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Structural ambiguity resolution in the process of reanalysis: Evidence from Japanese sentence comprehension

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Self-paced reading and speeded acceptability judgement experiments on Japanese sentence comprehension were conducted to elucidate the processing mechanisms of ambiguity resolution in structural reanalysis. The results suggest that the parser attempts to maintain an initial clause-mate relationship of noun phrases in the process of reanalysis, which is consistent with the prediction of the Minimal Revision Principle (Frazier & Clifton, 1998), but not with that of the Minimum Maximal-Projection Principle (Oishi, 2007).

Key words: sentence comprehension, ambiguity resolution, garden-path sentences, reanalysis, Japanese

Introduction

Psycholinguistic research on sentence comprehension has been concerned with how the language processing mechanism works in the brain. Traditional studies, focusing primarily on syntactic processing, have found that people parse continuous input incrementally, even in verb-final languages. For example, readers routinely experience processing difficulties when a temporarily ambiguous sentence is disambiguated in favour of a less preferred structure, such as in the case of '*The horse raced past the barn fell*' (Bever, 1970). The processing difficulty increases in such a sentence because readers process '*raced*' as a main verb in the past tense without waiting for the later information that signals that '*raced past the barn*' is a reduced relative clause (meaning '*the horse that was raced past the barn*'). Therefore, readers struggle to parse the structure correctly with '*fell*' occurring at the end. This extra processing cost is referred to as a garden-path (GP) effect. The GP effect indicates that people incorporate encountered words into the syntactic representation by resolving a structural ambiguity without a significant delay. The GP effect provides useful information to examine a parsing mechanism in the initial analysis (e.g., Frazier, 1979; Frazier & Clifton, 1986; Frazier & Fodor, 1978).

Relatively less known is the mechanism of ambiguity resolution in reanalysis. Upon encountering an error signal (a word that triggers reanalysis), there are sometimes multiple structural possibilities to be adopted, especially in head-final languages such as Japanese. For example, native speakers of Japanese prefer to initially analyse the sentence in (1a) below as a simple sentence, although more syntactically complex structures are available (Inoue,

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2006; Mazuka & Itoh, 1995). Since the relative clause in Japanese is pre-nominal and does not have a clause boundary marker, such as '*who*' in English (e.g., '*The girl who observed a child*'), Japanese speakers experience a GP effect upon encountering the head noun of the relative clause, such as '*girl-DAT*' in (1b). Consequently, they are required to revise a syntactic structure to incorporate it into an existing structure in a legitimate way. Importantly, there are (at least) two possible structures that the parser can build, as indicated in (2). In (2a), the accusative NP '*child-ACC*' is analysed as a constituent in the relative clause headed by the error signal '*girl-DAT*', whereas it exists in the matrix clause in (2b). Mazuka and Itoh (1995) have argued that Japanese speakers prefer (2a) to (2b) in resolving structural ambiguity on the basis of the intuitive judgement that (3a), which is compatible with the structure in (2a), is easier to comprehend than (3b), in which an inanimate NP '*taxi-DAT*' allows only for the structure in (2b) (see also Hirose & Inoue, 1998). Mazuka and Itoh (1995) suggest that as the number of constituents that are reanalysed as belonging to a different clause than the relative clause increases, such a structure is not preferred.

(1) a. Yoko-ga kodomo-o koosaten-de mikaketa
Yoko-NOM child-ACC intersection-LOC saw
'Yoko saw a child at the intersection'
b. Yoko-ga kodomo-o koosaten-de mikaketa onnanoko-ni ...
Yoko-NOM child-ACC intersection-LOC saw girl-DAT

(2) a. [Yoko-ga [[S-gap$_i$ kodomo-o koosaten-de mikaketa] onnanoko$_i$-ni] (V)]
Yoko-NOM child-ACC intersection-LOC saw girl-DAT
'Yoko (V) the girl who saw a child at the intersection.'
b. [Yoko$_i$-ga [kodomo-o [S-gap$_{i/j/k}$ O-gap$_{i/j/k}$ koosaten-de mikaketa] onnanoko$_j$-ni] (V)]
Yoko-NOM child-ACC intersection-LOC saw girl-DAT
'Yoko$_i$ (V) the child on/to the girl {who she$_i$/someone saw} at the intersection.'
'Yoko$_i$ (V) the child on/to the girl {who saw her$_i$/someone} at the intersection.'

(3) a. [Yoko-ga [[S-gap$_i$ kodomo-o koosaten-de mikaketa] onnnanokoni$_i$-ni] koe-o kaketa.]
Yoko-NOM child-ACC intersection-LOC saw girl-DAT called.
'Yoko called the girl who saw a child at the intersection.'
b. [Yoko$_i$-ga [kodomo-o [S-gap$_i$ O-gap$_j$ koosaten-de mikaketa] takushii$_j$-ni] noseta.]
Yoko-NOM child-ACC intersection-LOC saw taxi-DAT put.in
'Yoko$_i$ put the child in the taxi that she$_i$ saw at the intersection.'

Minimal Revision

Mazuka and Itoh's (1995) observation can be accounted for by the Minimal Revisions Principle (MRP), as stated in (4). This principle requires the parser to maintain an initial analysis to the extent possible. Accordingly, this principle successfully predicts that the parser

should select the structure in (2a), in which only the nominative subject belongs to a different clause than other constituents after revising an initial structure (see also Sturt & Crocker, 1996 for a different proposal).

(4) Minimal Revisions (MR): Do not make an unnecessary revision. When revision is necessary, make the minimal revision consistent with the error signal and maintain as much of the already assigned structure and interpretation as possible.

