The Interaction of Morphosyntactic and Semantic Processing in Japanese Sentence Comprehension: Evidence from Event-Related Brain Potentials

Masataka Yano

Kyushu University/
JSPS Research Fellow

Tsutomu Sakamoto

Kyushu University

Abstract: The present study examined event-related brain potential (ERP) responses to apparent Case-assignment violations to explore how morphosyntactic and semantic processing interact with each other during Japanese sentence comprehension. Consistent with previous studies on Case-assignment violation, the present results found that a Case-assignment violation elicited a left anterior negativity (LAN), followed by a posterior P600 compared with its grammatical counterpart. Crucially, the LAN-P600 effects were also elicited by a morphosyntactically well-formed sentence with a thematic implausible argument that may potentially force the sentence processor to perceive an apparent Case-assignment violation. Provided that the LAN effects can be interpreted as a morphosyntactic violation effect, these findings suggest that the morphosyntactic and semantic processing streams operate at least partially in parallel during sentence comprehension and that they begin to interact with one another at approximately 400 ms (at the latest) after encountering a verb.*

Key words: Japanese, Psycholinguistics, Sentence Comprehension, Event-Related Brain Potentials (ERPs), Left Anterior Negativity (LAN)

1. Introduction

Sentence comprehension involves various informational processes, such as syntactic, semantic, morphological, and pragmatic processes. Psycholinguists have been researching how and when such information is processed and interacts in real-time sentence comprehension. One of the core assumptions in traditional sentence comprehension models is that syntactic processing guides sentence processing. For example, in the syntax-first model, the parser initially builds a syntactic structure for the sequence based on (morpho)syntactic information (Ferreira and Clifton,

1986; Frazier, 1979, 1987; Friederici, 1995, 2002). In the latter stage, the processor constructs a semantic representation based on the output of the syntactic processing.

However, recent event-related potentials (ERP) evidence seemingly contradicts the traditional core assumption that the semantic processor computes an analysis that is consistent with syntactic phrase structures. A growing number of studies have repeatedly observed that the thematic plausibility of arguments has an influence on syntactic analysis (i.e., the semantic P600 phenomenon). This observation has led some researchers to propose the multi-stream processing model in which independent semantic processing proceeds at least partially in parallel with syntactic processing. For this model, the semantic processor can compute a semantically plausible interpretation, even when it contradicts unambiguous syntactic information and overwhelms the syntactic analysis in some circumstances. However, there is also controversy with regard to the interpretation of the semantic P600 phenomenon. Other researchers have argued that the semantic P600 phenomenon does not indicate the existence of a syntax-independent semantic processing stream (Brouwer, Fitz and Hoeks, 2012; Chow and Phillips, 2013). These studies suggest that the previous interpretation of the phenomenon is largely based on misunderstanding the functional significance of ERP components.

In this paper, first, we review major ERPs and their (traditional) functional interpretations to explain the semantic P600 phenomenon and its implication for sentence comprehension mechanisms (sections 2 and 3). Second, we aim to marshal the controversies on single- vs. multi-stream models to establish a foundation for testing their predictions (section 4). Third, we evaluate these two types of models by conducting an ERP experiment (sections 5 and 6). Section 7 concludes our study.

2. Event-related brain potentials in sentence comprehension

The N400 is an ERP component that consists of a negative deflection that peaks approximately 400 ms after the onset of every content word. Semantically anomalous words in a given context, such as in (1b), typically elicit an N400 effect compared with (1a) (Kutas and Hillyard, 1980, 1983):

(1)   a. He   spread   the   warm   bread   with   <u>butter</u>.
      b. *He   spread   the   warm   bread   with   <u>socks</u>.

The N400 effect is traditionally interpreted to reflect the semantic processing costs of integrating an anomalous word in a given context into the preceding semantic representation.

By contrast, (morpho)syntactic anomalies elicit left anterior negativity (LAN) and/or the P600 effect. The LAN effect is often observed in response to a morphosyntactic violation, such as a Case-assignment violation and a subject-verb disagreement in (2) (Coulson et al., 1998; Friederici, Pfeifer and Hahne, 1993; Friederici and Frisch, 2000; Osterhout and Mobley, 1995):

(2) a. The elected officials <u>hope</u> to succeed.
  b. *The elected officials <u>hopes</u> to succeed.

A P600 effect is an ERP component that consists of a positive deflection that peaks at approximately 600 ms. The P600 effect has been found for the syntactically anomalous sentence in (3) (Hagoort, Brown and Groothusen, 1993; Hagoort, Brown and Osterhout, 1999; Kaan and Swaab, 2003a, 2003b; Osterhout and Holcomb, 1992):

(3) a. The hungry guests helped <u>themselves</u> to the food.
  b. *The hungry guests helped <u>himself</u> to the food.

The traditional functional interpretation is that the LAN reflects a detection of morphosyntactic error, and the P600 reflects the syntactic repair process.

3. Semantic P600 phenomenon

Now, let us return to the issue of the semantic P600 phenomenon. Recent ERP evidence has shown that a syntactically well-formed but semantically anomalous word embedded in a context, such as (4b), elicits a P600 effect yet not an N400 effect (Hoeks, Stowe and Doedens, 2004; Kim and Osterhout, 2005; Kim and Sikos, 2011; Kolk et al., 2003; Kuperberg et al., 2003, 2006, 2007; van Herten, Kolk and Chwilla, 2005; see Bornkessel-Schlesewsky and Schlesewsky, 2008; Brouwer, Fitz and Hoeks, 2012; Kuperberg, 2007 for review):

(4) a. Passive Control: The hearty meal was <u>devoured</u> by the kids.
  b. Violation: *The hearty meal was <u>devouring</u> the kids.

