ERP Responses to Violations in Japanese Verb Conjugation Patterns

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Abstract

ERP (Event Related Potential) measurement using the violation paradigm of Japanese verb conjugation was conducted in order to investigate the mental and neural mechanisms involved in the processing of different conjugation patterns. A LAN-like component followed by a P600 was elicited for the anomaly of using a tense-bearing form with the negative ending, while only P600 was observed for the anomaly of using an infinitive form in the same environment. The non-application of morpho-phonological changes of verb roots ("onbin") yielded an N400 component and a P600. The P600 components observed in all types of errors reflect the cost of processing morphological and/or syntactic anomalies, while the difference in the negativities suggest that two different mechanisms of rule-based computation and lexical memory are involved in the processing of Japanese verb conjugation.

Keywords: verb conjugation; inflection; N400; LAN; P600; Dual Mechanism Model; rule; memory

Introduction

The aim of the present study is to elucidate the mental and neural mechanisms involved in the word-level language processing, exploiting the technique of ERP (Event Related Potential) measurement. More specifically, we investigated the processing of Japanese verb conjugation by recording ERP responses to different types of errors in the conjugation patterns. In doing so, we addressed the question of whether verb inflection involves more than one mechanism of processing in a language typologically different from European languages.

There has been heated debate since 1980's concerning the mental mechanisms involved in word-level processing, with the focus on inflectional morphology in European languages. On the one hand, Dual Mechanism Model (Pinker 1999, Ullman 2001, among others) argues that two qualitatively different mechanisms, namely, rule-based computation and associative memory, are involved; English "regular" *-ed* past forms, for instance, are dealt with by the former, while "irregular" forms like *sing/sang* are by the latter. On the other hand, Single Mechanism Model (Joanisse and Seidenberg 1999, among others) contends that one and the same mechanism can deal with both "regular" and "irregular" inflection.

Few studies have been conducted on Japanese in this context: a notable exception is Hagiwara et al. (1999), who argue for the Dual-Mechanism processing in Japanese derivational morphology. The present study places its focus on the processing of Japanese inflectional morphology, which has so far attracted little attention (cf. Vance 1991, Yu et al. 2011).

ERP Components Related to Language Processing

Three components, N400, LAN, and P600 are known to be related to language processing.

The N400 is a negativity which peaks at around 400 ms after the onset of stimuli with wide, often posterior-centered distribution (Kutas and Hillyard 1980). The component is known to reflect semantic or pragmatic anomaly. It is likely to be related to the search of lexical memory as well, since its amplitude is known to reflect the frequency of the stimulus word (Kutas & Federmeier 2000), and it is observed in word-specific argument structure violation, namely, anomaly with respect to lexical information (Friederici & Frisch 2000, Friederici and Meyer 2004).

The LAN (Left Anterior Negativity) component is also a negativity observed at around 300-500 ms after the onset of stimuli: it is distinguished from the N400 in its distribution, which is limited to the left anterior region. This component is known to reflect morpho-syntactic anomalies like agreement errors (Coulson, King and Kutas 1998, among others).

The P600 is a positive component observed at around 600 ms after the onset of stimuli. Both anterior and posterior distributions have been reported. This component has been claimed to reflect the process of reanalysis or repair in face of morpho-syntactic or syntactic violations of various types (Osterhout and Holcomb 1992 and Hagoort et al. 1993, among others).

ERP studies on regular and irregular inflection have yielded somewhat varied results. The general tendency is that inappropriately attached or omitted regular inflectional suffixes (as in *bringed* instead of *brought*, or in *wip* instead of *wipped*) tend to elicit a LAN, while modifications of irregular inflection (as in *pept* instead of *peeped*) tend to yield an N400-like component (Newman et al. 2007).

Conjugation of Japanese verbs

Japanese verb roots can be divided into two types in terms of their conjugation patterns. The verb roots ending with vowels (/e/ or /i/) take various inflectional endings without any phonological change on the root.

(1) vowel-ending root: tabe 'eat'
  a. non-past   tabe-r-u
  b. negative   tabe-nai[1]
  c. infinitive   tabe (-masu 'polite form', -owar 'finish')
  d. past   tabe-ta
  e. continuative   tabe-te

The infinitive (ren'yoo) form (1c) takes the polite ending *-masu* and various aspectual verbs. When the endings start with a vowel, a consonant /r/ is inserted (1a).

