24). The mean age of the participants was 19 years and 8 months old, ranging from 18 years and 3 months to 20 years and 7 months. The participation consent, compensation and privacy measures were the same as Experiment 1.

6.1.2. Materials

After embedding the stimulus sentences used in Experiment 1 into complex sentences, 36 pairs of canonical, short-scrambled and long-scrambled complex sentences were created. Each item contained three NPs and two verbs. As with Experiment 1, the three NPs were obtained from a top ten list of frequently used baby names in Japan. An example set of the three conditions is as follows.

(2) a. [S[SOV]V] complex canonical ordered sentence

Region 1	Region 2	Region 3	Region 4	Region 5	
Kenji-ga	*Masato-ga*	*Keiko-o*	t*asuketa*	*to*	*kii-ta*
NP-NOM	NP-NOM	NP-ACC	V(help)-PAST	Comp	V(hear)-PAST

'Kenji heard that Masoto helped Keiko.'

b. [S[O_1S*gap*$_1$V]V] short-distance scrambling ordered sentence

Region 1	Region 2	Region 3		Region 4	Region 5	
Kenji-ga	*Masato-o*	*Keiko-ga*		*tasuketa*	*to*	*kii-ta*
NP-NOM	NP-ACC_1	NP-NOM	*gap*$_1$	V(help)-PAST	Comp	V(hear)-PAST

'Kenji heard that Keiko helped Masoto.'

c. [O_1[S[S*gap*$_1$V]V]] long-distance scrambling ordered complex sentence

Region 1	Region 2	Region 3		Region 4	Region 5	
Kenji-o	*Masato-ga*	*Keiko-ga*		*tasuketa*	t*o*	*kii-ta*
NP-ACC_1	NP-NOM	NP-NOM	*gap*$_1$	V(help)-PAST	Comp	V(hear)-PAST

'Masato heard that Keiko helped Kenji.'

Each Region in (2a–c) referred to the visual area where the eye-tracker measured eye fixations and movements. Based on the canonically ordered complex sentence in (2a), a short-distance scrambled sentence (2b) and a long-distance scrambled sentence (2c) were created by moving the accusative-marked (*-o*) NP. As shown in the example set (2a–c), the three first names *Kenji*, *Masato* and *Keiko* were kept in the same positions (or the same regions) across all sentences. Due to this manipulation, these three NP regions can be directly compared using multiple indices of the eye-tracker. In both short-distance and long-distance scrambled sentences, the gap was placed in the same position between Region 3 and Region 4 in the subordinate clause. The experiment included 104 filler items and 36 sets of complex sentences (36 canonical, 36 short-distance and 36 long-distance; stimulus items in Appendix 2). All experimental sentences for Experiment 2 are downloadable from the web site http://tamaoka.org/en/scholarly/ under article #169. These items were placed into three counterbalanced lists to ensure that the participants would only see one condition of each item per experimental session. The filler items included sentences with numerical classifiers, *ga-no* conversion and relative clauses.

6.1.3. Procedure

The procedure of Experiment 2 was the same as that of Experiment 1. As with Experiment 1, eight practice items were given to the participants in Experiment 2.

6.2. Results

6.2.1. Data and analysis

Data editing was the same as for Experiment 1. In Experiment 2, 1,938 fixation points (7.52% of all fixations) were cleaned, and 1.53% of the reading time data were removed as data outliers. For the main effects in the LME models, the conditions were coded as a continuous variable: the canonical condition was coded as 1, short-scrambling was 2, and long-scrambling was 3. In other words, we predicted a linear relationship between these variables with the hypothesis that the canonical condition would be the easiest to parse, the short-scrambling condition more difficult and the long-distance scrambling condition engendering the most processing difficulty. For the simple comparisons between the conditions, the three conditions were recoded as categorical. Following the initial LME analysis, a post hoc multiple comparison (Tukey's contrasts) was conducted for each model to provide simple comparisons between conditions. We do not believe that this approach would differ substantially were the conditions releveled within the initial LME analysis. The means and standard errors for reading times and regression-out/-in ratios in each region are reported in Table 3. The data analyses were the same as for Experiment 1. The detailed results of the linear mixed effect model are shown in Table 4.

6.2.2. Overall sentence processing

The main effect of sentence type was significant for total reading time ($p < .001$)

and accuracy ($p < .001$). Multiple comparisons revealed that canonical complex sentences had shorter reading times than complex sentences with short-distance scrambling. Sentences with short-distance scrambling, in turn, had shorter reading times than sentences with long-distance scrambling (see Table 3 for details of the means and Table 4 for the results of Tukey's contrasts). The canonical sentences were much more accurately processed than those with both short-distance and long-distance scrambling. Although the processing speed was slower for the sentences with long-distance scrambling, the accuracy results did not differ between sentences with short-distance and long-distance scrambling.