Given the traditional assumption of the syntax-first model and the functional interpretation of the N400 and P600, this finding is unexpected for two reasons: First, according to the syntax-first model, the English parser should assign an AGENT role to '*the hearty meal*' based on information related to its syntactic position and the inflection of the verb. Because the semantic processor should subsequently detect the thematic implausibility of '*the hearty meal*' as an AGENT, the processor should judge (4b) as a *semantically* anomalous sentence. However, (4b) does not elicit an N400 effect compared with (4a) (but see Hoeks et al., 2004 for the N400-P600 pattern). The second unexpected result is that (4b) elicited a P600 effect, although it is grammatically well-formed.

To account for these two findings, some researchers have challenged the traditional sentence processing models instead of challenging the functional interpretation of ERP components. For example, Kim and Osterhout (2005) propose that the semantic combinatorial processor can compute a semantically attractive analysis even when it contradicts simple unambiguous syntactic information. Under this model, the semantic processor analyses '*the hearty meal*' as a THEME in (4b) because a meal is much more likely to be devoured than to devour. Accordingly, the sentence processor fails to detect the semantic anomaly of the sentence. Thus, the N400 is not elicited (cf. semantic illusion, Hoeks et al., 2004). In such a case

wherein the semantic attraction to the THEME interpretation is so compelling, the semantic processor overwhelms an analysis dictated by the syntactic information and forces the syntactic processor to erringly perceive a grammatically well-formed sentence as being ill-formed. This incorrect recognition of the syntactic anomaly triggers a syntactic repair process, leading to the P600 effect in (4b).

The semantic P600 phenomenon, in the case where the syntactic reanalysis of unambiguous syntactic information is triggered by thematic implausibility, is seemingly unexpected in the syntax-first model. This is because the model assumes that the syntactic processor guides sentence processing. Thus, it has been argued that this finding constitutes evidence against the model. According to Kim and Osterhout (2005), the semantic P600 effect indicates the existence of a syntax-independent semantic processing stream and that a semantic processor can challenge a syntactic analysis.

4. Counterarguments to syntax-independent semantic processing

The essential assumption of the multi-stream models is that the N400 is tied to a *semantic integration* difficulty and the P600 to a *syntactic integration* difficulty. However, accumulating ERP evidence challenges the traditional functional interpretation of the N400 and P600. The N400 is not always sensitive to semantic/pragmatic violations (e.g., Fischler et al., 1983; Urbach & Kutas, 2010). Thus, the semantic integration view of the N400 fails to account for this observation.

A number of previous studies found that the N400 is sensitive to semantic relatedness and word predictability (see Kutas and Federmeier, 2011, 2000 for review). This observation suggests that the N400 reflects the ease of lexical retrieval of a word from long-term memory. From this perspective, N400 reduction to semantically related words is attributable to the fact that lexical access to relevant lexical representation is facilitated by the preceding semantically related words that activate it to some extent via automatic spreading activation. The fact that a more predicted word attenuates the N400 amplitudes can be explained by suggesting that comprehenders pre-activate the meaning of upcoming words in advance of their actual input. Accordingly, the lexical retrieval of more predicted words is easier than that of less predicted words.

The lexical retrieval view of the N400 can account for the absence of an N400 effect in the thematically reversed sentence in (4). The retrieval cost for the critical verb should not differ between the conditions because the critical verb has an identical semantic relatedness with the subject-noun phrase (NP) (i.e., the hearty meal/devour) (Brouwer et al., 2012; Chow and Phillips, 2013). Once the N400 is interpreted to reflect pre-integrative lexical access, the absence of an N400 in role-reversed sentences should not be taken as evidence that the independent semantic processor computes a semantically plausible analysis that is inconsistent with the syntactic information and thus does not encounter a semantic integration difficulty.

With regard to P600, recent ERP experiments have demonstrated that the P600 is not specific to syntactic (repair) processes. For example, a P600 is found

for a word that establishes a new reference in a discourse, an ironic word in a given situation or a grammatical sentence that incorrectly describes a picture (Burkhardt, 2005, 2006; Ragel, Gunter and Friederici, 2011; Vissers et al., 2008). Considering the one-to-many relationship between a P600 effect and its antecedent conditions, it is difficult to infer what factor triggers a P600 effect. In other words, the P600 effect in role-reversed sentences does not necessarily reflect the syntactic repair process triggered by a semantic-thematic implausibility.

We have reviewed two different views on the time course of syntactic and semantic processing. The first view assumes a syntax-first single processing stream model. Under this view, the N400 reflects lexical access, and the P600 reflects a more general process than syntactic processing. The second view posits a multi-stream model in which the independent semantic processor computes a semantically plausible analysis and sometimes challenges an analysis dictated by the syntactic information. The proponents of this view interpret the N400 as an index of semantic integration difficulty and the P600 as an index of syntactic integration difficulty (Kim and Osterhout, 2005).

Given that the functional interpretation of the N400 and P600 differs between the two views, we cannot use these ERPs to reliably evaluate which model is more adequate for the architecture of human sentence comprehension. It is appropriate to use a morphosyntactically related component, or a phasic LAN. There are several advantages to using the LAN to investigate whether morphosyntactic processing difficulty arises due to thematic implausibility in morphosyntactically well-formed but semantically anomalous sentences. The LAN reflects more automatic process than the P600. Crucially, the functional interpretation of a LAN effect is relatively unambiguous and widely acknowledged: a LAN relates that there are morphosyntactic processing difficulties. For example, a morphosyntactic violation elicits a greater LAN, whereas a semantic violation, such as in (1), does not elicit a LAN. Assuming a LAN effect reflects an automatic morphosyntactic processing difficulty but not a semantic process, it is more credible to infer that the sentence processor detects a morphosyntactic anomaly if we observe the LAN effect under certain conditions (but see the Discussion below).