In contrast, with consonant-ending roots, a vowel /a/ is inserted in the negative form and /i/ in the infinitive form (2b,c). In addition, the root-final consonants go through morpho-phonological changes called "onbin" in traditional Japanese grammar. Past tense ending *-ta* and continuative *-te* takes infinitive forms in both vowel-ending and consonant-ending verbs, but "onbin" takes place in consonant-ending verbs, as shown in (2d,e).

(2) consonant-ending root: shaber 'chat'
  a. non-past   shaber-u
  b. negative   shaber-a-nai
  c. infinitive   shaber-i (-masu 'polite', -owar 'finish')
  d. past   shabeʔ -ta
  e. continuative   shabeʔ -te

The onbin forms are conditioned by the final consonants of the roots, as summarized below.

(3) morpho-phonological changes (onbin)
  a. r,t,w→ʔ (glottal stop):
     shaber 'chat' / shabeʔ -ta; kat 'win'/ kaʔ -ta
  b. k,g→i: kak 'write' / kai-ta; kag 'smell' / kai-da
  c. b,m,n→n: tob 'fly' / ton-da; yom 'read' / yon-da

As illustrated in (3b,c), the initial consonant /t/ of the ending is voiced after /b, m, n, g/. The roots ending with /s/ do not undergo "onbin" (*tas* 'add' /*tas-i-ta*).

It should be noted here that these morpho-phonological changes occur only with /t/-initial inflectional endings, but not with /t/-initial derivational suffixes. For instance, an agent nominal suffix *-te* does not trigger similar changes on the root: *kaki-te* 'writer' cf. *kai-te* 'write (continuative)' (Tagawa 2008). This confirms our assumption that these are not purely phonological changes, but are morpho-phonologically conditioned.

[1] The ending *-nai* in (1b) is the non-past form of the negative ending, which we will represent as one element for expository purposes.

Stimuli and Predictions

We focused on two aspects of Japanese conjugation. First, various vowels are added to consonant-ending verb roots as shown in (2a)-(2c): /a/ in Neg-form selecting a negative-ending *-nai* (2b), and /i/ in an infinitive form (2c), while the tense-marking morpheme /u/ yields a non-past form (2a), constituting minimal triplets with the same number of morae. We constructed our stimuli by adding the negative ending *-nai* to such triplets, resulting in one well-formed negative conjugation (4a) and two different illicit forms (4b,c).

(4) a. shaber-a-nai (Neg-form + -nai)
  b. *shaber-i-nai (infinitive form + -nai)
  c. *shaber-u-nai (non-past form + -nai)

Insertion of these vowels to yield the forms (2a-c) is perfectly regular with consonant-ending verb roots, and hence we can hypothesize that these involve rule-based computation.

It should also be noted that the two types of illicit forms have different types of anomaly. (4b) contains a simple morphological ill-formedness, where a wrong non-tensed form (i.e., infinitive instead of Neg-form) is chosen. (4c), on the other hand, involves a phrase-structure violation, where the tense morpheme (non-past *-u*) is added before the negative ending, yielding the ungrammatical phrase structure where Tense is adjoined to V below the NEG node: $[[[\text{ shaber }]_V \text{ -u }]_T \text{ -nai }]_{NEG}$ (the correct configuration would be: $[[[\quad]_V]_{NEG}]_T$).

Consideration of the nature of unacceptability of these forms, together with the nature of ERP components surveyed above, leads us to predict that these illicit forms (4b, c) will elicit computation-related components (LAN and/or P600) when compared to the well-formed counterparts. Also, it can be expected that the two different illicit forms exhibit some difference in ERP responses.

The second aspect we focus on is onbin-forms exemplified in (2d,e). Although onbin-forms are determined by each root-final consonant as described in (3), there are some exceptions: the past form of *ik* 'go' is not *ii-ta*, but *iʔ-ta*, and the past form of *tow* 'ask' is not *toʔ-ta*, but *tow-ta*. It is also reported by Vance (1991) that native speakers experience difficulty in producing the past form of a novel verb. These facts suggest that onbin forms are lexically memorized. We constructed illicit forms by replacing onbin forms with the forms without onbin, namely infinitive forms (root+/i/), as shown in (5b). These forms can be predicted to elicit a memory-related ERP component N400 compared to the well-formed forms (5a).

(5) a. shabeʔ-ta / ka-i-ta / ton-da
  b. *shaber-i-ta / *kak-i-ta / *tob-i-ta

Method

Participants A total of 21 (15 males and 6 females) Japanese right-handed undergraduate students at the University of Tokyo participated in the experiment.