6.2.3. Main effects throughout three complex sentence types

The scrambling effect was analyzed with the main effects in the five regions. Main effects were found in all five regions. In the first NP of Region 1, re-reading time ($p < .001$), dwell time ($p < .001$) and regression-in ($p < .001$) were all highly significant. In the second NP of Region 2, go-past time ($p < .05$), re-reading time ($p < .001$), and dwell time ($p < .001$) were significant. As with Region 1, re-reading time ($p < .001$), dwell time ($p < .001$), and regression-in ($p < .001$) were highly significant in the third NP of Region 3. In Region 4, where the verb in the subordinate clause is located, go-past time ($p < .001$), re-reading time ($p < .001$), and dwell time ($p < .001$) were highly significant. In the main clause verb of Region 5, go-past time ($p < .001$) was highly significant. However, these main effects only indicate the overall differences among the three sentence types. Thus, multiple comparisons were performed on the three sentence types after these significant main effects were discovered.

Table 3. Means of canonical, short-distance scrambling and long-distance scrambling

Eye-tracking indexes	Canonical		Short-distance		Long-distance		*p*
	M	*SE*	*M*	*SE*	*M*	*SE*	
Whole sentence							
Total time	3,263	46	3,598	62	4,408	77	**2.66E-15**
Accuracy	91.2%	1.2%	75.2%	1.9%	73.5%	2.0%	**1.84E-07**
Region 1: NP							
First-fixation time	208	3	201	3	212	4	.538
First-pass time	406	10	390	10	417	12	.513
Re-reading time	471	18	546	20	763	23	**2.71E-10**
Dwell time	720	17	818	22	1,100	26	**1.51E-14**
Regression-in	0.69	0.02	0.75	0.02	0.91	0.01	**1.01E-11**
Region 2: NP							
First-fixation time	229	4	226	4	227	4	.435
First-pass time	358	9	326	9	357	11	.908
Go-past time	549	17	515	17	598	21	**.019**
Re-reading time	882	22	1,025	28	1,138	33	**1.13E-05**
Dwell time	1,208	23	1,307	29	1,437	34	**1.47E-04**
Regression-out	0.27	0.02	0.27	0.02	0.33	0.02	.077
Regression-in	0.89	0.01	0.85	0.02	0.85	0.02	.156
Region 3: NP							
First-fixation time	225	3	221	4	232	4	.378
First-pass time	324	8	313	7	307	8	.471
Go-past time	617	24	676	33	654	36	.456
Re-reading time	605	18	765	23	974	31	**1.34E-10**
Dwell time	849	19	992	23	1,223	32	**5.44E-10**
Regression-out	0.34	0.02	0.33	0.02	0.30	0.02	.206
Regression-in	0.32	0.02	0.34	0.02	0.51	0.03	**9.07E-07**
Region 4: Verb in the subordinate clause							
First-fixation time	224	3	223	4	233	4	.146
First-pass time	296	6	303	8	310	7	.110
Go-past time	1,340	44	1,599	66	2,099	81	**6.85E-06**
Re-reading time	346	14	398	18	509	22	**6.73E-11**
Dwell time	475	12	496	15	646	20	**5.11E-09**
Regression-out	0.74	0.02	0.70	0.02	0.77	0.02	.434
Regression-in	0.04	0.01	0.05	0.01	0.05	0.01	.614
Region 5: Verb in the main clause							
First-fixation time	197	6	188	7	200	9	.613
First-pass time	204	7	191	8	208	11	.442
Go-past time	1,693	82	2,051	103	2,810	155	**2.96E-05**
Re-reading time	179	12	194	15	212	21	.464
Dwell time	237	10	228	11	251	14	.82
Regression-out	0.94	0.02	0.94	0.02	0.96	0.02	.407

Note: N=46. Bold p values indicate statistical significance. M=mean. SE=standard error.