Minimum Maximal-Projection Principle

Oishi (2007) identified several problems with the MRP. First, although this principle stipulates what structure the parser should select, it does not stipulate *how* the parser does so. Under this principle, the parser might compute all possible structures and choose the best structure in accordance with the principle, but this is unlikely in terms of the limitation of cognitive resources (Oishi, 2007: 33). Second, it is not clear how to analyse a syntactic structure when the error signal is encountered *before* completion of an initial analysis (i.e., simple clause) (Oishi, 2007: 34–35). In (5), a simple clause analysis is semantically incongruent after reading a verb, signalling that this analysis is unlikely. Thus, the parser has to posit a gap inside the relative clause with or without '*secretary-dat*', as shown in (6). According to Oishi (2007), the MP principle cannot make an explicit prediction with respect to which structure the parser builds in the case of (5).

(5) ? daijin-ga hisho-ni atsumatta
minister-NOM secretary-DAT gathered
Lit. 'The minister gathered at the secretary.'

(6) a. daijin-ga [S-gap$_i$ hisho-ni atsumatta] NP$_i$ ...
minister-NOM secretary-DAT gathered
b. daijin-ga hisho-ni [S-gap$_i$ atsumatta] NP$_i$ ...
minister-NOM secretary-DAT gathered

Oishi (2007) proposed an alternative principle that he referred to as the Minimum Maximal-Projection Principle (MMPP), as defined in (7), to solve the problems of the MRP. In the case of (2), the MMPP expects that the parser will select the structure in (2a) because (2a) has fewer gaps than (2b) in the relative clause. Furthermore, since it does not require the parser to maintain an initial analysis, this principle may potentially explain structural ambiguity resolution preferences, such as in the case of (5), wherein the verb induces a reanalysis process even before completion of a simple clause analysis. The MMPP predicts that the parser will prefer (6b) to (6a) because the number of nodes in the relative clause is fewer in (6b) than (6a) while the number of gaps is the same between (6a) than (6b). [2]

(7) Minimum Maximal-Projection Principle (MMPP):
When an error signal is encountered, construct the minimum maximal-projection that has the fewest number of nodes among those that can dominate the error signal and can be attached into the existing structure in a legitimate way such that grammatical rules are not violated. Fill each argument position in the minimum maximal-projection with an overt element if possible. (Oishi, Yasunaga, & Sakamoto, 2007)

Oishi (2007) conducted a self-paced reading experiment to test the MMPP using four types of sentences in (8), in which animacy of the dative object (animate vs. inanimate) and type of matrix verb (ditransitive vs. monotransitive) were crossed. (The error signals were underlined.)

(8) a. Animate/ditransitive:

akumyoodakai	daijin-ga	jitoo-no	hisho-ni	atsumatta	uragane-o	azuketa.
notorious	minister-NOM	own.party-GEN	secretary-DAT	gathered	bribe-ACC	entrusted

'The notorious minister entrusted the bribe that was disbursed to the secretary of his own party.'

b. Animate/monotransitive:

akumyoodakai	daijin-ga	jitoo-no	hisho-ni	atsumatta	uragane-o	nusunda.
notorious	minister-NOM	own.party-GEN	secretary-DAT	gathered	bribe-ACC	stole.

'The notorious minister stole the bribe that was disbursed to the secretary of his own party.'

c. Inanimate/ditransitive:

akumyoodakai	daijin-ga	jitoo-no	honbu-ni	atsumatta	uragane-o	azuketa.
notorious	minister-NOM	own.party-GEN	headquarters-DAT	gathered	bribe-ACC	entrusted

'The notorious minister entrusted the bribe that was disbursed to the headquarters of his own party.'

d. Inanimate/monotransitive:

akumyoodakai	daijin-ga	jitoo-no	hisho-ni	atsumatta	uragane-o	nusunda.
notorious	minister-NOM	own.party-GEN	headquarters-DAT	gathered	bribe-ACC	stole.

'The notorious minister stole the bribe that was disbursed to the headquarters of his own party.'

If the parser follows the MRP, it should build a monotransitive structure including an accusative object with a relative clause (i.e., [the bribe that was disbursed to the secretary/headquarters of his own party]) after encountering an error signal because this structure allows it to maintain an initial analysis of '*secretary/headquarters-DAT*' as an NP co-occurring within the same clause as the verb '*gathered*'. Thus, this principle predicts a longer reading time for the ditransitive condition than the monotransitive condition, reflecting a second reanalysis

2. One may think that MMPP should predict a preference for (6a) because the dative NP position is occupied by the overt phrase '*secretary-DAT*' in (6a) but not in (6b). Thus, the second condition of MMPP ('*Fill each argument position in the minimum maximal-projection with an overt element if possible*') forces the parser to select a structure in (6a). However, Oishi (2007) assumes that the dative NP phrase is an adjunct and that there is no gap for this adjunct when '*secretary-DAT*' is interpreted outside of the relative clause.

cost. [3] On the other hand, the MMPP offers an opposite prediction regarding a processing asymmetry between the monotransitive and ditransitive verbs. This principle predicts that the monotransitive verb should incur a larger processing cost than the ditransitive verb because the ditransitive structure with fewer nodes inside the relative clause should be selected when encountering an error signal. The result of the self-paced reading experiment showed a longer reading time for the monotransitive verb than the ditransitive verb, irrespective of the input timing of the error signal (i.e., the manipulation of animacy), thus supporting the MMPP. [4]

To summarise, two principles have been proposed to account for ambiguity resolution preference in reanalysis, namely, the MRP and the MMPP. The MMPP has been borne out by Oishi's (2007) observation that the parser has a strategy for analysing a dative NP as a constituent outside the relative clause rather than inside the relative clause.