Stimulus Sentences The target sentences were created on 162 consonant-ending verbs. For 90 verbs, we constructed illicit forms with violation of negative conjugations, and for 72 verbs, we constructed illicit forms with violation of onbin forms (See "Stimuli and Predictions"). Three experimental lists were created according to a Latin square design, so that each list contained 30 sentences in each of the three negative conjugation error conditions and 36 sentences in each of onbin error conditions. A total of 252 sentences, 162 target and 90 filler sentences, were presented. Half of these sentences were well-formed. All sentences used in this experiment had the structure [NP-adjunct-NP-V-X]. An additional element X, nominal + copula or Auxiliary predicate, was added after the verb where we manipulated the conjugation, so that the sentences do not end with the critical word.

(6) Negative conjugation error
Zyuumin-wa danti-de otiba-o
residents-TOP housing.complex-in fallen.leaves-ACC
(a) moyas-a-nai (Neg-form+ nai)
burn-NEG
(b) *moyas-i-nai (infinitive form+nai)
(c) *moyas-u-nai (non-past form+nai)
kisoku-da.
rule-COP
'Residents are not allowed to burn fallen leaves in the site of the housing complex'

(7) Onbin error in past form
Kazoku-wa ima-de syasin-o
family-TOP living.room-in pictures-ACC
(a) to?-ta (onbin form +past)
take-PAST
(b) *tor-i-ta (infinitive form+past)
rasii.
seem
'It seems that the family took pictures in the living room.'

Procedures Electroencephalogram (EEG) signals were recorded while the participants read to themselves the stimulus sentences shown automatically on the PC screen phrase by phrase. They were asked to refrain from blinking their eyes or moving their bodies until the end of the sentences. Each sentence had 5 phrases, and each phrase appeared on the screen for 600 ms with a 200 ms blank between each phrase. The critical word, i.e. the verb in all conditions, is the fourth phrase in the stimulus sentences. Following the presentation of a sentence, participants were instructed to make a grammaticality judgment (yes/no decision) by clicking a computer mouse. The 252 sentences were divided into 3 blocks, and within the blocks, sentences were randomized. The participants took a short break between each block.

EEG signals were recorded from 64 Ag/AgCl electrodes mounted in an elastic cap (Quikcap, NeuroScan) according to the International 10–20 system. To control the participants' horizontal and vertical eye movements, a bipolar electroencephalogram (EOG) was also recorded using four electrodes. All the EEG and EOG channels were digitized at a 250 Hz sampling rate using a Neuroscan Synamp2s amplifier with a band-pass between DC and 70 Hz. Recordings were referenced to the electrode located between Cz and CPz and then re-referenced offline to the average of the left and right mastoids. Electrode impedance was kept below 10 kOhm. ERP averages were computed with a 100 ms baseline and an 800 ms ERP time window. In the ERP analysis, 9.19% of the trials were rejected because of eye blinks or movement artifacts (the EOG rejection criterion was 70 μV).

Results

Data analysis

Participants showing high rates of artifacts or error responses to yes/no questions (greater than 20% in the two types of trials combined) were excluded from the analysis. Six participants were excluded and the data from the remaining 15 participants (11 males and 4 females) were analyzed.

Since the visual inspection revealed a negativity with the focus in the left temporal area for (6c) compared with (6a), the following two regions of interest (ROIs) were used in the ANOVAS for the left-lateralized negativity: left-temporal (T7, C5, CP5, and P7) and right-temporal (TP8, C6, CP6, and P8). For statistical analyses of the N400 effect, four regions of interest (ROIs) are derived by crossing two factors; hemisphere (HEMI: left vs. right) and region (REGION: anterior vs. posterior). The ROIs are defined as follows: left-anterior (F5, F3, F1, FC5, FC1, C5, and C1); left-posterior (CP5, CP1, P5, P1, PO7, PO5, and PO3); right-anterior (F2, F4, F6, FC2, FC6, C2, and C6); and right-posterior (CP6, CP2, P6, P2, PO8, PO6, and PO4).

For statistical analyses of the P600, four regions of interest (ROIs) are derived by crossing two factors; hemisphere (HEMI: left vs. right) and region (REGION: anterior vs. posterior). The ROIs are defined as follows: left-anterior (F5, F3, F1, FC5, FC3, FC1, C5, C3, and C1); left-posterior (CP5, CP3, CP1, P5, P3, P1, PO7, PO5, and PO3); right-anterior (F2, F4, F6, FC2, FC4, FC6, C2, C4, and C6); and right-posterior (CP6, CP4, CP2, P6, P4, P2, PO8, PO6, and PO4).

