Neuromagnetic Evidence of Early Syntactic Responses to C-selection Violations of English Infinitives and Gerunds by L1 and L2 Speakers

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ABSTRACT

Purposes: Previous magnetoencephalography (MEG) studies of syntactic processing by first language (L1) speakers revealed an early syntactic component peaking at around 150ms after within-phrase violations in German (Knösche et al. 1999, Friederici et al. 2000) and English (Kubota 2002). The current study examined whether this component would apply to English c-selection violations and whether it would be observed in both L1 speakers and second language (L2) learners.

Methods: Subjects were 5 American L1 adults and 5 Japanese advanced L2 learners. Stimuli consisted of 400 English sentences categorized into 4 conditions, grammatical and ungrammatical

versions of two structures with infinitive (I) and gerund (G) complements: for example, I(a) *He happened to use it*, *I(b) *He postponed to use it*, G(a) *He postponed using it*, *G(b) *He happened using it*. MEG responses were recorded with a dual 37-channel gradiometer system (MAGNES II, BTi). The task was to listen to the stimuli and make a covert grammaticality judgment.

Results: A prominent magnetic syntactic field component peaking at approximately 150 ms (so called "SF-M150") was generated by a syntactic violation of the *G(b) condition in the left hemisphere of L1 speakers and L2 learners. Such a prominent component was not observed in any other condition for L1 and L2 groups.

Conclusion: There exists a neural response, labeled the SF-M150 component, associated with c-selection violations of infinitives in English for both L1 and L2 speakers. L2 learners may possess similar pre-attentive neuronal mechanisms as L1 speakers for syntactic parsing of infinitive c-selection violations.

1. INTRODUCTION

Previous magnetoencephalography (MEG) studies have found that early neuronal responses were observed in response to syntactically incorrect sentences in German (Knösche et al. 1999, Friederici et al. 2000) and English (Kubota 2002). Such an early syntactic component with a 150 ms peak latency, labeled the "SF-M150" (Kubota 2002), was evoked by violations occurring only within a phrase (i.e., within-phrase errors), whether the sentence breaks a phrase structure rule or not (i.e., phrase-structure violations or non-phrase-structure violations). In my previous study (Kubota 2002), a case-feature mismatch that determines the ungrammaticality of the sentence (e.g., *I believe him is a spy*) elicited the SF-M150 component for native speakers, but not for low-advanced second language learners.

The current research focuses on English categorical selections (c-selections) that determine the grammaticality of the sentences. The purposes of the present study are to investigate whether the SF-M150 component is evoked by two types of c-selection violations (i.e., infinitive and gerund violations) and whether L2 learners exhibit neuromagnetic responses comparable to L1 speakers.

2. METHODS

2.1 Subjects

The subjects were 5 native speakers of American English as a first language (L1), aged 23-49 (average=34.8; 2 females) and 5 Japanese learners of English as a second language (L2), aged 23-29 (average=25.2; 4 females). All subjects were healthy and right-handed with normal hearing and no known neurological disorders. All L2 learners were graduate students in San Francisco and started studying English as a foreign language (EFL) in junior high school at age 13. The average length of L2 classroom study was 12.5 years mostly in EFL classroom settings in Japan. The English proficiency level, as reflected by TOEFL scores, was evaluated as low-advanced (not bilingual); their TOEFL scores ranged from 570 to 590 (average=579.4). MEG recording was performed with the approval of the institutional committee for human research, and informed written consent was obtained from each subject prior to the MEG experiment.

2.2 Stimuli

Stimuli were categorized into four conditions, and syntactically correct and incorrect versions of two English structures with infinitive (I) and gerund (G) complements were compared. The number of correct and incorrect sentences was equal. Each sentence followed the frame: [personal pronoun] [matrix verb] ["*to use*/*using*"] ["*it*"]. For example,

I (infinitive) condition: I(a) He happened to use it.

*I(b) He postponed to use it.

G (gerund) condition: G(a) He postponed using it.

*G(b) He happened using it.

[*: ungrammatical]

An invalid syntactic category is used in the incorrect conditions *I(b) and *G(b); the *I(b) condition contains c-selection violations of gerunds and the *G(b) condition includes c-selection violations of infinitives. A structure with an infinitive complement, as in I(a), is formed by merging the infinitive particle with the VP that contains the uninflected base form of the verb. A structure with a gerund complement as in G(a) requires the +*ing* form of the verb, but not the infinitive form (Radford 1997). The meaning represented by I(a) is never expressed via a gerund complement, whereas the meaning of G(a) is not expressed by an infinitive complement (Yule 1998). In general, infinitives are likely to represent events that are hypothetical, future, and unfulfilled, while gerunds are likely to depict events which are vivid, real, fulfilled (Bolinger 1968).