The present study aims to test the MMPP using transitive sentences wherein the thematic relationship between co-arguments differs from that of intransitive sentences in the initial analysis. In Oishi's (2007) experiment, the parser has two options as to the position of a left clause boundary of the relative clause, as indicated by '[' in (9) below. As discussed above, Oishi (2007) showed that the parser selects the second boundary immediately before the verb upon encountering an error signal. Although Oishi (2007) explained this result by proposing the MMPP, it might be accounted for by a preference for not abandoning a close relationship between the nominative subject '*minister-NOM*' and the dative object '*headquarters-DAT*', which are initially analysed as the THEME and GOAL of 'gathered *vi*', respectively. [5] In other words, the parser initially interprets this sentence as '*The minister(s) move to the headquarters*' and later reanalyses as '*The minister(s) move to the headquarters with the bribe*', expecting a verb such as '*hakonda*' (brought) to avoid abandoning a relationship between the THEME '*minister*' and the GOAL '*headquarters*'. If this possibility is on the right track, we expect a different preference in the transitive sentence, such as that exemplified in (10). The parser should initially analyse this sentence as '*The minister causes the bribe to move to the headquarters*' before encountering an error signal. In other words, '*headquarters-DAT*' is a GOAL and '*bribe-ACC*' is a THEME of the first verb. If the parser prefers to maintain the clause-mate relationship between a THEME phrase and a GOAL phrase even after reanalysis, it should insert a left clause boundary at the second position rather than the third position to include the GOAL phrase '*headquarters-DAT*' inside the relative clause. This prediction is the same as

3. At the end of a sentence, there are two possible ways to revise a monotransitive structure into a ditransitive one. The parser can posit a *pro* in the GOAL position of '*entrusted*'. Alternatively, the parser can reanalyse the dative NP '*secretary/headquarters-DAT*' as a GOAL of '*entrusted*'. In the latter case, however, the parser has to abandon a structural relationship between the dative NP and the first verb, and thus this revision is less likely under the MRP.
4. Oishi (2007: 43) reported no significant effect of ANIMACY at the fifth region (i.e., the verb of the relative clause) or the sixth phrase (i.e., the head noun of the relative clause) (see Oishi, 2007: 44 and Experiment 2 for discussion).
5. Here, we assume that the subject of '*atsumatta*' (gathered *vi*) is a THEME argument because the subject of this verb can be inanimate, as shown in (i).
   (i) uragane-ga honbu-ni atsumatta.
   bribe-nom headquarters-dat gathered.
   'The bribe was disbursed to the headquarters.'

that predicted by the MRP. In contrast, the MMPP predicts that the parser should adopt the third clause boundary by taking '*headquarters-DAT*' out of the clause with '*bribe-ACC*' to make the maximal projection as small as possible. We conducted two behavioural experiments using similar sentences as in (10), where our hypothesis/MRP and the MMPP offer different predictions.

(9) Oishi (2007):

daijin-ga	[honbu-ni	[atsumatta	uragane-o ...	
minister-NOM	headquarters-DAT	gathered $_{vi}$	bribe-ACC	

(10) [daijin-ga [honbu-ni [uragane-o atsumeta hisho-o ...

minister-NOM	headquarters-DAT	bribe-ACC	gathered $_{vt}$	secretary-ACC

Experiment 1

The purpose of this experiment is to examine the parser's preference in resolving structural ambiguity during the process of reanalysis using a self-paced reading task. Specifically, we examined whether the MRP and MMPP correctly predict a GP effect induced by the parser's prior disambiguation process.

Stimuli

We created four types of experimental sentences, such as those listed in (11), in which the presence of GP (GP/non-GP) and VERB type (monotransitive/ditransitive) were manipulated. The GP conditions comprised six phrases, whereas the non-GP conditions consisted of four phrases. In the fifth region of the GP conditions, the parser was required to revise a structure to incorporate a (head) noun into an existing structure. The region of interest in this experiment centred on the matrix verbs at the end of a sentence (underlined), which were matched between monotransitive and ditransitive verbs on the number of characters (t (18) = 0.001, $p > 0.10$), the number of morae (t (18) = 0.22, $p > 0.10$), and auditory/visual word familiarity taken from the Lexical Properties of Japanese database (Amano & Kondo, 1999) (t (18) = 0.24, $p > 0.10$).

(11) a. GP/monotransitive:

geinin-ga	gakuya-ni	keeki-o	sashiireshita	fan-o	hometa.
comedian-NOM	room-DAT	cake-ACC	brought	fan-ACC	praised.

'The comedian praised the fan who brought a cake to the dressing room.'

b. GP/ditransitive:

geinin-ga	gakuya-ni	keeki-o	sashiireshita	fan-o	maneita.
comedian-NOM	room-DAT	cake-ACC	brought	fan-ACC	invited.

'The comedian invited the fan who brought a cake to the dressing room.'

c. non-GP/monotransitive:

shishoo-ga kinoo deshi-o hometa.
professor-NOM yesterday pupil-ACC praised.
'The professor praised a pupil yesterday.'

d. non-GP/ditransitive:
sensei-ga shogakkoo-ni hogosha-o maneita.
teacher-NOM E.S-DAT parents-ACC invited.
'The teacher invited parents to the elementary school.'

A total of 60 sets of experimental sentences were distributed into two lists following the Latin square method so that participants saw either a monotransitive or ditransitive verb in each GP condition. The lists were counterbalanced among the participants.

Each sentence was presented in a phrase-by-phrase, non-cumulative manner. Participants were asked to read a sentence phrase by phrase at a natural speed by pressing a space key. To ensure that our participants were paying enough attention to the reading task, a yes-no comprehension question was given following half of the trials of the GP conditions. Prior to the experiment, eight practice trials were given to familiarise the participants with the self-paced reading task. The experimental sentences were presented in a random order using LinguaTools.

Participants

Twenty native speakers of Japanese from Kyushu University participated in the experiment (four males and 16 females, mean age = 21.4 years, range: 20–23). All participants had normal or corrected-to-normal vision and no history of reading disability or neurological or mental disorder. Written informed consent was obtained from all participants prior to the experiment, and they were paid for their participation.