Negative conjugation error

Figure 1 shows the grand average ERPs for the critical verb, in correct, infinitive, and non-past form conditions.

correct vs. illicit (infinitive+*nai*) As shown in Figure 1, a positivity around 500-800 ms after the onset was elicited by the infinitive form, in comparison with the correct form. The latency and the distribution suggest that it is a P600 component, which is supported by the statistical analysis as follows: The analyses for the time window 500-800 ms revealed a significant main effect of condition,

$F(1,14)=21.98$, $p<.001$. The infinitive form condition was more positive going than the correct. No other ERP components besides the P600 were observed in the comparison of the correct form and the infinitive form conditions (*p*s>.05).

correct vs. illicit (non-past+*nai*) The non-past form condition, when compared with the correct form condition, elicited a negativity in the left temporal region at the time range of 300-400 ms and a positivity around 500-800 ms. The analyses for the time window 300-400 ms revealed a significant interaction between HEMI and the correct form vs. the non-past form, $F(1,14)=4.54$, $p<.05$. The non-past form condition was more negative going than the correct form condition in the left-temporal sites ($F(1,14)=3.76$, $p=.066$), but not in the right-temporal sites. The latency and the distribution of the positivity suggest that it is a P600 component, which is supported by the statistical analysis as follows: The analyses for the time window 500-800 ms revealed a significant main effect of condition, $F(1,14)=25.80$, $p<.001$. The non-past form condition was more positive going than the correct form.

Onbin error

Figure 2 shows the grand average ERPs for the critical verb, in the onbin and the infinitive form conditions. The illicit infinitive form condition, when compared with the correct onbin form condition, elicited a negativity at the time range of 200-500 ms with a focus in posterior sites, and a positivity around 600-800 ms. The latency and the distribution suggest that the negativity is an N400 component, which is supported by the statistical analysis as follows: The analyses for the time window 200-500 ms revealed a marginally significant interaction between REGION and the onbin form vs. the infinitive form, $F(1,14)=3.47$, $p=.08$ and a significant main effect of condition, $F(1,14)=5.17$, $p<.05$. The infinitive form condition was more negative going than the onbin form condition in the posterior sites ($F(1,14)=8.36$, $p<.01$), but not in the anterior sites. The latency and the distribution of the positivity suggest that it is a P600 component, which is supported by the statistical analysis as follows: The analyses for the time window 600-800 ms revealed a significant main effect of condition, $F(1,14)=35.36$, $p<.001$. The infinitive form condition was more positive going than the onbin.

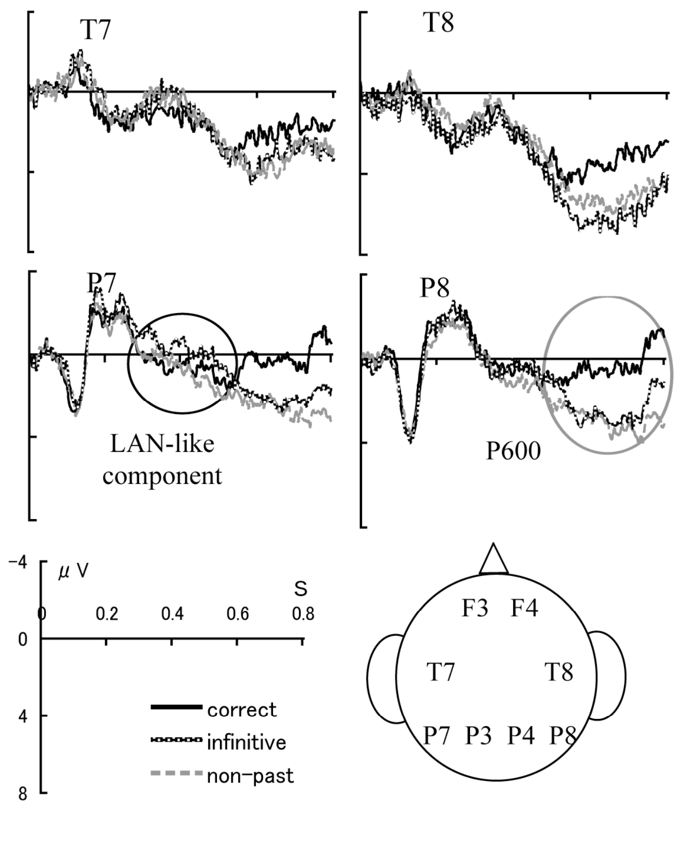


Figure 1: Grand average ERPs at selected electrodes at the position of the target verb (onset at the vertical bar) for the correct form vs. the infinitive form vs. the non-past form. Negativity is plotted upwards.