In the current experiment, only the personal pronoun and the matrix verb varied; two pronouns and 50 matrix verbs were used. Everything else remained the same in each sentence across all conditions. The matrix verbs chosen in the current study took only an infinitive or only a gerund as complements; the type of verbs that take both infinitive and gerund complements was not selected.

The sentences were recorded with a natural speech rate and a natural intonation by an American male on a PC computer at a sampling rate of 44,100 Hz. Various samples of sentences were recorded, and perceptually good exemplars were selected for sound editing on the basis of sound quality, speaking rate, and average duration of phrases. The stimuli were edited using SoundEdit 16 software (version 2; Macromedia, Inc., San Francisco, CA, USA). The average length of 100 different sentences created was 1604.7

ms in the I condition and 1744.4 ms in the G condition. Four L1 speakers listened to the edited sentences and evaluated the stimuli as natural.

2.3 Data Acquisition

Neuromagnetic fields were recorded for each subject using a dual 37-channel gradiometer system (MAGNES II, Biomagnetic Technologies, Inc., San Diego, CA, USA) housed in a magnetically shielded room. MEG recording was time-locked to the onset of the critical word. The critical word was '*to*' (infinitive particle) in the I condition and '*using*' (gerund) in the G condition.

During MEG recording, the subjects were instructed to listen to English sentences and make a covert grammaticality judgment on each stimulus. The task was to covertly say 'Yes' for grammatically correct sentences and 'No' for grammatically incorrect ones without any vocalization. 100 different sentences were repeated four times, and all 400 sentences were presented randomly by Psyscope software (version 1.2, Cohen et al. 1993) on a Power Macintosh computer. The inter-trial interval (ITI) varied randomly between 3300 and 3700 ms in steps of 200 ms.

The subjects lay on a bed with the head positioned between the two MEG sensors. Each sensor was placed over the temporal lobe, and evoked responses to 100 epochs of 1 kHz pure tones with a 400 ms duration were collected to assure effective positioning of two sensors over the primary auditory cortex.

Recording epochs of 1100 ms duration, including 100 ms pre-trigger duration, were acquired at a sampling rate of 1041.7 Hz and subject to an online 1-100 Hz band-pass filter. The stimuli were binaurally delivered at an intensity of at least 53 dB SL, using insert earphones and plastic air tubes (ER-3A; Etymotic Research, Elk Grove Village, IL, USA). The MEG recording during the syntactic experiment took approximately 25 minutes.

2.4 Data Analysis

All epochs were inspected for artifacts, and epochs were rejected if the min-max value of any sensor exceeded a threshold of 3000 femto Teslas (fT). The recorded data were selectively averaged by stimulus condition for each hemisphere. The initial 20 epochs were excluded from averaging so as to avert the startle effect. Averaged waveforms were filtered off-line with a 1-40 Hz band-pass filter and with the removal of a DC offset to correct for the drift from the 100 ms pre-trigger baseline.

The root mean square (RMS) of the magnetic field strength across each 37-channel sensor array was calculated. The time window of 100-200 ms were selected for the RMS field amplitude analyses of early syntactic responses, since previous MEG studies observed the peak latency to be approximately 140-150 ms (Knösche et al. 1999, Friederici et al. 2000, Kubota 2002). The peak latencies were determined as the time point corresponding to the maximum RMS field amplitude value in the 100-200 ms time window. The alpha level was α=.05. RMS evoked field amplitudes in the time range of 100-200 ms were compared by a two-way repeated-measures ANOVA for two subject groups (L1 and L2 speakers) and four conditions in the G and I (left hemisphere (LH): correct and incorrect conditions; right hemisphere (RH): correct and incorrect conditions).

Source localization analysis was performed using the Brain Electric Source Analysis (BESA, Scherg and Berg 1991). The generators of the prominent syntactic components obtained by

BESA software were transposed to the anatomical MR axial images of a representative subject within an estimated 4 mm error of measurement (Knowlton et al. 1997). MR images were obtained by a 1.5 Tesla MRI scanner (Signa, GE Medical Systems, Milwaukee, WI, USA; repeat time (TR) = 34 ms, echo time (TE) = 3 ms, flip angle = 30 degrees, slice thickness = 1.5 mm, matrix = 256 x 256 pixels, field of view (FOV) = 260 mm x 260 mm).