Using the LAN as an index of the morphosyntactic process, we aim to re-evaluate the single-stream model and the multi-stream model. The crucial difference between these models is that only the latter assumes that morphosyntactic processing may be susceptible to thematic plausibility. The multi-stream model assumes that the independent semantic processor computes a semantically coherent analysis and interacts with a morphosyntactic processor. On the other hand, in the single-stream model, the morphosyntactic processor initially begins to analyse an input based on word category and agreement information, regardless of the semantic and thematic plausibility of the sentence. The semantic processor subsequently computes a semantic analysis based on the parsed structure. Thus, this model predicts that the thematic plausibility of an argument does not have any influence on morphosyntactic processing when morphosyntactic information is unambiguous.

Considering these different assumptions, if the LAN is enhanced by the thematic implausibility of an argument despite the absence of morphosyntactic violations, then the implication is that the morphosyntactic analysis is challenged by the semantic processor and that the sentence processor wrongly perceives a morphosyntactically well-formed sentence as morphosyntactically anomalous (by analogy to Kim and Osterhout's (2005) interpretation of the semantic P600 phenomenon). In other words, a semantic LAN effect would be evidence in favour of multi-stream models. By contrast, if the LAN is not modulated by the thematic plausibility of an argument, then there is no essential need to assume independent semantic processing, thus offering weak support for the single-stream model.

To test whether a morphosyntactic analysis respects the thematic plausibility of an argument and to re-evaluate which processing model is more adequate, we conducted an ERP experiment that examines apparent Case-assignment violations in Japanese.

5. ERP experiment

The present study employed Japanese sentences with apparent Case-assignment violations to elicit LAN and P600 effects. A Case-assignment violation has repeatedly been found to elicit biphasic LAN-P600 effects in English and German sentences (Coulson et al. 1998, Friederici and Frisch, 2000). Taking into consideration the well-established observation that Case-assignment anomalies elicit LAN effects, it is appropriate to use such anomalies to elicit a LAN effect and to test whether a LAN effect is enhanced by the thematic implausibility of an argument.

5.1. Stimuli

We used verbs with transitive/intransitive alternations in Japanese (e.g., *agar-u* 'rise' vs. *age-ru* 'raise'; *ak-u* 'open *vi*' vs. *ake-ru* 'open *vt*.'). The experimental sentences, which consisted of two phrases, were adopted from Sakamoto, Arao, and Suwazono (2011). A total of 120 sets of stimuli were created by combining two types of Case particles (nominative/accusative) and two types of verbs (unaccusative intransitive/transitive).

(5) Intransitive constructions:
    a. Intransitive verbs with a nominative NP (Ga-intransitive)
        Nedan-ga   agaru.
        price-NOM   rise
       'Price rises.'
    b. Intransitive verbs with an accusative NP (O-intransitive)
        *Nedan-o   agaru.
        price-ACC   rise
       Lit. '*rises price.'

(6) Transitive constructions:

    a. Transitive verbs with an accusative NP (O-transitive)

       pro   nedan-o   ageru.
       (Someone)   price-ACC   raise
       '(Someone) raises price.'

    b. Transitive verbs with a nominative NP (Ga-transitive)

       *Nedan-ga   *pro*   ageru.
       price-NOM   (something) raise
       Lit. '*Price raises (something).'

The intransitive verb *agaru* 'rise' can assign a nominative Case to its argument but cannot assign an accusative Case. Thus, (5b) involves a Case-assignment violation, whereas (5a) does not. The ungrammatical (5b) is supposed to elicit a LAN-P600 effect compared with the grammatical (5a).

The transitive verb *ageru* 'raise' can assign both a nominative Case and an accusative Case to its argument. However, (6b) is less acceptable than (6a) because *nedan* 'price' is more likely to be a THEME than an AGENT of *ageru* 'raise' (i.e., role-reversed sentence).

5.2. Procedure for the ERP experiment

A total of 120 sets of stimuli in (5) and (6) were distributed into four lists such that the participants did not see more than one item of the same set. The lists and response buttons were counterbalanced among the participants. The stimuli were presented randomly between the participants using Presentation 16.3 software (Neurobehavioral Systems).

The participants were seated in a dimly lit soundproof room with a CRT monitor positioned approximately 130 cm in front of them. The presentation of the stimuli occurred in the centre of the screen in a non-cumulative manner. Each trial started with the fixation of 1,000 ms followed by a blank for 300 ms. After the blank, the first phrase (i.e., *nedan-ga/o* 'price-nom/acc') was presented for 700 ms, with an inter-stimulus interval of 600 ms. The second phrase (i.e., *agaru/ageru* 'rise/raise') was presented for 800 ms followed by a blank for 500 ms. After the blank, an acceptability judgement task was given in each trial to check how acceptable the experimental sentences were to the participants.

5.3. Participants

The participants were 16 native speakers of Japanese at Kyushu University (14 females and two males, M = 21.5, SD = 2.5). All participants were classified as right-handed based on the Edinburgh handedness inventory (Oldfield, 1971), and all of them had normal or corrected-to-normal vision. None of the participants had a history of reading disability or neurological disorders. Written informed consent was obtained from all participants prior to the experiment, and the participants were paid for their participation.

5.4. Electrophysiological recording

EEGs were recorded from 19 Ag electrodes (Nihon Kohden, NE-113A) located at Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz according to the international 10–20 system (Jasper, 1958). Additional electrodes were placed on the left side of and beneath the left eye to monitor horizontal and vertical eye movements. The C3 and C4 electrodes served as online references, and EEGs were re-referenced to the average value of the earlobes offline. The impedances of all electrodes were maintained at less than 5 kΩ throughout the experiment. The EEGs were amplified with a bandpass of 0.03 to 60 Hz and digitised at 200 Hz.