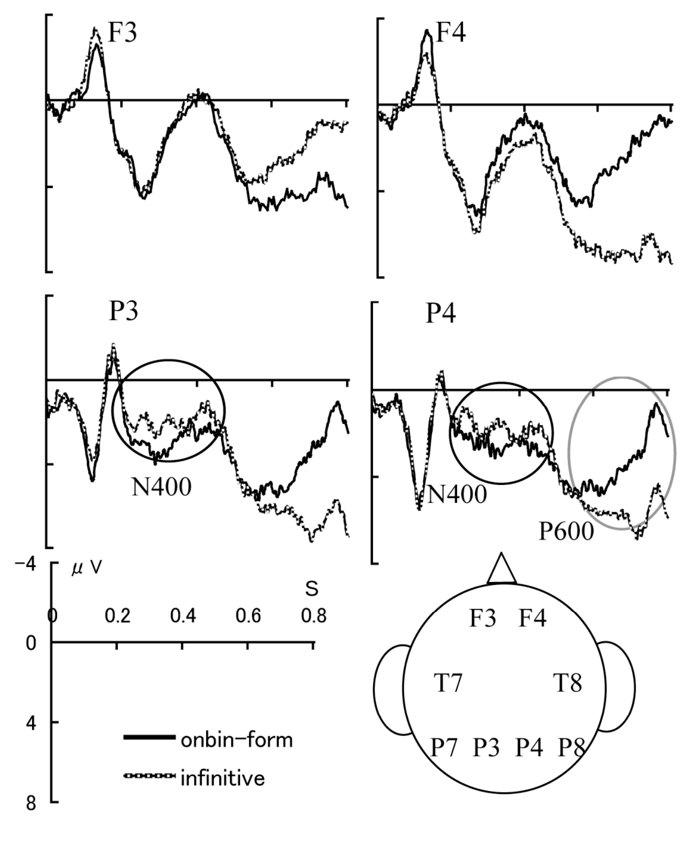
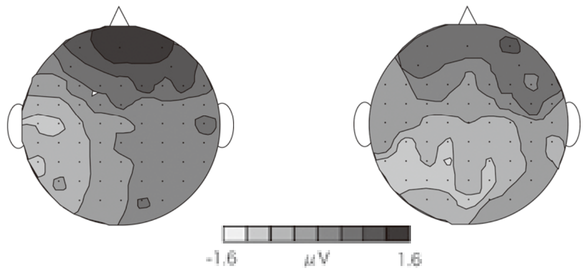


Figure 2 Grand average ERPs at selected electrodes at the position of the target verb (onset at the vertical bar) for the onbin-form vs. the infinitive form. Negativity is plotted upwards.



300-400ms 200-500ms

(1) Non-past - Correct (2) Infinitive - Onbin-form

Figure 3. The topographical potential maps display the distribution of the negativities, (1) for the illicit non-past form as compared to the correct form and (2) for the illicit infinitive form as compared to the correct onbin form in the time window used for the statistical analysis. Lighter shading indicates more negative potential differences.

Discussion

The above results are compatible with what our hypotheses predict: both conditions in negative conjugation errors elicited a P600, while a negative component was observed only in the non-past+*nai* condition, but not in the infinitive+*nai*. The onbin errors elicited an N400 component followed by a P600. We will discuss these results, focusing on what each component can be interpreted to reflect.

Negative components

First, the negative component observed in negative conjugation errors (6c) and the one observed in onbin errors (7b) were clearly different in their distribution, and hence can be judged to be different components. Secondly, the negativity in negative conjugation errors was observed only for the non-past+*nai* condition, and not for the infintive+*nai* condition.