Table 4. Results of linear mixed effect (LME) modeling and multiple comparisons

Eye-tracking indexes	Estimate	*SE*	*DF*	*t/z* value	*p*	C vs. S	S vs. L	C vs. L
Whole sentence								
Total reading time	0.15	0.01	45	11.7	***	C < S	S < L	C < L
Accuracy	-0.57	0.11	1,592	−5.215	***	C > S	S = L	C > L
Region 1: NP								
First-fixation time	0.01	0.01	59	0.619		C = S	S = L	C = L
First-pass time	0.01	0.02	48	0.659		C = S	S = L	C = L
Re-reading time	0.26	0.03	40	8.362	***	C < S	S < L	C < L
Dwell time	0.21	0.02	47	10.92	***	C < S	S < L	C < L
Regression-in	0.79	0.12	1,266	6.805	***	C = S	S < L	C < L
Region 2: NP								
First-fixation time	-0.01	0.01	674	-0.781		C = S	S = L	C = L
First-pass time	0.00	0.02	29	-0.116		C = S	S = L	C = L
Go-past time	0.05	0.02	43	2.448	*	C = S	S < L	C < L
Re-reading time	0.13	0.03	34	5.142	***	C < S	S < L	C < L
Dwell time	0.08	0.02	37	4.227	***	C = S	S < L	C < L
Regression-out	0.14	0.08	1,275	1.767		C = S	S = L	C = L
Regression-in	-0.21	0.15	1,275	-1.419		C = S	S = L	C = L
Region 3: NP								
First-fixation time	0.01	0.01	44	0.891		C = S	S = L	C = L
First-pass time	-0.01	0.02	30	-0.731		C = S	S = L	C = L
Go-past time	-0.02	0.03	35	-0.754		C = S	S = L	C = L
Re-reading time	0.25	0.02	22	11.18	***	C < S	S < L	C < L
Dwell time	0.18	0.02	34	8.534	***	C < S	S < L	C < L
Regression-out	-0.12	0.09	1,274	-1.265		C = S	S = L	C = L
Regression-in	0.46	0.09	1,274	4.911	***	C = S	S < L	C < L
Region 4: Verb in the subordinate clause								
First-fixation time	0.02	0.01	46	1.478		C = S	S = L	C = L
First-pass time	0.02	0.02	972	1.601		C = S	S = L	C = L
Go-past time	0.20	0.04	34	5.313	***	C = S	S < L	C < L
Re-reading time	0.18	0.03	584	6.65	***	C < S	S < L	C < L
Dwell time	0.15	0.02	42	7.315	***	C = S	S < L	C < L
Regression-out	0.08	0.10	1,191	0.782		C = S	S = L	C = L
Regression-in	-0.15	0.30	1,191	-0.505		C = S	S = L	C = L
Region 5: Verb in the main clause								
First-fixation time	-0.01	0.02	107	-0.507		C = S	S = L	C = L
First-pass time	-0.02	0.03	105	-0.772		C = S	S = L	C = L
Go-past time	0.25	0.05	23	5.168	***	C < S	S < L	C < L
Re-reading time	0.04	0.06	57	0.737		C = S	S = L	C = L
Dwell time	-0.01	0.03	27	-0.229		C = S	S = L	C = L
Regression-out	0.27	0.32	395	0.83		C = S	S = L	C = L

Note: N=46. * p<.05. ** p<.01. *** p<.001. *SE*=standard error. C=canonical. S=short-distance scrambling. L=long-distance scrambling.

6.2.4. Comparisons of sentences between canonical order and short-distance scrambling

Differences in sentence processing were first examined by comparing two types of complex sentences with canonical and short-distance scrambling. Refer to Table 4 for the comparison results of canonical and short-distance scrambling (C vs. S).

Region 1 (NP-NOM vs. *NP-NOM)*

At the reading of the first region of the sentence, the later-processing index of re-reading time was significant; sentences with short-distance scrambling had longer re-reading times than canonical sentences. Additionally, dwell time was also significant; sentences with short-distance scrambling had longer dwell times than canonical sentences. Dwell time is the total duration of all fixations in this region including first-pass times and re-reading times. However, since the first-pass time was not significant, it only reflects later processing stages.

Region 2 (NP-NOM vs. *NP-ACC)*

In Region 2, re-reading time was significant. Sentences with short-distance scrambling had longer re-reading times in this region than canonical sentences. The significance of dwell time also confirmed this result. Additionally, no differences were found in dwell time, regression-in or regression-out.

Region 3 (NP-ACC vs. *NP-NOM) Crucial NP for Short-distance Scrambling*

The crucial NP (assumed to include the gap at the same region) is located in Region 3. Re-reading time significantly differed between canonical sentences and short-distance scrambling sentences. Additionally, dwell time revealed a similar pattern between canonical sentences and sentences with short-distance scrambling.

Region 4 (Verb in the Subordinate Clause)

At the subordinate clause verb, only the re-reading index revealed a difference between these two conditions: short-distance scrambling sentences required longer re-reading times than canonical sentences.

Region 5 (Verb in the Main Clause)

Here, the only difference was found during go-past time. Canonical sentences were shorter than short-distance scrambled sentences.

6.2.5. Comparisons between canonical/short-distance and long-distance scrambling

The processing of complex sentences with long-distance scrambling was further investigated by comparing these sentences to their corresponding canonical sentences and sentences with short-distance scrambling. Multiple comparisons (Tukey's contrasts) in sentence processing were performed between canonical and long-distance scrambling (C vs. L) and between short-distance and long-distance scrambling (S vs. L). Please refer to the comparison results in Table 4.

Region 1 (the first NP)

In complex sentences with long-distance scrambling, the NP in Region 1 is the filler NP (NP-ACC) that removed from the NP in the subordinate clause (i.e., syntactic movement). This gap (or trace) is placed between the NP of Region 3 and the verb of Region 4. Re-reading time significantly differed between canonical and long-distance scrambling and between short-distance and long-distance scrambling. Furthermore, regression-in showed differences between canonical and long-distance scrambling and between short-distance and long-distance scrambling. Dwell time also differed significantly among the three types of complex sentences, reflecting differences in reading time.