5.5. Electrophysiological data analysis

Trials with large artefacts (exceeding ±80 μV) were automatically removed from the analyses (0.78%). All EEGs were filtered offline with a 30 Hz low-pass filter. The baseline was set to 100 ms prior to the onset of the second phrase. The ERPs were quantified by calculating the mean amplitude for each participant relative to the baseline using the following three time windows: 350–500 ms (LAN), 500–700 ms (early P600), and 700–1000 ms (late P600) (cf. Kaan & Swaab, 2003a, 2003b; Molinaro, Barber and Carreiras, 2011).

The analyses were conducted separately at the midline (Fz, Cz, and Pz), lateral (F3, F4, C3, C4, P3, and P4), and temporal (Fp1, Fp2, F7, F8, T3, T4, T5, T6, O1, and O2) arrays. The method, in which ERP data from all electrodes are divided into sub-groups, is standard in ERP experiments on sentence comprehension (e.g., Chow & Phillip, 2014; Kim & Osterhout, 2005; Kuperberg et al., 2003, 2006, 2007; van Herten et al., 2005). The midline analysis consisted of repeated measures of the analyses of variance (ANOVAs) with three within-group factors: CASE (nominative/accusative) × VERB (intransitive/transitive) × ANTERIORITY. The lateral and temporal analyses consisted of four within-group factors: CASE × VERB × LATERALITY × ANTERIORITY. The Greenhouse-Geisser correction was applied for all effects involving more than one degree of freedom (Greenhouse and Geisser, 1959). We report the original degrees of freedom and the corrected p-value.

5.6. Prediction

The O-intransitive sentence in (5b) involves a Case-assignment violation. Thus, it should elicit a LAN-P600 effect. The focus of the experiment is on whether a similar LAN effect is elicited in the Ga-transitive condition compared with the O-transitive condition.

The single-stream processing model assumes that morphosyntactic processing is completed before semantic combinatorial processing. Although *nedan* ('price') is thematically plausible as a THEME, this model predicts that the morphosyntactic processor would analyse *nedan-ga* 'price-NOM' as an AGENT based on unambiguous morphosyntactic cues, such as a Case particle and the subcategorisation information of a verb. Thus, the processor cannot perceive a nominative Case marking as a Case violation. As a result, this model predicts no LAN effect related

to morphological error detection in the Ga-transitive condition. In other words, only the ungrammatical O-intransitive condition may elicit a LAN effect relative to the other three conditions. Note that this model may expect P600 effects in the Ga-transitive condition, reflecting difficulty in updating/reorganising a mental representation because the output of the subsequent semantic processing would contradict world knowledge (cf. Brouwer et al., 2012).

The multi-stream model offers a different prediction. This model assumes that thematic plausibility can affect morphosyntactic analysis even when morphosyntactic information is unambiguous and less complex to process. Thus, the thematic plausibility of *nedan* 'price' as a THEME may immediately affect morphosyntactic analysis, leading the parser to wrongly perceive a Case-assignment violation in the Ga-transitive condition and result in a LAN-P600 effect. In other words, the two unacceptable conditions (i.e., the Ga-transitive and O-intransitive conditions) would elicit larger LAN effects than the acceptable conditions.

5.7. Results
5.7.1. Behavioural data
At the end of each trial, the acceptability judgement task was conducted to assess the extent to which Japanese speakers accept each condition of the experimental sentences. Figure 1 shows the mean acceptability of each condition across the participants.
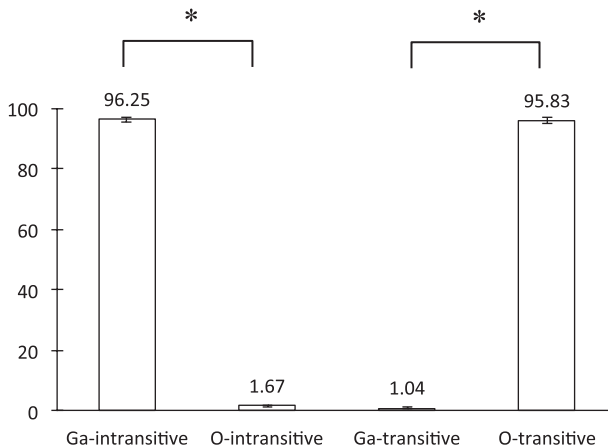

Figure 1. Mean acceptability in the acceptability judgement task. Error bars indicate standard errors.

The repeated measure ANOVA was conducted with two within-group factors: CASE (nominative/accusative) × VERB (intransitive/transitive). The main effects of CASE and VERB were not significant (CASE: $F(1, 15) = 0.12$, $p = 0.72$, VERB: $F(1, 15) = 1.57$, $p = 0.22$). Because the interaction was significant ($F(1, 15) = 1531.48$, $p < 0.001$), we conducted a planned comparison. The result showed that both of the

simple main effects were significant ($ps < 0.001$). This result indicates that the participants judged the O-intransitive and Ga-transitive conditions to be unacceptable and the Ga-intransitive and O-transitive conditions to be acceptable, which is consistent with the five-scale offline acceptability judgement test (Sakamoto, Arao and Suwazono, 2011).