The negativity elicited by the illicit infinitive form without onbin (7b), although not so robust in its amplitude, was judged to be an N400, given its distribution with centro-parietal focus and no hemispheric lateralization (Figure 3 (2)). This suggests that detecting this anomaly involved accessing of lexical memory. As has been discussed in the literature (e.g. Kutas and Federmeier 2000), difficulty in lexical access is one of the factors reflected in N400. Thus, this result is in accordance with our hypothesis that onbin does not involve computation by rule but the onbin forms for each verb root are memorized in the lexicon, hence application or non-application of onbin for a specific verb root with the past tense ending *-ta* must be checked against the lexicon.

The negativity elicited by the illicit non-past forms (6c) in comparison with the well-formed control (6a) has clearly different distribution from the N400 component, in that it was limited to the left hemisphere, as supported by the significant difference between the two hemispheres (Figure3 (1)). Even though its distribution is also different from the classic LAN component in that its focus is in the temporal sites, it is similar in distribution to a left-lateralized negative component reported as a LAN by Rodriguez-Fornells et al. (2001) for Catalan overregularization of stem formation rule. Thus, it is not implausible to consider the negativity observed in our non-past condition as a LAN-like component. This component can be interpreted as reflecting the parser's detection of a phrase-structure violation of (6c), where the tense morpheme is placed below the Neg node. Thus the illicit non-past forms exhibited the biphasic pattern of the LAN-like negativity followed by a P600, which is in accordance with the literature reporting a LAN-P600 pattern for phrase structure violations (Friederici and Meyer 2004).

It is consistent with our prediction that there was a difference concerning negative components between the illicit infinitive forms (6b) and the illicit non-past forms (6c) in negative conjugation errors. It calls for some explanation, however, that a LAN-like component was not observed in (6b). In previous studies on morpho-syntactic anomalies, anterior negative components (LAN or AN) followed by a P600 are reported for agreement errors or case violations, which require syntactic computation of subject-verb or verb-object relation (e.g., Osterhout and Mobley 1995, Coulson et al. 1998). These errors are similar in nature to our non-past condition (6c). In contrast, our infinitive condition (6b) involves a purely morphological error, as mentioned above in "Stimuli and Predictions". Thus, even though our hypothesis holds that (6b) as well as (6c) involves rule-based computation, the violation in (6b) is, in a sense, much simpler, and hence it is conceivable that the cost of detecting the ill-formedness is too weak to elicit a statistically significant LAN-like component. In this vein, it is significant that the illicit infinitive forms did not elicit an N400 component, which supports our contention that the detection of the anomaly in (6b) does not involve lexical memory.

Positive components

We observed late positive components, which can be judged to be a P600, in all the three illicit conditions (infinitive+*nai* (6b), non-past+*nai* (6c), and infinitive+*ta* (7b)) when compared to the well-formed counterparts. As discussed above, we contend that different mechanisms are involved in the processing of the negative conjugation and onbin forms. And yet, a P600 was observed across all three illicit conditions, which suggests that this component reflects the cost of dealing with conjugation errors, irrespective of their nature, namely, whether purely morphological (6b), morpho-syntactic (6c), or morpho-phonological (7b), and whether rule-based (6b,c) or memory-based (7b).

Concluding Remarks

These findings taken together suggest the following points on the processing of Japanese verb conjugation. First, conjugation of Japanese roots with a specific vowel for each ending involves rule-based computation. On the other hand, the morpho-phonological change (onbin) that takes place on the final consonant of some subclasses of the verb roots in the environment of certain ending forms such as past and continuative requires lexical memory. It can be thus concluded that Japanese verb conjugation involves two different mental mechanisms, rule-based computation and lexical memory, depending on the type of conjugation and particular set of endings. Hence our findings are consistent with the Dual Mechanism Model.

As mentioned in "ERP Components Related to Language Processing", the ERP responses to regular/irregular inflection so far reported are rather varied, especially on negative components. While a LAN is observed for over-application of regular morphology in studies on English and German for instance (Morris and Holcomb 2005, Penke et al. 1997), it is also reported in Morris and Holcomb that the over-regularized irregulars (*bringed*) elicited an N400 when presented in a word-list format (in contrast to a LAN observed in a sentential context). Similarly, Gross et al. (1998) reports an N400-like negativity for overregularized Italian irregulars in a word-list format, where difference between stem-based inflection and affixal inflection is suggested to be relevant. In other words, a number of factors including methods of stimuli presentation and differences in inflectional systems between languages seem relevant, and hence more investigation is obviously needed. Our study has shown that different inflectional processes within one language can involve different mental mechanisms and thus induce different ERP components in the violation paradigm, indicating the importance of studying languages typologically different from European languages.

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