Region 2 (the second NP)

Differences were found in the go-past time between canonical and long-distance scrambling and between short-distance and long-distance scrambling. Differences were also seen in the re-reading time between canonical and long-distance scrambling and between short-distance and long-distance scrambling. In addition, a difference in dwell time was found between canonical and long-distance scrambling and between short-distance and long-distance scrambling. Participants read the second NP in complex sentences with long-distance scrambling much more slowly than with canonical and short-distance scrambled sentences.

Region 3 (the third NP)

Region 3 is the crucial NP region assumed to include the gap. As with short-distance scrambling in simple OSV sentences from Experiment 1, re-reading time clearly indicated significant differences between canonical and long-distance scrambling and between short-distance and long-distance scrambling; complex sentences with a long-distance scrambling required longer re-reading times than the other two sentence types. Significance in regression-in frequency ratios among the three sentence types also indicated that participants read back into this crucial NP-NOM region from either the verb of the subordinate clause or the verb of the main clause.

Region 4 (Verb in the Subordinate Clause)

Go-past time, re-reading time and dwell time significantly differed between canonical sentences and sentences with long-distance scrambling, as well as between sentences with short-distance and long-distance scrambling (see Table 4 for details). All indices indicated that longer reading times were needed to process the verb in Region 4 within long-distance scrambling sentences.

Region 5 (Verb in the Main Clause)

Differences were found for re-reading times in complex sentences between canonical and long-distance scrambling. Given that go-past time was the only index to show a difference in processing cost for long-distance scrambling at the main-clause verb in complex sentences, it must show that participants did not need to spend any extra time understanding the main-clause verb itself. Despite having already spent more time processing the previous three NPs and the subordinate-clause verb prior to reaching the final main-clause verb (see Region 4 go-past), participants spent a considerable amount of time revisiting the prior four regions after seeing the subordinate-clause verb, which might reflect the global comprehension difficulty associated with long-distance scrambling.

6.3. Discussion

Experiment 2 compared the processing of complex sentences with three different word orders: canonical, short-distance scrambling, and long-distance scrambling. For the reading time of the whole sentence, Experiment 2 clearly indicated that canonical complex sentences were more quickly and accurately processed than their corresponding counterparts with short- or long-distance scrambling. Moreover, complex sentences with short-distance scrambling were processed more quickly than their long-distance counterparts. First, when complex sentences with short-distance scrambling were compared to their canonical counterparts, it was revealed that subordinate clauses with short-distance scrambling had significantly longer re-reading times at the crucial NP (NP-NOM) in Region 3. Recall that Region 3 contains the gap site immediately before the verb, consistent with the results of Experiment 1. Second, complex sentences with long-distance scrambling showed even longer re-reading times and frequent regressions-in, compared with their counterparts with short-distance scrambling. Even greater differences were found when scrambled sentences were compared with sentences with canonical word order. These results were found across multiple eye-tracking measurements. Only minimal evidence was found between short-/long-distance scrambling and their canonically ordered counterparts for first fixation, first-pass time or go-past time in the first NPs. Therefore, as indicated by the previous eye-tracking study of double-scrambled sentences with ditransitive verbs (Tamaoka et al., 2014), heavy head-driven processing is most likely involved in the processing of scrambled complex sentences. That is, once the involvement of factors, such as noun type, the semantic likelihood of verb-object/subject combination, and the semantic nature of the subject/object, are controlled, the results might suggest head-driven processing. Both indices of re-reading time and regression-in were found to be significant in the crucial NP-NOM region in both short-distance and long-distance scrambling and the filler NP-ACC in long-distance scrambling. Third, two consecutive NP-NOMs appeared in canonical sentences, while the second NP was marked as NP-ACC for short-distance scrambling. According to Miyamoto (2002), this word order difference was expected to induce longer reading times in Region 2 for canonical sentences during the early stage indices of first pass time and go-past time, compared to short-distance scrambling sentences. However, nothing was significantly differed between canonical and short-distance scrambling. As such, a clause boundary might not require that much of an extra cognitive load.

7. General Discussion

Using an eye-tracking technique, the present study aimed to clarify when and where filler-gap dependencies in scrambled word orders become resolved in Japanese, both before and after the participants see the head-verb. Experiment 1 focused on the processing of simple intransitive sentences, while Experiment 2 focused on the same type of simple sentences embedded in complex sentences. These two experiments used high-frequency first names across the same NP positions in paired stimulus sentences to exclude the involvement of influences such as noun type, semantic likelihood of verb-object/subject combination (collocation frequency effects) and semantic nature of subject/object (e.g., animacy). This stimulus manipulation made it possible to directly compare scrambled and canonically ordered sentences. Here, we discuss the main question of this study: at what point (or to what degree) are scrambled word orders resolved before seeing the verb (i.e., pre-head) and after seeing the verb (head-driven)?