5.7.2. Electrophysiological data

Figure 2 shows the grand average ERPs in the second phrase. A visual inspection suggested that the ERPs of the unacceptable conditions (O-intransitive and Ga-transitive) elicited a greater negativity with an anterior focus compared with those of the acceptable conditions (Ga-intransitive and O-transitive) at 350 ms. In the following time window, a positive-moving shift with a posterior focus was observed in the O-intransitive and Ga-transitive conditions compared with the Ga-intransitive and O-transitive conditions.
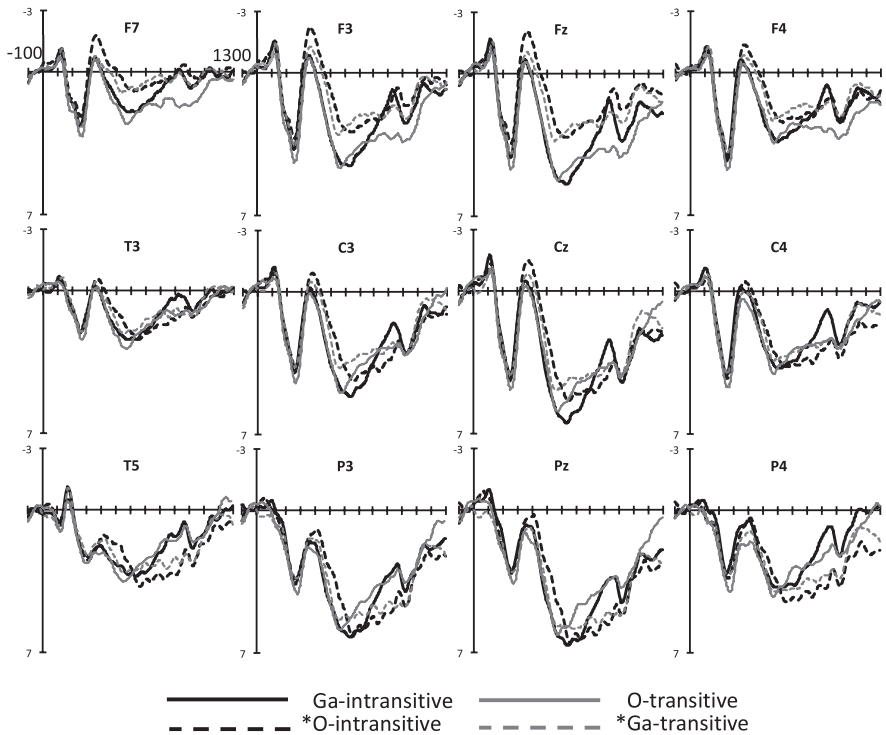

Figure 2. Grand average ERPs in the second phrase. The solid black line indicates the Ga-intransitive condition, the dotted black line indicates the O-intransitive condition, the dotted grey line indicates the Ga-transitive condition, and the solid grey line indicates the O-transitive condition. The X-axis represents the time duration, and each hash mark represents 100 ms. The Y-axis represents the voltage, which ranged from -3 to 7 µV. Negativity is plotted upward.

5.8.2.1. The LAN time window (350–500 ms)

Figure 3 shows the amplitudes of the LAN effects at F4, F3, and Fz. Figure 4 shows their topographical distributions at the intransitive (left) and transitive (right) conditions.
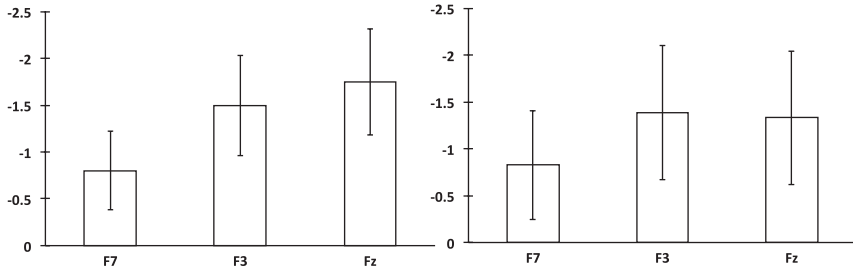

Figure 3. The amplitude differences in 350–500 ms in the intransitive (left) and transitive (right) conditions. Negativity (μV) is plotted upward. Error bars indicate standard errors.

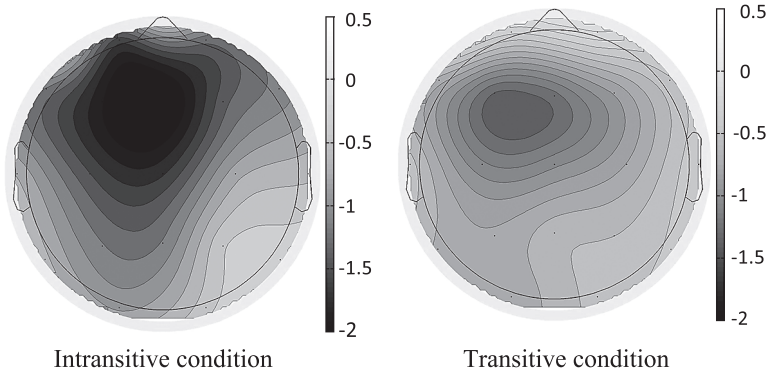Intransitive condition   Transitive condition

Figure 4. The topographical isovoltage map at 350–500 ms. The intransitive condition represents the mean difference calculated as the O-intransitive condition minus the Ga-intransitive condition. The transitive condition represents the mean difference calculated as the Ga-transitive condition minus the O-transitive condition. Negative deflection is indicated in grey.

The interaction of VERB × CASE was significant in all arrays (MIDLINE: $F(1, 15) = 5.148$, $p < 0.05$, LATERAL: $F(1, 15) = 5.673$, $p < 0.05$, TEMPORAL: $F(1, 15) = 4.883$, $p < 0.05$). The planned comparison revealed that the O-intransitive condition elicited a negative ERP component compared with the Ga-intransitive condition (MIDLINE: $F(1, 30) = 4.203$, $p < 0.05$, LATERAL: $F(1, 30) = 4.228$, $p < 0.05$, TEMPORAL: $F(1, 30) = 4.229$, $p < 0.05$). The Ga-transitive condition also elicited a negativity compared with the O-transitive condition in the midline and lateral

arrays, although only marginal effects were observed (Midline: $F(1, 30) = 2.961$, $p = 0.09$, Lateral: $F(1, 15) = 3.406$, $p = 0.07$). The interaction of Verb × Case × Anteriority was marginally significant in the midline because the negativity was pronounced more anteriorly ($F(2, 30) = 2.758$, $p = 0.07$).