Data analysis

We analysed only the trials in which the comprehension question was answered correctly. Reading time data exceeding 2.5 standard deviations from a participant's mean at each region were discarded. Statistical analysis was conducted using linear mixed-effects (LME) models fitted with the *lmer* function of the *lme4* package in R (Bates, Maechler, Bolker, & Walker, 2015). The models included the independent variables of interest (i.e., GP and VERB) as fixed factors. Each experimental condition was coded such that the GP and non-GP conditions were assigned −0.5 and 0.5, respectively. Similarly, the monotransitive and ditransitive conditions were assigned values of −0.5 and 0.5, respectively. The participants and items were treated as random factors. The maximal model was built, as shown in (12) below, and then a final model was selected using the backward stepwise method by comparing models using the *anova* function of the *lme4* package. *P*-values were calculated by submitting the final model to the *lmer* function of the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2015). An interaction of GP by VERB was decomposed by conducting separate analyses at each GP type.

(12) Model = lmer (RT ~ GP * VERB + (1 + GP * VERB | Subj) + (1 + GP * VERB | Set) + TrialOrder, data = data)

Prediction

Assuming that our participants prefer a simple sentence analysis upon reaching the first verb (i.e., '*brought*') in the GP condition, they have to revise this analysis to build a structure in (13a) or (13b) after encountering the head noun of the relative clause (i.e., '*fan-ACC*').

(13) a. [[comedian-NOM] [gap_1 room-DAT cake-ACC brought fan-ACC_1] ...]
b. [[comedian-NOM] [room-DAT] [gap_1 cake-ACC brought fan-ACC_1] ...]

The MMPP requires the parser to build a maximal projection headed by an error signal (i.e., '*fan-ACC*') with the fewest nodes upon encountering the error signal. Accordingly, this principle predicts that the parser would select (13b), in which the error single ('*fan-*ACC') does not include a dative phrase (i.e., '*room-DAT*') in the relative clause. [6] The structure in (13b) is compatible with a ditransitive verb, such as '*invited*', but not with a monotransitive verb, such as '*praised*'. Therefore, the MMPP predicts a longer reading time at the matrix verb for the GP/monotransitive condition compared to the GP/ditransitive condition, reflecting a second structural reanalysis.

On the other hand, the MRP proposes that the parser holds an existing structure as much as possible to incorporate an error signal into it. Accordingly, (13a) should be constructed based on this principle. A monotransitive verb such as '*praised*' can complete this existing structure in a legitimate way. In contrast, a ditransitive verb requires the parser to revise an disambiguated structure again by positing an empty category at the dative NP position or by reanalysing '*room-DAT*' as a GOAL of the matrix verb '*invited*'. Consequently, the ditransitive verb should incur a longer reading time than the monotransitive verb in the GP condition if the parser adopts the MRP.

The difference between the monotransitive and ditransitive verb in the non-GP conditions was not predicted by the MMPP or MRP. In other words, only the interaction between GP and VERB was of interest to test these two hypotheses.

Results

Figure 1 shows mean reading times at each region, and Figure 2 shows mean reading times at the matrix verb (i.e., the sixth region in the GP conditions and the fourth region in the non-GP conditions). The linear mixed-effects model of reading times at the verb region showed a marginally significant effect of GP due to a longer time for the GP condition than the non-GP condition (Table 1). The interaction did not reach significance, although the reading time of the GP/ditransitive condition was numerically longer than that of the GP/monotransitive condition.

6. Following Oishi (2007), we do not posit a gap for the GOAL phrase.

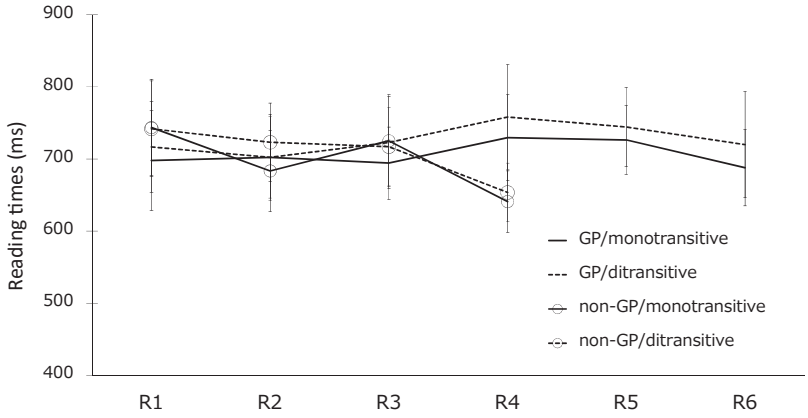


Figure 1. Mean reading times at each region. Error bars indicate standard errors.

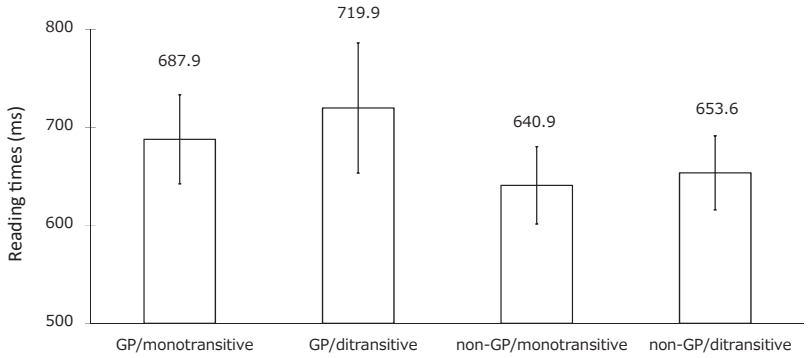


Figure 2. Mean reading times (ms) at the verb region. Error bars indicate standard errors.

Table 1. Summary of the fixed effects in the linear mixed-effects (LME) model of reading times at the verb region.

	Estimate	*SE*	*t*	*p*
Intercept	757.35	50.9	14.87	< 0.01
GP	−59.95	30.87	−1.95	0.06 +
Verb	18.73	15.77	1.18	0.24
GP × Verb	−16.23	36.49	−0.45	0.66
ItemOrder	−1.34	0.12	−10.73	< 0.01 **

For the comprehension question task, the effect of VERB was marginally significant in the response times and significant in accuracy (Figure 3 and Table 2). [7] This result showed that

7. As noted above, the comprehension questions were given only for the GP conditions. Hence, the effect of interest was only an effect of VERB in the comprehension question task. The length (the number of morae) was matched between the GP/monotransitive and GP/ditransitive conditions (t (62) = −0.28, p > 0.10).

the participants took more time to answer a comprehension question and that their answers were less accurate in the GP/ditransitive condition than in the GP/monotransitive condition.