7.1. Processing of scrambled simple intransitive sentences

The whole sentence processing data in Experiment 1 showed that canonically ordered simple intransitive SOV sentences were processed more quickly and more accurately than OSV scrambled counterparts. Consistent with previous studies (e.g., Koizumi and Tamaoka 2004, 2010, Mazuka et al. 2002, Miyamoto and Takahashi 2004, Tamaoka et al. 2005, 2014), the scrambling effect was observed in Experiment 1. According to the results of the eye-tracking measurements, Figure 1 depicts the processing of OSV scrambled sentences. These simple intransitive sentences consisted of three regions: two NPs and the verb. The details of these three phrases (or regions) were examined using multiple indices of eye-tracking measurements.

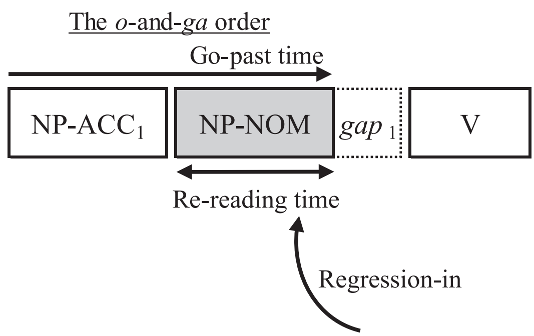

Figure 1. The processing of a simple scrambled intransitive sentence

No index of eye-tracking showed significance in the first NP region of NP- ACC_1. In the second NP region of NP-NOM, the go-past time was significant when comparing canonical and scrambled sentences. This significant go-past time could imply pre-head processing that initiated the construction of the phrasal structure of the two NPs. As depicted in Figure 1, the NP-ACC and

NP-NOM order or the *o*-and-*ga* order in Regions 1 and 2 might initiate scrambling resolution by partially constructing the syntactic structure based on the two noun phrases. In this sense, we could call this *time-triggered processing* initiated by reading the *o*-and-*ga* order. However, in the present study, there was no semantic contrast of subject/object, such as an animacy contrast, so the *o*-and-*ga* order did not provide sufficient information to establish a filler-gap dependency in the NP-NOM of Region 2. Because the nouns of NP-ACC$_1$ and NP-NOM consisted of popular, highly frequent first names, such as *Tomoko*, *Taroo*, and *Kenji*, these nouns could not provide sufficient information to properly construct the phrasal structure, including a filler-gap dependency at the early processing stage in Region 2; native Japanese speakers must seek the verb information in Region 3 to complete the relationship between the two NPs and create a filler-gap dependency.

Re-reading time and regression-in in Region 2 were highly significant (see Tables 1 and 2); native Japanese speakers must read ahead to the ending verb to obtain the argument information to establish the relationship between two NPs. Because the verb in Region 3 is in the only region after Region 2, it implies that native Japanese speakers read back to NP-NOM close to *gap*$_1$ in Region 2 from the head verb. Participants were likely to stay in Region 2 longer at the late processing stage. Consequently, we consider *pre-head processing* to be insufficient, although it could be initiated by the *o*-and-*ga* order.

Importantly, the verb agreement information is required to establish a *filler-gap dependency* to complete a whole sentence structure and understand a sentence once all nouns are controlled. Using argument information from the verb, native Japanese speakers read back to the crucial NP-NOM region close to *gap*$_1$ to resolve the dependency of the filler NP (NP-ACC$_1$) and *gap*$_1$. *Gap-filling parsing* would be performed around the crucial NP-NOM region after processing the head verb (i.e., head-driven processing).

It should be noted that, as in [φ (*Watashi-wa* 'I') *Kenji-o* [*Masumi-ga kita toki*] *yobi-yose-ta*] '[I] called Kenji when Mayumi came', the scrambled order of NP-ACC (*Kenji-o*) and NP-NOM (*Masumi-ga*) could be interpreted as a complex sentence with a subordinate clause having an empty subject (Miyamoto 2006). Since the go-past time of NP-NOM in Region 2 was significant, this result implies the initiation of the construction of a phrasal structure. Thus, we assume that native Japanese speakers are unlikely to expect a relative clause by the NP-ACC and NP-NOM order; rather, they initiate the *gap-filling parsing* by the *o*-and-*ga* order despite the highly frequent first names of the first two NPs used in Experiment 1.

7.2. Processing of short-distance scrambled complex sentences

The scrambling effect found with simple sentences in Experiment 1 was further examined by comparing different types of scrambling in complex sentences in Experiment 2. Whole sentence processing in Experiment 2 indicated that canonical complex sentences were processed more quickly and accurately than their short-distance scrambling counterparts. The scrambling effect (e.g., Koizumi and Tamaoka 2004, 2010, Mazuka et al. 2002, Miyamoto and Takahashi 2004, Tamaoka et al. 2005, 2014) was again observed in Experiment 2.