One may think that the LAN effect for the O-intransitive condition is greater than that for the Ga-transitive condition. However, the primary purpose of this experiment is to examine the presence/absence of the LAN effect in the Ga-transitive condition. The amplitude difference between the Ga-transitive and O-intransitive conditions or the duration/timing of the LAN effect is of no interest in the present study. Thus, we do not address the issue any further.

5.8.2.2. The Early P600 time window (500–700 ms)

In the temporal array, ANOVA revealed a significant interaction of Verb × Case × Anteriority and Verb × Case × Laterality ($F(4, 56) = 5.553$, $p < 0.01$, $F(1, 14) = 8.163$, $p < 0.01$). The planned comparison showed that the anterior negativities in the O-transitive and Ga-transitive conditions continued into this time-window in the anterior electrodes (O-transitive: Fp1/2: $F(1, 14) = 19.334$, $p < 0.01$, F7/F8, Ga-transitive: Fp1/2: $F(1, 14) = 4,012$, $p = 0.06$). In other arrays, the significant effect of interest was not observed.[1]

5.8.2.3. The Late P600 time window (700–1000 ms)

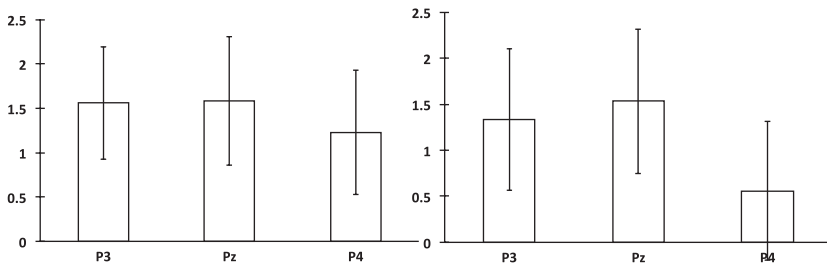Figure 5 shows the amplitudes of the P600 effects at P3, Pz, and P4.

Figure 5. The amplitude differences in 700–1000 ms in the intransitive (left) and transitive (right) conditions. Positivity (μV) is plotted upward. Error bars indicate standard errors.

In the midline and lateral arrays, the interaction of Verb × Case × Anteriority was significant (Midline: $F(2, 30) = 18.010$, $p < 0.01$, Lateral: $F(2, 30) = 15.215$, $p < 0.01$). In the temporal array, a four-way interaction of Verb × Case × Anteriority × Laterality was observed.

The planned comparison revealed that the O-intransitive condition elicited a posterior positivity and a frontal negativity compared with the Ga-intransitive

---

[1] This analysis was conducted in accordance with the reviewer's comment.

condition. The Ga-transitive condition also elicited a posterior positivity and a frontal negativity relative to the O-transitive condition.

Repeated measures ANOVAs confirmed that there was no significant main effect of Case or interaction with Laterality/Anteriority in any time window at the first phrase (all *ps* > 0.10). Thus, the baseline of the second phrase was not contaminated by the potential ERP difference of the preceding region.

Overall, these analyses confirmed our visual inspection. Both the O-intransitive condition and the Ga-transitive condition elicited left anterior negativities at 350 ms, followed by a posterior positivity from 700 to 1000 ms.[2]

6. General discussion

This study employed Japanese sentences with (apparent) Case-assignment violations to examine the interaction of morphosyntactic and semantic processing. Importantly, the results of the ERP experiment showed biphasic LAN-P600 effects for unacceptable intransitive and transitive sentences.

Previous studies suggest that the LAN effect is a manifestation of processing difficulty caused by a morphosyntactic mismatch (Coulson et al., 1998; Friederici and Frisch, 2000; Münte, Matzke and Johannes, 1997). In the case of the ungrammatical O-intransitive condition, the parser encounters an intransitive verb following the accusative NP. Thus, the parser recognises the Case mismatch between a nominative-taking verb and an accusative Case, which is reflected in a LAN effect. The posterior positivity has been repeatedly observed for syntactic constraint violations. According to Kaan and Swaab (2003a, 2003b), the posterior P600 (at least partially) reflects a syntactic repair process, although there is controversy concerning the functional interpretation of the P600. In our experiment, the posterior P600 in the O-intransitive condition may indicate syntactic repair difficulties due to a Case mismatch.

The major finding in our experiment is that the Ga-transitive condition also elicited similar LAN effects compared with the O-transitive condition. If semantic processing operates only after morphosyntactic processing, in accordance with the single-stream model, then it would not detect a Case mismatch in the

---

[2] One may consider that ERP effects in transitive constructions reflect the differences of pro-drop positions. In Japanese, object pro-drop is less frequent than subject pro-drop (Ueno and Polinsky, 2008). However, a previous ERP study showed no ERP effect in any time window between a subject pro-drop and object pro-drop construction when there was no semantic attraction between a verb and its argument (proper name) (Yano, Tateyama and Sakamoto, 2014). Thus, the LAN and P600 effects are not solely due to processing difficulty induced by object pro-drop.