3. RESULTS

The RMS field amplitude comparison with a two-way repeated-measures ANOVA found that a group by condition interaction was not statistically significant ($F_{(7,56)}$=1.12, p=.365) but the main effect of conditions was significant ($F_{(7,56)}$=3.05, p=.0086). Fishers' Least-Significant-Difference (LSD) multiple comparisons revealed that in the I condition, the incorrect condition *I(b) failed to induce stronger fields than the correct conditions I(a). Figure 1 illustrates peak RMS evoked field amplitudes of early syntactic responses averaged in the 100-200 ms time window across subjects in each group for the I and G conditions in both hemispheres.

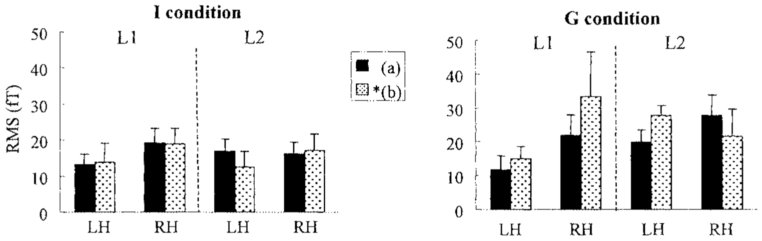

Figure 1: Peak RMS evoked field amplitudes of early syntactic responses averaged in the 100-200 ms time window across subjects in L1 and L2 groups for the I (infinitive) and G (gerund) conditions in each hemisphere [Error bar = 1 SD]

In the G condition, neuromagnetic fields were stronger in the incorrect condition *G(b) than in the correct condition G(a) in the LH only (p<.05), although there existed a trend toward statistical significance in the RH of NS subjects. The early syntactic magnetic field component generated by syntactically incorrect sentences in the *G(b) condition peaked at approximately 150 ms poststimulus (L1 subjects – LH: 135.36 ms, L2 subjects – LH: 159.35 ms). This latency was in accord with the latency triggered by incorrect within-phrase case-feature violations in my previous study (Kubota 2002). Figure 2 shows the overlaid waveforms in each hemisphere for a representative subject in each group.

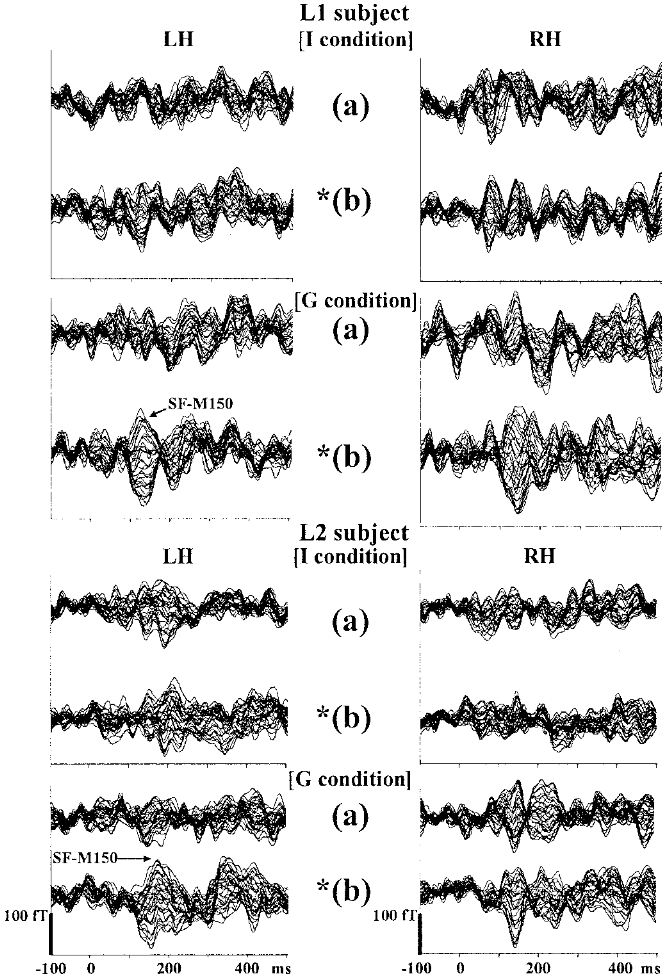

Figure 2: Overlaid waveforms in response to the I (infinitive) and G (gerund) conditions for a representative subject in each group (L1, L2 subjects)

The source analyses of the SF-M150 in response to the incorrect condition *G(b) showed that for a representative L1 subject, a single source was identified in the LH (fit intervals: 120.96 to 134.40 ms, an unexplained residual variance (RV): 1.10 %). One source in the LH was estimated to be in the lateral fissure, as displayed in Figure 3.