No indices of early stage processing including go-past time showed significance in the three NPs from Regions 1-3 when compared to canonical sentences (see Table 4). As shown in Figure 2, in complex sentences with short-distance scrambling, the crucial NP (NP-NOM) closest to gap_1 immediately before the verb in subordinate clauses is located in Region 3. Both NP-ACC$_1$ in Region 2 and NP-NOM in Region 3 in short-distance scrambled sentences had significantly longer re-reading times than their corresponding canonical complex sentences (see Table 4). This outcome suggests that Japanese speakers must read through from the first NP-NOM to the verb in the subordinate clause and read back to the second and third NP.

In short-distance scrambling, the early sequence of NP-NOM and NP-ACC$_1$ in Regions 1 and 2 indicates the canonical order of a simple SOV sentence. The following NP-NOM in Region 3 follows this order, which partially creates the NP-ACC$_1$ and NP-NOM or the *o*-and-*ga* order. However, unlike in Experiment 1, no significant go-past time was observed in short-distance scrambling. Given three sequential NPs before seeing the verb, native Japanese speakers did not have sufficient information to establish both the filler and gap dependency and the clause boundary; they needed to have the verb argument information in Region 4. Consequently, they read ahead to see the verb in the subordinate clause without initiating filler-gap parsing (i.e., no pre-head processing).

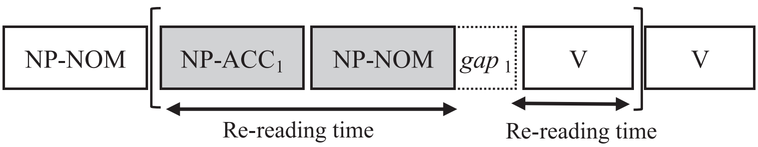

Figure 2. The processing of a complex sentence with short-distance scrambling

The re-reading time in the verb of the subordinate clause in Region 4 was significant (see Table 4), so they must read back and forth between the verb and the crucial NP-NOM closest to gap_1 and the NP-ACC$_1$. Unlike with OSV-ordered simple sentences shown in Figure 1, OSV-ordered subordinate clauses required native Japanese speaker to re-read NP-ACC$_1$, shown in Figure 2 as the extension of the re-reading time required for both the NP-ACC$_1$ and the NP-NOM of the subordinate clause. The verb in the main clause in Region 5 only showed significance in the go-past time. This go-past time in the sentence final position indicates the overall reading time because nothing comes after it. Thus, this result suggests a longer wrapping-up time for the processing of short-distance scrambled sentences. Nevertheless, the basic mechanism for the processing of short-distance scrambled sentences would be quite similar to the processing of the OSV-ordered simple sentences. After processing the head verb of the subordinate clause, native Japanese speakers would perform *gap-filling parsing* (Frazier and Clifton 1989) to establish a filler-gap dependency within the subordinate clause to understand a scrambled intransitive sentence embedded in a complex sentence.

As shown in Figure 3, a canonical SOV-ordered intransitive sentence embedded in a complex sentence displays two consequential NP-NOMs or two subjects. In such a case, since the second NP-NOM indicates the clause boundary between the main and subordinate clauses, the second NP-NOM slows down to establish the clause boundary (Miyamoto 2002). In contrast, the sequential NP-NOM and NP-ACC order appears in a scrambled OSV-ordered intransitive sentence embedded in a complex sentence. In this order, native Japanese speakers will wait until seeing the third NP-NOM to establish the clause boundary. Therefore, we expected that canonical sentences would have longer reading times in the second NP-NOM region, compared to the same region in scrambled sentences. However, Experiment 2 demonstrated that neither first-pass time nor go-past time significantly differed between canonical and short-distance scrambling (see Table 4). Thus, the detection delay for the clause boundaries (Miyamato 2002) might require little processing effort, at least during early stage processing.

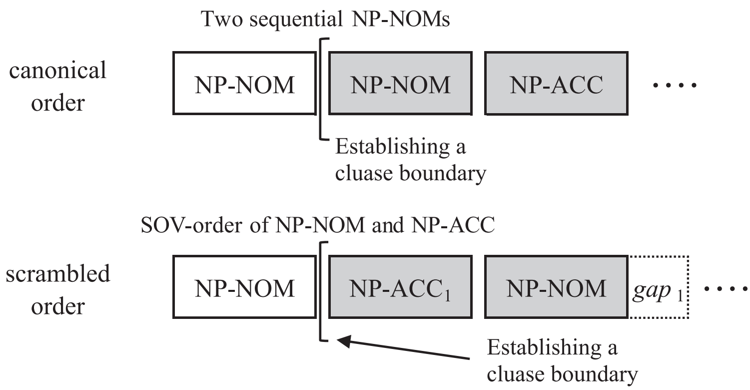

Figure 3. No extra processing load in establishing a clause boundary in sequential NP-NOMs during early stage processing