  (i) a. Kinoo   Ichiro-ga   pro   hinanshita
             Yesterday Ichiro-NOM   criticised
             'Ichiro criticised (someone) yesterday' (object pro-drop)
      b. Kinoo   pro   Ichiro-o   hinanshita
             Yesterday   Ichiro-ACC   criticised
             '(someone) criticised Ichiro yesterday' (subject pro-drop)

Ga-transitive condition. Thus, under the single-stream model, it is less clear why the LAN effect was observed in the Ga-transitive condition.

On the contrary, the LAN effect can be explained in the multi-stream model: In this model, semantic information and morphosyntactic information may interact with one another. When semantic information contradicts an analysis dictated by morphosyntactic information, the semantic processor may challenge a morphosyntactic analysis. In the transitive condition, *nedan* ('price') is highly plausible as a THEME but not as an AGENT. Thus, the sentence processor misperceives the Case marking in the Ga-transitive condition as morphosyntactically anomalous. This may lead to a LAN effect in the Ga-transitive condition.

It is noteworthy, however, that recent ERP studies suggest that (E)LAN may reflect the violation of *expectation* for upcoming functional morphology or phrase structures (Molinaro et al., 2011; Lau et al., 2006). For instance, Lau et al. (2006) report that the ELAN is enhanced by the violation of expectation for the subsequent word category (e.g., *Although Erica kissed Mary's mother, she did not kiss the Dana's of the bride (NP ellipsis possible) vs. *Although the bridesmaid kissed Mary, she did not kiss Dina's of the bride (NP ellipsis impossible)). In transitive conditions, the nominative Case attached to the inanimate noun may trigger an expectation for an unaccusative verb, whereas the accusative Case may lead to the anticipation of a transitive verb. In the Ga-transitive condition, the appearance of transitive verbs may violate such an expectation. Accordingly, the LAN effect in the Ga-transitive condition may reflect such an expectation violation rather than morphosyntactic processing difficulty. If this is the case, then the LAN effect does not falsify the single-stream processing models. Therefore, to examine the interaction mechanism of morphosyntactic and semantic processing, future research must take the effect of expectation on the ERPs of verbs into consideration.[3]

7. Conclusion

The present study explored the interaction of morphosyntactic and semantic processing during Japanese sentence comprehension. The result of our ERP experiment showed that violations of Case assignment elicited left anterior negativity and posterior P600 effects relative to their grammatical counterpart. Similar electrophysiological patterns were observed in an apparent Case assignment violation induced by the thematic implausibility of an NP. Provided that the LAN effects can be interpreted as morphosyntactic violation effects, these results offer support for the immediate interaction of syntactic and semantic processing in Japanese.

References
Bornkessel-Schlesewsky, Ina and Matthias Schlesewsky (2008) An alternative perspec-

---

[3] Yano (2015) conducted two ERP experiments that manipulated SOAs and verb types to assess the extent to which the expectation affected the ERPs of verbs and what type of expectation is generated by the first phrase. The results of these ERP experiments will be reported in another paper currently in preparation. We appreciate the reviewer's insightful comment.

tive on "semantic P600" effects in language comprehension. *Brain Research Review* 59: 55–73.

Brouwer, Harm, Hartmut Fitz and John Hoeks (2012) Getting real about semantic illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research* 1446: 127–143.

Burkhardt, Petra (2005) *The syntax–discourse interface: Representing and interpreting dependency*. Philadelphia, Pennsylvania: John Benjamins.

Burkhardt, Petra (2006) Inferential bridging relations reveal distinct neural mechanisms: Evidence from event-related brain potentials. *Brain and Language* 98: 159–168.

Chow, Wing-Yee and Colin Phillips (2013) No semantic illusions in the "semantic P600" phenomenon: ERP evidence from Mandarin Chinese. *Brain Research* 1506: 76–93.

Coulson, Seana, Jonathan W. King and Marta Kutas (1998) Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes* 13: 21–58.

Ferreira, Fernanda and Charles Clifton Jr. (1986) The independence of syntactic processing. *Journal of Memory and Language* 25: 348–368.

Fischler, Ira, Paul A. Bloom, Donald G. Childers, Salim E. Roucos and Nathan W. Perry Jr. (1983) Brain potentials related to stages of sentence verification. *Psychophysiology* 20: 400–409.

Frazier, Lyn (1979) On comprehending sentence: Syntactic parsing strategies. *Doctoral dissertation*, University of Connecticut.

Frazier, Lyn (1987) *Sentence processing: A tutorial review*. In: Max Coltheart (ed.) *Attention and performance* 12: *Psychology of reading*, 559–586. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Friederici, Angela D. (1995) The time-course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language* 50: 259–281.

Friederici, Angela D. (2002) Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences* 6: 78–84.

Friederici, Angela D. and Stefan Frisch (2000) Verb argument structure processing: The role of verb-specific and argument-specific information. *Journal of Memory and Language* 43: 476–507.

Friederici, Angela D., Erdmut Pfeifer and Anja Hahne (1993) Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research* 1: 183–192.

Greenhouse, Samuel W. and Seymour Geisser (1959) On methods in the analyses of profile data. *Psychometrika* 24: 95–112.

Hagoort, Peter, Colin Brown and Jolanda Groothusen (1993) The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes* 8: 439–483.

Hagoort, Peter, Colin Brown and Lee Osterhout (1999) The neurocognition of syntactic processing. In: Peter Hagoort and Colin Brown (eds.) *The neurocognition of language* 273–316. Oxford, United Kingdom: Oxford University Press.

Hoeks, John, Laurie A. Stowe and Gina Doedens (2004) Seeing words in context: The interaction of lexical and sentence level information during reading. *Cognitive Brain Research* 19: 59–73.

Jasper, Herbert H. (1958) The ten-twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology* 10: 371–375.