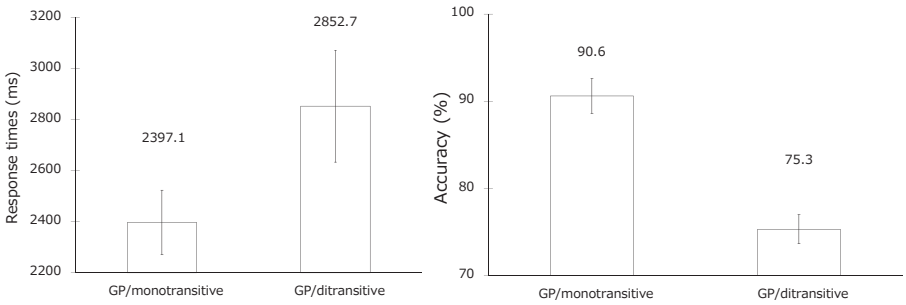


Figure 3. Mean response times (left) and accuracy (right) in the comprehension question task. Error bars indicate standard errors.

Table 2. Summary of the fixed effects in the linear mixed-effects (LME) model of response times (left) and accuracy (right) in the comprehension question task.

	Estimate	*SE*	*t*	*p*	
Intercept	2829.77	203.41	13.91	< 0.01	
Verb	374.49	196.13	1.90	0.06	+
ItemOrder	−4.65	1.60	−2.89	< 0.01	**

	Estimate	*SE*	*z*	*p*	
Intercept	2.23	0.30	7.30	< 0.01	
Verb	−1.37	0.24	−5.50	< 0.01	**

Discussion

In Experiment 1, we failed to find an interaction of GP by VERB at the verb region, which was not predicted by the MMPP or the MRP. Since our critical region was at the end of a sentence, the lack of interaction may be due to a delayed effect of processing cost, which has often been observed in the self-paced reading task. In other words, the processing cost may increase after participants finished reading a sentence, and thus, we could not measure it successfully. In Experiment 2, we tested our prediction using a different task to avoid the delayed effect.

Experiment 2

Experiment 2 employed a speeded yes-no acceptability judgement task to detect processing costs at the end of a sentence. This task required participants to judge the acceptability of a sentence as quickly as possible. We assume that when participants need to reanalyse a syntactic structure upon encountering a matrix verb, they should experience a processing difficulty, and their responses should be delayed accordingly. Thus, by using response times as an index of reanalysis cost, we can assess the syntactic structure into which participants disambiguate a temporally ambiguous structure.

Stimuli

The same stimuli used in Experiment 1 were employed for the target sentences (i.e., YES responses). A total of 60 unacceptable sentences for NO responses were added into each list. Unacceptable sentences included case-assignment violation or semantic anomaly between a verb and its argument. Half of the filler sentences consisted of six phrases including a relative clause, and the other half consisted of four phrases without a relative clause. The lists were counterbalanced among the participants.

After a fixation was presented for 700 ms, each phrase was presented at the centre of the screen for 700 ms with an inter-stimulus interval of 100 ms. The participants were instructed to judge the acceptability of a sentence and press YES (acceptable) or NO (unacceptable) buttons as soon as possible after the matrix verb and a period appeared. [8] After every five trials in the GP condition, a comprehension question was given to check whether the participants could understand the sentences correctly. The experimental sentences were presented in a random order using Presentation 16.5 (Neurobehavioral Systems).

Participants

Sixteen native speakers of Japanese were recruited from Kyushu University (11 males and five females, mean age = 21.5 years, range: 20–24). All participants had normal or corrected-to-normal vision and no history of reading disability or neurological or mental disorder. Written informed consent was obtained from all participants prior to the experiment, and they were paid for their participation.

Prediction

According to the MMPP, a temporarily ambiguous structure should be disambiguated into the ditransitive structure with the fewest nodes inside of the relative clause headed by the error signal. Hence, this principle predicts a longer response time for the GP/monotransitive condition than for the GP/ditransitive condition. On the other hand, the MRP offers the opposite prediction. If the parser follows this strategy, it should not reanalyse a dative NP ('*room-DAT*') and an accusative NP ('*cake-ACC*') belonging to a different clause at the head noun since this principle requires the parser to maintain as much of the existing structure as possible when required to revise a structure (see (13)).

Results

The statistical analyses were conducted in the same way as in Experiment 1. Figures 4 and 5 show the mean response times and accuracy in the acceptability judgement task, respectively. The result showed a significant interaction of GP by VERB on response times (Table 3). The planned comparison revealed a significant effect of VERB in the GP condition (β = 140.7, SE = 52.79, t = 2.66, p = 0.01) but not in the non-GP condition (β = −3.30,

8. In every type of sentence used in Experiment 2, a yes-no response was possible only after reading a matrix verb. The response time refers to duration (ms) from the onset of the matrix verb to the response.

SE = 37.76, *t* = −0.09, *p* = 0.93). This result indicates that participants experienced greater processing difficulty in the GP/ditransitive condition than in the GP/monotransitive condition. The interaction was also significant for accuracy of the acceptability judgement (β = 1.73, *SE* = 0.54, *z* = 3.18, *p* < 0.01). Again, the planned comparison found a significant effect of VERB only in the GP condition (GP: β = −1.24, *SE* = 0.30, *z* = −4.11, *p* < 0.01; non-GP: β = 0.51, *SE* = 0.46, *z* = 1.1, *p* = 0.26).