7.3. Processing of long-distance scrambled complex sentences

Long-distance scrambling in complex sentences was examined by comparing sentences with long-distance scrambling to counterparts with either canonical word order or an instance of short-distance scrambling. Whole sentence processing in Experiment 2 indicated that both canonical and short-distance complex sentences were processed more quickly than sentences with long-distance scrambling; however, only the canonical complex sentence had higher accuracy. The syntactic structure of long-distance scrambling is $[_{IP'}$ NP-ACC$_1$ $[_{IP}$ NP-NOM $[_{CP}$ $[_{IP}$ NP-NOM $[_{VP}$ t_1 V]] C] V]], consisting of three NPs and two verbs. The detailed results of phrase-by-phrase processing indicated by eye tracking are depicted in Figure 4.

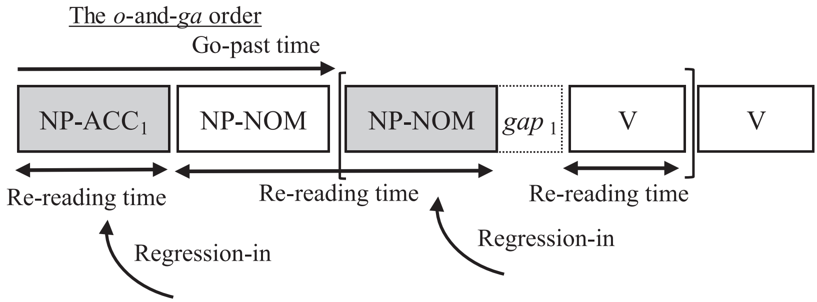

Figure 4. The processing of a complex sentence with long-distance scrambling

No differences were found between long-distance scrambling and short-distance scrambling or between long-distance scrambling and canonical word order in first fixation, first-pass or go-past time in the first NPs, except for the go-past time in Region 2 (see Table 4). As shown in Figure 4, the long-distance scrambling in Experiment 2 displays the NP-ACC$_1$ and NP-NOM sequence or the *o*-and-*ga* order in Regions 1 and 2.

Here, the reader could begin to partially construct a phrasal structure to prepare for the establishment of the filler and gap dependency. This result was consistent with the *o*-and-*ga* order of the simple scrambled intransitive sentences in Experiment 1 (see Figure 1). After the *o*-and-*ga* order comes NP-NOM, the sequential NP-NOMs in Regions 2 and 3 could begin to establish the clause boundary. However, we did not find any reading delay in Region 3 at the early processing stage, which could indicate that no extra processing load is required for the clause boundary (see Figure 2). Otherwise, as with Experiment 1, highly frequent first names of the three NPs cannot provide sufficient information to establish both the filler-gap dependency and the clause boundary. Thus, native Japanese speakers read ahead until they reach the verb in the subordinate clause located in Region 4.

In contrast, the later stage processing measurements for re-reading time and regression-in were found to be highly significant, compared to sentences with both canonical and short-distance scrambling (see Table 4). These significances were shown in the crucial NP-NOM region in long-distance scrambling. Therefore, native Japanese speakers read through the sentence from the first NP-ACC$_1$, the second NP-NOM, the third NP-NOM and the two verbs. Then, as shown in Figure 4, they read back to NP-ACC$_1$ and the crucial NP-NOM (close to the gap). This pattern is especially salient after they see the verb in the subordinate clause (supported by the significant re-reading times in Regions 2, 3 and 4). The filler NP-ACC$_1$ is placed in the sentence-initial position of Region 1. Due to this longer scrambling distance, native Japanese speakers showed a strong trend toward reading back to the filler NP-ACC$_1$ after seeing the verb in Region 4. This processing trend was shown for two indices: re-reading time in the sentence-initial position of the filler NP-ACC$_1$ and regression-in into this NP region (see Table

4). It is also possible to read the final verb in the main clause before reading back, as the go-past time was significant in Region 5. However, the re-reading time at the verb of the subordinate clause was highly significant, so native Japanese speakers probably read the verb of the subordinate clause longer to obtain the verbal argument information required to resolve the filler-gap dependency.