Kaan, Edith and Tamara Y. Swaab (2003a) Electrophysiological evidence for serial sentence processing: A comparison between non-preferred and ungrammatical continuations. *Cognitive Brain Research* 17: 621–635.

Kaan, Edith and Tamara Y. Swaab (2003b) Repair, revision, and complexity in syntactic analysis: An electrophysiological differentiation. *Journal of Cognitive Neuroscience* 15: 98–110.

Kim, Albert and Lee Osterhout (2005) The independence of combinatory semantic processing: Evidence from event-related potentials. *Journal of Memory and Language* 52: 205–225.

Kim, Albert and Les Sikos (2011) Conflict and surrender during sentence processing: An ERP study of syntax-semantics interaction. *Brain and Language* 118: 15–22.

Kolk, Herman. H. J., Dorothee J. Chwilla, Marieke van Herten and Patrick J. W. Oor (2003) Structure and limited capacity in verbal working memory: A study with event-related potentials. *Brain and Language* 85: 1–36.

Kuperberg, Gina R. (2007) Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research* 1146: 23–49.

Kuperberg, Gina R., David Caplan, Tatiana Sitnikova, Marianna Eddy and Phillip J. Holcomb (2006) Neural correlates of processing syntactic, semantic and thematic relationships in sentences. *Language and Cognitive Processes* 21: 489–530.

Kuperberg, Gina R., Donna A. Kreher, Tatiana Sitnikova, David Caplan and Phillip J. Holcomb (2007) The role of animacy and thematic relationships in processing active English sentences: Evidence from event-related potentials. *Brain and Language* 100: 223–237.

Kuperberg, Gina. R., Tatiana Sitnikova, David Caplan and Phillip J. Holcomb (2003) Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive Brain Research* 17: 117–129.

Kutas, Marta and Kara D. Federmeier (2000) Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences* 4: 463–470.

Kutas, Marta and Kara D. Federmeier (2011) Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology* 62: 621–647.

Kutas, Marta and Steven A. Hillyard (1980) Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science* 207(4427): 203–205.

Kutas, Marta and Steven A. Hillyard (1983) Event-relate brain potentials to grammatical errors and semantic anomalies. *Memory and Cognition* 11: 539–550.

Lau, Ellen, Clare Stroud, Silke Plesch and Colin Phillips (2006) The role of structural prediction in rapid syntactic analysis. *Brain and Language* 98: 74–88.

Münte, Thomas F., Mike Matzke and Sönke Johannes (1997) Brain activity associated with syntactic incongruencies in words and pseudo-words. *Journal of Cognitive Neuroscience* 9: 318–329.

Oldfield, Richard C. (1971) The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia* 9: 97–113.

Osterhout, Lee and Linda A. Mobley (1995) Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language* 34: 739–773.

Osterhout, Lee and Phillip J. Holcomb (1992) Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language* 31: 785–806.

Regel, Stefanie, Thomas C. Gunter and Angela D. Friederici. (2011). Isn't it ironic? An electrophysiological exploration of figurative language processing. *Journal of Cognitive*

Neuroscience 23: 277–293.

Sakamoto, Tsutomu, Hiroshi Arao and Shugo Suwazono (2011) Zita doshi-to kakujoshi-no kumiawase-nitaisuru bogo-washa-no yooninsei handan: kotonaru shudan-kan-no hikaku [*Native Japanese speakers' acceptability judgment on combination of verbs and case markers: A comparison between two different groups of participants*]. *Bulletin of the Faculty of Letters Kyushu University* 108: 31–48.

Ueno, Mieko and Maria Polinsky (2009) Does headedness affect processing? A new look at the VO-OV contrast. *Journal of Linguistics* 45: 675–710.

Urbach, Thomas, P. & Marta Kutas (2010) Quantifiers more or less quantify on-line: ERP evidence for partial incremental interpretation. *Journal of Memory and Language* 63: 158–179.

van Herten, Marieke, Herman H. J. Kolk and Dorothee J. Chwilla (2005) An ERP study of P600 effects elicited by semantic anomalies. *Cognitive Brain Research* 22: 241–255.

Vissers, Constance, Th. W. M., Herman H. J. Kolk, Nan van de Meerendonk and Dorothee J. Chwilla (2008) Monitoring in language perception: Evidence from ERPs in a picture-sentence matching task. *Neuropsychologia* 46: 967–982.

Yano, Masataka (2015) Is semantic LAN effect elicited by thematic anomaly or expectation violation? Evidence from Japanese sentence processing. *The 28th Annual CUNY Conference on Human Sentence Processing*, p. 268. University of Southern California.

Yano, Masataka, Yuki Tateyama, and Tsutomu Sakamoto (2014) Processing of Japanese cleft constructions in context: Evidence from event-related brain potentials. *Journal of Psycholinguistic Research* 43: 277–286.

Author's contact information:
Graduate School of Humanities
Kyushu University
6-19-1 Hakozaki, Higashi-ku, Fukuoka 812-0053, Japan
e-mail: masayano@kyudai.jp

【要　旨】

日本語文理解における形態統語的・意味的処理の相互作用
——事象関連脳電位を指標として——

矢野　雅貴　　　　　　　　　坂本　勉
九州大学／日本学術振興会特別研究員　　　九州大学

　本研究は，事象関連電位を指標として，形態統語的処理と意味的処理がどのように相互作用しているのかを検討した。実験の結果，格違反文（値段をあがる）に対して左前頭部陰性波と P600 が観察された。また，格違反は含まないが意味役割が逆転した文（値段があげる）において，同様の左前頭部陰性波と P600 が観察された。もしこの左前頭部陰性波が形態統語的な違反効果を反映しているとすれば，この結果は，形態統語的な処理と意味的処理が，動詞の呈示開始語 400 ms 辺りで相互作用していることを示唆している。