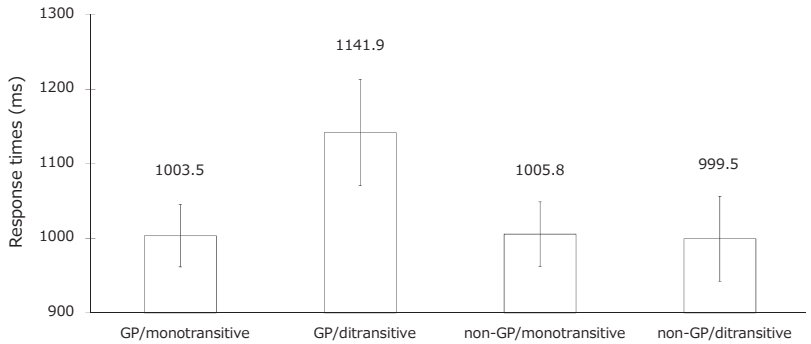


Figure 4. Mean response times in the acceptability judgement task. Error bars indicate standard errors.

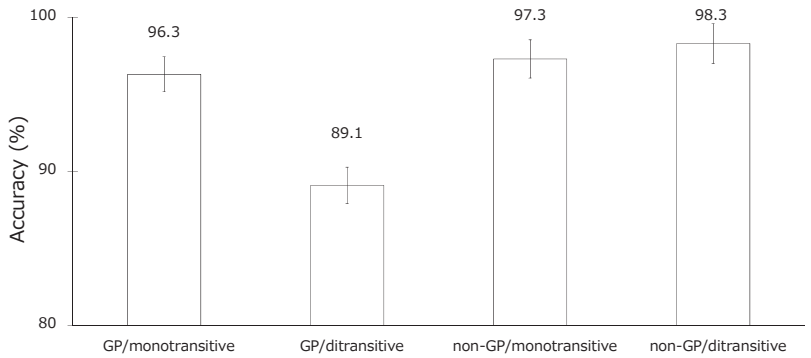


Figure 5. Mean accuracy in the acceptability judgement task. Error bars indicate standard errors.

Table 3. Summary of the fixed effects in the linear mixed-effects (LME) model of response times in the acceptability judgement task.

	Estimate	*SE*	*t*	*p*
Intercept	1188.86	50.28	23.64	< 0.01
GP	−68.32	37.25	−1.84	0.08 +
Verb	69.27	42.01	1.64	0.11
GP × Verb	−144.16	37.36	−3.86	< 0.01 **
ItemOrder	−1.64	0.18	−8.90	< 0.01 **

We also compared response times and accuracy in the comprehension question task between the GP/monotransitive and GP/ditransitive conditions (Figure 6). The effect of VERB did not reach significance in the response time data, whereas the response was significantly more accurate in the GP/monotransitive condition than in the GP/ditransitive condition (Table 4). This result indicates that our participants computed their final interpretation of the GP/ditransitive sentence less accurately at the end of a sentence.

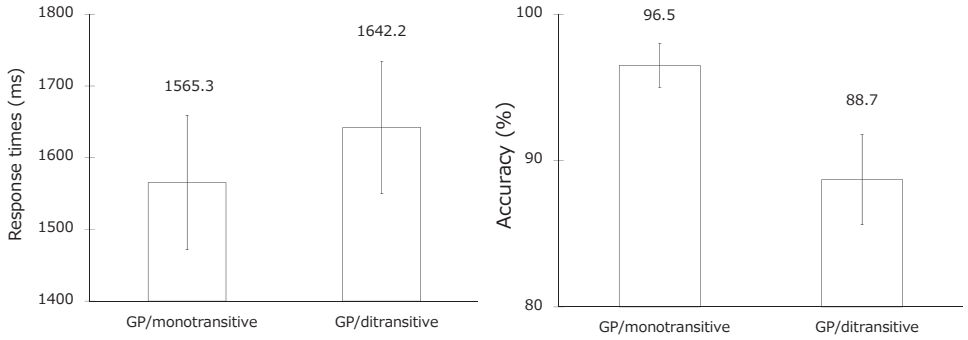


Figure 6. Mean response times (left) and accuracy (right) in the comprehension question task. Error bars indicate standard errors.

Table 4. Summary of the fixed effects in the linear mixed-effects (LME) model of response times (left) and accuracy (right) in the comprehension question task.

	Estimate	*SE*	*t*	*p*
Intercept	1852.18	117.35	15.78	< 0.01
Verb	59.58	64.14	0.92	0.35
ItemOrder	−14.91	3.75	−3.97	< 0.01 **

	Estimate	*SE*	*z*	*p*
Intercept	2.14	0.3	6.92	< 0.01
Verb	−1.11	0.28	−3.82	< 0.01 **

Discussion

The result of the speeded acceptability judgement task revealed a longer response time for the GP/ditransitive condition than for the GP/monotransitive condition. This increased response time for the GP/ditransitive verb should not reflect lexical differences of verbs, such as lexical frequency and familiarity that are known to modulate lexical access costs, because there was no difference between the non-GP/ditransitive and non-GP/monotransitive conditions. The accuracy in the GP/ditransitive condition was lower than that in the other three conditions. These results indicate that the participants faced processing difficulty when reading a ditransitive verb in the GP condition, suggesting a second reanalysis cost in this condition. In other words, this result indicates that when reading an unexpected head noun, the parser disambiguated a temporally ambiguous structure into a monotransitive structure, such as in (14a) below, rather than a ditransitive structure, as in (14b). This finding is in favour of the prediction based on the MRP. This principle predicts that the participants did not need to revise a structure again when reading monotransitive verbs, such as '*praised*', since

(14a) is compatible with it. However, a ditransitive verb such as '*invited*' forced participants to reanalyse '*room-DAT*' as a GOAL argument or posit a GOAL that was not mentioned in the sentence. Thus, this principle successfully predicts a higher processing cost for the GP/ditransitive condition, which is consistent with our results. In contrast, if the parser disambiguated an ambiguous structure into the ditransitive one in (14b), as expected by the MMPP, the parser would have needed to reanalyse '*room-DAT*' as a constituent inside the relative clause when reading a monotransitive verb, as the monotransitive verb cannot take three arguments ('*comedian-NOM*', '*room-DAT*', and '*fan-ACC*'). Accordingly, the monotransitive verb should have incurred a higher processing load than the ditransitive condition. Because this expectation is contrary to the processing asymmetry of the monotransitive and ditransitive verbs in Experiment 2, this principle cannot offer a plausible explanation for our results.