7.4. Ending remarks: Mechanism for the processing of scrambled sentences

Previous studies have proposed *pre-head anticipation processing* for even head-final languages such as Japanese. When the NP-ACC and NP-NOM order or the *o*-and-*ga* order was apparent, the indication of pre-head processing was found during the go-past time in Experiment 1 and Experiment 2 (only long-distance scrambling). Eye-tracking, however, clearly showed longer re-reading times in the crucial NP region and frequent regression-in from the verb to the crucial NP-NOM in Experiments 1 and 2 and the filler NP-ACC in Experiment 2. These results indicated heavy *head-driven processing*. Although the gap is not visually presented in a sentence, native Japanese speakers are still able to locate the *gap* in a sentence. The crucial NP was located near the *gap* before the verb: in the NP-NOM in Region 2 of Experiment 1 and in Region 3 of Experiment 2. To perform gap-filling parsing, native Japanese speakers must establish a relationship between the filler NP-ACC and the *gap* by reading back to the crucial NP after obtaining the verb agreement information. Because all nouns in Experiments 1 and 2 were controlled as the same noun type of highly frequent first names, the head verb argument information was necessary to construct phrasal structure. If so, semantic factors, such as the semantic likelihood of verb-object/subject combinations and/or the semantic nature of the subject/object, might act as cues for pre-head processing. When no such pre-head cues are available, the pre-head processing does not function appropriately. Thus, we can assume that native Japanese speakers can perform both *pre-head* and *head-driven* (or *post-head*) processing, depending upon the availability of the processing cues. In other words, the relative strength of the two sets of *pre-head* and *head-driven* processing types varies based on the cues available.

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Appendix

All experimental sentences for Experiments 1 and 2 are downloadable from the web site http://tamaoka.org/en/scholarly/ under article #169 [accessed March 2019]. The following are the materials used to perform the experimental sentences for Experiment 1.

The nouns used were the following proper names: 友子, 太郎, 次郎, 順子, 和子, and 健二. The verbs used were the following: ほめた, 助けた, 殴った, 雇った, だました, 殺した, 憎んだ, 許した, 産んだ, 信じた, 指導した, 疑った, 叩いた, 追いかけた, 尊敬した, 逃がした, 突き飛ばした, 驚かした, 蹴った, 投げ飛ばした, 刺した, 縛った, 呼び止めた, 引っ掻いた, 起こした, 誤解した, 背負った, にらんだ, 突き落とした, 見つけた, 脅した, 見送った, 捕まえた, 呼んだ, 泣かせた, and 押した.

Sentence 1 contains a scrambled variation (3b) of the canonical (3a) word order. The interest regions are designated between asterisks.

(3) a. Canonical *友子が*太郎を*ほめた。*
b. Scramble *友子を*太郎が*ほめた。*

The following are the materials used to create the experimental sentences for Experiment 2. The nouns used the following proper names: アキラ, アケミ, アサミ, アスカ, オサム, カズヤ, クミコ, ケイコ, ケンジ, サチコ, サトコ, シゲル, ススム, タカシ, タクマ, タツヤ, ツトム, ツヨシ, テツヤ, トオル, トモコ, ナオキ, ナナミ, ハナコ, ヒデキ, ヒロシ, マサト, マナブ, マユミ, ミチコ, ミハル, メグミ, ユウコ, ユカリ, ユタカ, ユミコ, and ヨウコ.

The embedded verbs used were the same verbs as in Experiment 1. The matrix verb phrase was always と聞いた. Sentence 1 contains both the short scrambled and long scrambled variations of the canonical word order. The interest regions are designated between asterisks.

(4) a. Canonical *ケンジが*マサトが*ケイコを*助けた*と聞いた。*
b. Short Scrambled *ケンジが*マサトを*ケイコが*助けた*と聞いた。*
c. Long Scrambled *ケンジを*マサトが*ケイコが*助けた*と聞いた。*

Author's contact information:
Katsuo Tamaoka
Graduate School of Humanities, Nagoya University
Furo-cho, Chikusa-ku, Nagoya-shi, Aichi-ken, 464-8601, Japan
E-mail: tamaoka@nagoya-u.jp

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【要　旨】

日本語のかき混ぜ文の主要部前と主要部駆動処理に関する視線計測研究

玉岡　賀津雄　　Michael P. Mansbridge
名古屋大学　　名古屋大学

動詞を読む前の予測処理がかき混ぜ文の処理に影響すると報告されている。しかし，これらの研究は，文の同じ位置で名詞を比較しておらず，名詞の種類も異なっていた。そこで，高使用頻度の人名を文の同じ位置に配置して，他動詞の単文とそれらを埋め込んだ複文の２つの実験で，短距離・長距離のかき混ぜを句ごとに視線計測した。NP-ACC（ヲ）とNP-NOM（ガ）が連続して現れる場合は，２つ目の名詞句の NP-NOM（ガ）の部分で，両実験のかき混ぜ文の通過時間が有意に長くなった。これは，埋語補充解析が始まることを示唆している。しかし，その後，動詞を読んでからの再読時間と読み戻り頻度が，埋語が想定される付近の名詞句を中心に観察された。意味的な手掛かりが欠如する場合には，動詞の情報に準拠した主要部駆動処理に強く依存することが示された。手掛かりの有無によって，主要部前処理か主要部駆動処理かの依存の度合いが異なってくると考えられる。