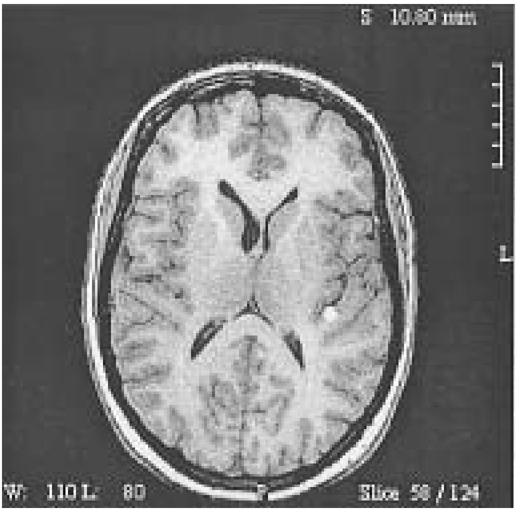

Figure 3: Estimated source localizations of SF-M150 elicited by the incorrect condition *G(b) in the left hemisphere (LH) for a representative L1 subject

4. DISCUSSION

A prominent early syntactic response was elicited by c-selection violations of infinitives (incorrect condition *G(b)) in the left hemisphere of L1 speakers and L2 learners. Such a component peaked at approximately 150 ms after stimulus onset and it was labeled the SF-M150 in my previous study (Kubota 2002). The source analyses demonstrated that the sources of SF-M150 were interpreted to be in the temporal region of the left hemisphere in a representative L1 speaker.

The SF-M150 component was not generated in the incorrect condition *I(b) with c-selection violations of gerunds in L1 and L2 subjects. This result implies that infinitival phrases in the incorrect condition *I(b) (e.g., *He postponed *to use it*) may be grammatically ambiguous at an initial stage of structure building operations that start with the critical word (*to*), such that the infinitive phrase denotes a purpose as in the adverbial phrase (e.g., *in order to use it*). One might surmise that such a grammatical ambiguity introduces parsing variability in syntactic processes, lessening the robustness of encoding for the early syntactic response for this structure or somehow interfering with its elicitation.

Two previous event-related potential (ERP) studies (Hahne 2001, Hahne and Friederici 2001) showed that unlike L1 speakers, L2 learners failed to exhibit an electrical early syntactic component (i.e., early left anterior negativity: ELAN) in response to within-phrase phrase-structure violations in German (e.g., *Das Geschäft wurde* [*am geschlossen*] = *The shop was being* [*on closed*]; Hahne 2001, Hahne and Friederici 2001). A recent MEG study conducted by the present researcher (Kubota 2002) found an early syntactic component of the evoked magnetic field (i.e., SF-M150) in response to within-phrase non-phrase-structure violations in English (e.g., *I believe* [*him is a spy*]), with the L1 speakers exhibiting the response but not L2 learners. The current finding revealed the existence of the SF-M150 component in L2 learners as well as L1 speakers in response to c-selection violations of infinitives occurring within a non-finite verb complement (i.e., within-phrase violations). This result supports my previous speculation that local (phrase-internal) processing is a trigger for an early syntactic response (Kubota 2002). In particular, the findings of my previous and current studies suggest that low-advanced L2 learners are likely to exhibit an early syntactic component in response to c-selection violations rather than syntactic feature violations as in a case-feature mismatch.

In my previous report (Kubota 2002), we speculate that there exists a continuum of error gravity with certain types of violations eliciting the early syntactic component. The absence of the SF-M150 in response to c-selection violations of gerunds in the present study is consistent with my previous results of across-phrase violations (e.g., " I believe he *to* be a spy"; Kubota 2002). Gerund c-selection violations may be considered weak at a neuronal level. In the infinitive c-selection violation condition *G(b), both L1 and L2 subjects elicited the SF-M150 in the left hemisphere. To my knowledge, this is the first MEG report of the early syntactic response in L2 learners, suggesting that the infinitive c-selection violations used in the current experiment may be particularly salient to them. The exact nature of how an early syntactic response develops with L2 learning in each hemisphere needs to be addressed in future studies, particularly how syntactic error gravity interacts with L2 proficiency.

5. CONCLUSION

The present study investigated whether English c-selection violations would elicit the SF-M150 component in both L1 and L2 subjects. The results showed that such an early response was observed by c-selection violations of infinitives (but not gerunds) in the left hemisphere of L1 speakers and L2 learners. Advanced L2 learners may possess similar pre-attentive neuronal mechanisms as L1 speakers for syntactic parsing of infinitive violations.

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