(14) a. [[comedian-NOM] [gap_1 room-DAT cake-ACC brought fan-ACC_1] ...]
b. [[comedian-NOM] [room-DAT] [gap_1 cake-ACC brought fan-ACC_1] ...]

General Discussion

The purpose of this study was to explore an ambiguity resolution mechanism in the process of reanalysis by testing the MRP and the MMPP. The result of the self-paced reading experiment neither supported the MRP nor the MMPP due to the lack of a significant effect at the sentence-final matrix verb region. This may be due to a delayed effect of the processing cost induced by the matrix verb. However, the response times for the comprehension question gave us a hint as to the disambiguation preference for the monotransitive structure over the ditransitive one. In Experiment 2, we performed a speeded yes-no acceptability judgement experiment to avoid a delayed effect and measured the processing cost pertaining to a second reanalysis. The results of Experiment 2 showed a processing advantage for a monotransitive structure over a ditransitive one only when a sentence fragment could be analysed as either structure in the ambiguity resolution (i.e., GP sentences). Our evidence argues for the MRP, but not for the MMPP. [9] However, it is fair to say that the MMPP can account for the result obtained by Oishi (2007), but the MRP cannot. To summarise, the MRP cannot account for the result of Oishi's (2007), whereas the MMPP cannot account for the result of Experiment 2 of the present study. We propose a new account below that correctly predicts a disambiguation preference in the present and previous experiments.

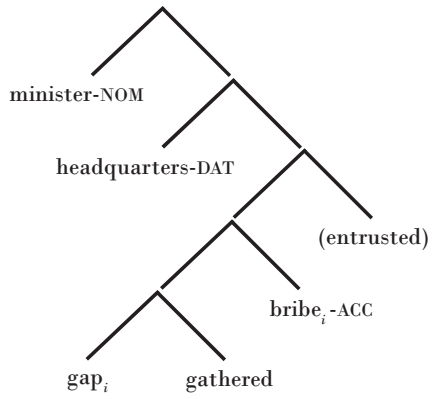
Here, we summarise relevant empirical data obtained from Oishi (2007) and the present study before going to the details of the new account. (15a) shows an initial analysis of a sentence before facing the first GP effect. (15b) and (15c) show available disambiguated structures in which (15b) is compatible with a ditransitive verb and (15c) is compatible with a monotransitive verb. According to Oishi (2007), the monotransitive verb incurred a larger processing cost than the ditransitive verb, suggesting that the parser selected the structure in

(15b). This structure includes fewer nodes within the relative clause headed by an error signal of '*bribe-ACC*' in comparison to the one in (15c). Therefore, his result supported the MMPP.

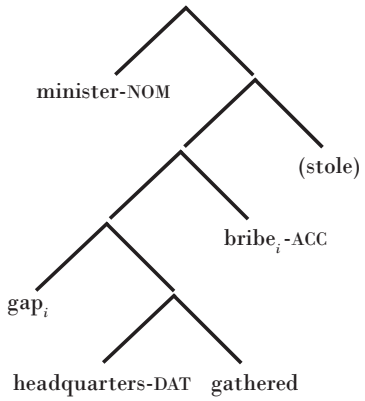
(15) Oishi (2007):

a. daijin-ga honbu-ni atsumatta
minister-NOM headquarters-DAT gathered
'The minister(s) gathered at the headquarters'

b.



c.



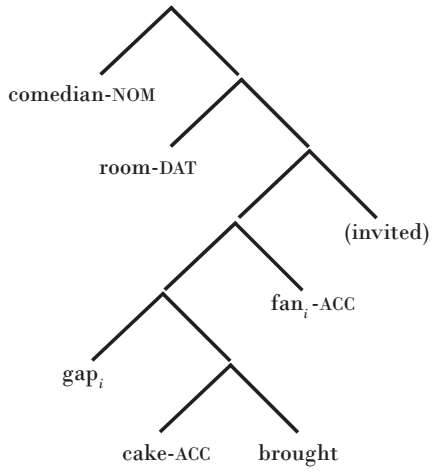
The example (16a) shows an initial analysis of the GP sentence used in Experiments 1 and 2. The examples (16b) and (16c) show ditransitive and monotransitive structures, respectively. The MMPP predicts that (16b) should be selected out of these two options for the same reason mentioned above. However, our findings suggest that the parser built the structure in (16c), evidenced by the longer response times and less accurate responses for the ditransitive verb than for the monotransitive verb. To summarise, the Japanese parser builds a ditransitive structure when encountering an error signal preceded by an intransitive verb, whereas it constructs a monotransitive structure when encountering an error signal preceded by a transitive verb.

9. One might think that if a dative GOAL phrase is analysed as an argument rather than an adjunct of '*brought*', the MMPP successfully predicts a GP effect in the present study, since this principle states that the parser needs to fill an argument position with an overt constituent if possible. Thus, the dative phrase '*room-DAT*' should be located inside the relative clause. However, if this view is correct, it is not obvious why the dative GOAL phrase '*headquarters-DAT*' should be analysed as a constituent *outside* of the relative clause with '*gathered vi*', which is also supposed to take a GOAL argument in Oishi's (2007) experiment. Since the argument/adjunct distinction is not clear-cut, this issue awaits further investigation.

(16) Experiments 1 and 2

a. geinin-ga gakuya-ni keeki-o sashiireshita
comedian-NOM room-DAT cake-ACC brought
'The comedian brought the cake to the dressing room'

b.



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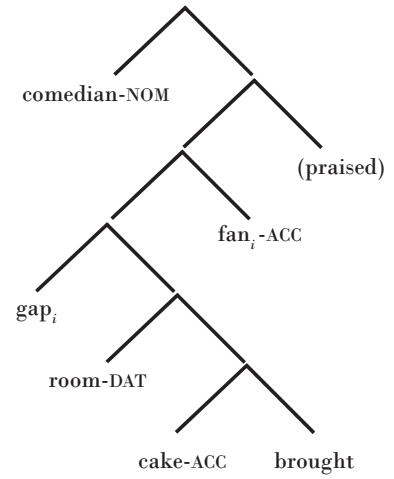
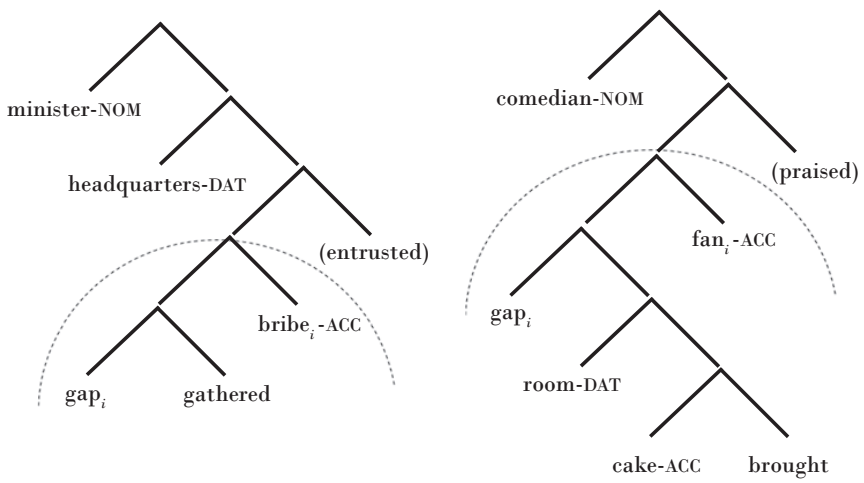


As shown in (17) below, the common feature of the disambiguated structure in Oishi's (2007) study and the present experiment is that the initially analysed clause-mate relationship between a THEME phrase and a GOAL phrase holds even after incorporating an error signal into an initial structure. In the case of Oishi's (2007) experiment, '*minister-NOM*' and '*headquarters-DAT*' are analysed as clause-mate constituents belonging to the matrix clause. On the other hand, the parser analyses '*room-DAT*' as a constituent inside of the relative clause to maintain the clause-mate relationship with the following '*cake-ACC*'. Therefore, when required to revise a syntactic structure of a sentence, the Japanese parser favours positing NPs that are initially analysed as the THEME and GOAL as clause-mate constituents governed by the same verb. This hypothesis can correctly predict a GP effect in both Oishi's (2007) experiment and the present research.

(17)



Conclusion

We investigated structural preference pertaining to ambiguity resolution in the process of reanalysis during Japanese sentence comprehension through self-paced reading and speeded yes-no acceptability judgement experiments. Our findings favour the Minimal Revision Principle, which assumes that the parser should avoid unnecessary structural analysis to the extent possible. In contrast, our evidence is not consistent with the Minimum Maximal-Projection Principle, which posits that the parser builds the smallest maximal projection headed by an error signal. We proposed a new account following the spirit of the MRP to provide a consistent explanation for the present and previous experiments. That is, the Japanese parser prefers to maintain an initial analysis of THEME and GOAL phrases as being constituents of the same clause upon encountering an error signal (i.e., head noun).

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References

Amano, S., & Kondo, T. (Eds.). (1999). Nihongo-no goitokusei [Lexical Properties of Japanese]. NTT Communication Science Laboratories, Sanseido, Tokyo: Japan.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-8.

Bever, T. G. (1970). The cognitive basis for linguistic structures. In J. R. Hayes (Ed.), *Cognition and the Development of Language*, 279–362, New York: Wiley & Sons.

Ferreira, F., & Clifton, C., Jr. (1986). The independence of syntactic processing. *Journal of Memory and Language*, *25*(3), 348–368.

Frazier, L. (1979). On comprehending sentences: syntactic parsing strategies. *Doctoral Dissertation*, University of Massachusetts.

Frazier, L., & Clifton, C., Jr. (1998). Sentence Reanalysis, and Visibility. In J. D. Fodor, & F. Ferreira (Eds.), Reanalysis in sentence processing, Dordrecht, The Netherlands: *Kluwer Academic Publishers*, 143–176.

Frazier, L., & Fodor, J. D. (1978). A sausage machine: A new two-stage parsing model. *Cognition*, *6*(4), 291–325.

Hirose, Y., & Inoue, A. (1998). Ambiguity of reanalysis in parsing complex sentences in Japanese. *Syntax and semantics, 31*, 71-93.

Inoue, M. (2006). Nihongobun-no rikai-niokeru aimaisei-no kaisho-to horyuu [Ambiguity resolution and retention in Japanese sentence comprehension]. *Cognitive Studies*, *13*(3), 353–368.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2015). lmerTest: Tests in linear mixed effects models. R package version 2.0-29.

Mazuka, R., & Itoh, K. (1995). Can Japanese speakers be led down the garden-path? In R. Mazuka, & N. Nagai (Eds.) Hillsdale, NJ: Lawrence Erlbaum, *Japanese sentence processing,* 295–329.

Oishi, H. (2007). Saibunseki-niokeru ichijitekiaimaisei-no kaisho-katei-nituite: Tajuujoohookan-no kyoogoo-no kanoosei [On temporal ambiguity resolution process in reanalysis: Possibility of competition between multiple (sources of) information]. *Doctoral Dissertation*, Kyushu University.

Oishi, H., Yasunaga, D., & Sakamoto, T. (2007). Revision process in Japanese sentence processing: Evidence from event-related brain potentials. In T. Sakamoto (Ed.), *Communicating Skills of Intention*, 367–381, Tokyo: Hitsuji Syobo.

Sturt, P., & Crocker, M. W. (1996). Monotonic syntactic processing: A cross-linguistic study of attachment and reanalysis. *Language and Cognitive Processes*, *11*(5), 449–494.

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