

Neuromagnetic Responses to English NP-raising and Case Filter Violations by L1 and L2 Speakers

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Abstract

My previous study [3] revealed that an early syntactic response (labeled the “SF-M150”) was elicited in first language (L1) speakers for within-phrase syntactic violations but not across-phrase counterparts, implying that there may exist a continuum of error gravity. Furthermore, for only c(ategorical)-selection violations of infinitives (but not gerunds), the present researcher found that the SF-M150 component was elicited even in L2 learners [4]. The current study investigated whether two types of syntactic violations would elicit a prominent early syntactic component in each hemisphere for both L1 speakers of English and Japanese learners of English as a second language (L2). Stimuli included syntactically correct and incorrect versions of noun-phrase raising (NP-raising) and case-filter constructions in English. 400 sentences were aurally presented to each subject,

while neuromagnetic fields were recorded using a dual 37-channel gradiometer system. A prominent magnetic syntactic field component, peaking at approximately 150 ms poststimulus (labeled “SF-M150”), was observed in both hemispheres of L1 and L2 speakers in response to NP-raising violations (e.g., *The man was believed was killed*), but not case filter violations (e.g., *It was believed the man to have been killed*). The findings imply that L1 and L2 speakers have similar neuronal mechanisms subserving syntactic parsing of strong movement-related violations, such as NP-raising violations.

Key words: Magnetoencephalography (MEG); Language; Syntax; Syntactic violation; SF-M150; NP-raising; Case filter

1. Introduction

Previous magnetoencephalography (MEG) studies have discovered that a prominent early syntactic component peaking at around 150 ms poststimulus was elicited by syntactically incorrect sentences for first language (L1) speakers in German [1,2] and English [3,4]. For such L1 speakers, the trigger of this early response, labeled the SF-M150, was a syntactic violation that takes place within a phrase (i.e., within-phrase violations), independent of whether a sentence breaks a phrase structure rule or not. However, low-advanced second language (L2) learners failed to exhibit such an early component in response to a within-phrase violation that does not break a phrase structure rule (i.e., case-feature mismatch as in the sentence *I believe [him is a spy]*) [3], whereas the SF-M150 component was elicited in L2 learners by a c(ategorical)-selection violation of infinitives as in the sentence *He happened using it* [4]. That is, L1 and L2 speakers exhibit a different neuronal sensitivity to a within-phrase violation according to whether it is related to a syntactic feature or a c-selection. The current study tested whether the SF-M150 component would be evoked by two types of violations,

noun-phrase raising (NP-raising) and case filter violations, and whether L2 learners would exhibit similar neuromagnetic responses as L1 speakers for both types of violations.

2. Materials and Methods

2.1. Subjects

The subjects were 5 native speakers of American English as a first language (L1), aged 23-39 (average=30.2; 2 females) and 5 non-native Japanese speakers of English as a second language (L2), aged 26-30 (average=28.2; 3 females). All subjects were healthy and right-handed with normal hearing and no known neurological disorders. All L2 subjects 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 13.2 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 574 to 600 (average=591). MEG recording was performed with the approval of the 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 NP-raising (NP condition) and without NP-raising (case filter (CP) condition) were compared. The number of correct and incorrect sentences was equal. Each sentence followed one of two frames: “[*It*] [*was* + past participle (pp)] [NP] [*was/to have been* + pp]” or “[NP] [*was* + pp] [*was/to have been* + pp].” For example,

CF condition: CF(a) It was believed the man was killed.

NP condition: *NP(b) The man was believed was killed.

NP condition: NP(a) The man was believed to have been killed.

CF condition: *CF(b) It was believed the man to have been killed.

[*: ungrammatical]

The stimuli are analyzed according to the Government and Binding theory. Briefly, the incorrect condition *NP(b) contains an NP-raising violation in which the predicate of the subordinate phrase is not changed to the infinitival phrase, or the subject of the

subordinate phrase (NP: e.g., *the man*) should not be raised out of the phrase and moved into a higher matrix clause. In NP(a) below, the governing category (the local domain) for the trace (*t*) of the moved NP is the higher matrix clause, since there is no agreement (Agr) in the embedded inflectional phrase (IP) [5]. The moved NP is coindexed with its trace (i.e., the $\text{man}_i - t_i$) and binds it within the governing category of the trace. Hence, the sentence is grammatical. On the contrary, in *NP(b) below, the governing category is the embedded complementizer phrase (CP) because of the existence of Agr in the tensed phase. However, the trace lacks an antecedent (i.e., *the man*) within its own CP phrase, so that the sentence is ungrammatical.

NP(a) The man_i was believed [_{IP} t_i to have been killed].

*NP(b) The man_i was believed [_{CP} t_i was killed].

The incorrect condition *CF(b) includes a case filter violation; the NP (e.g., *the man*) is left in the subject position of the infinitival phrase, so that a case cannot be assigned [6]. A passive participle in the matrix clause does not license an accusative case on the subject of an infinitival phrase [7]. Either the NP movement from the subject position of the lower infinitival phrase to the

subject position of the higher matrix clause (i.e., *The man was believed [to have been killed]*) or the change of the infinitival phrase to the tensed phrase (i.e., *It was believed [the man was/has been killed]*) enables the NP to pass the case filter.

In the current experiment, only the NP and the past participle forms of the matrix and subordinate verbs varied; 5 NPs, 5 past participles of the matrix verbs, and 6 past participles of the subordinate verbs were used. Everything else remained the same in each sentence across all conditions.

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 the 100 different sentences created was 2288.49 ms (min: 1692.80, max: 3168.90). 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 that was in a mid-sentence position. The critical word was '*was*' (verb of the subordinate phrase) in the CF(a) and *NP(b) conditions and '*to*' (infinitival particle of the subordinate phrase) in the NP(a) and *CF(b) conditions. Consequently, subsequent comparisons are made between conditions possessing the same critical word (i.e., CF(a) vs. *NP(b) conditions or NP(a) vs. *CF(b) conditions).

During MEG recording, the subjects were required to listen to English sentences and make a covert grammaticality judgment on each stimulus. 100 different sentences were repeated four times, and all 400 sentences were presented randomly by Psyscope software (version 1.2, [8]) on a Power Macintosh computer. The inter-trial interval (ITI) varied randomly between 3900 and 4100 ms in steps of 200 ms. The subjects lay on a bed with the head positioned between the two MEG sensors. Prior to the experiment,

positioning of each sensor over the auditory cortex was confirmed by neuromagnetic responses to 1 kHz pure tones.

Recording epochs of 1100 ms duration, including 100 ms pre-trigger baseline, 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 57 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 27 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 fT. The recorded data were selectively averaged by stimulus condition for each hemisphere. Averaged waveforms were filtered off-line with a 1-40 Hz band-pass filter and adjusted to the 100 ms pre-trigger baseline to correct for the drift associated with the DC offset.

The root mean square (RMS) of the magnetic field strength across sensor channels was calculated. The peak latency of early

syntactic processes was determined as the time point corresponding to the maximum RMS field value across each 37-channel sensor array in the time window of 80-220 ms. The alpha level with the Bonferroni adjustment was $\alpha=.025$ for two tests (i.e., CF(a)/*NP(b) and NP(a)/*CF(b) conditions). A two-way repeated-measures ANOVA was employed to compare the means.

Source localization analysis was performed using the Brain Electric Source Analysis (BESA 2000; MEGIS, Munich, Germany [9]). The generators of the prominent syntactic components obtained by BESA software were transposed to the anatomical MR axial images of a representative subject in each group within an estimated 4 mm error of measurement [10]. MR images were obtained by 1.5 Tesla MRI scanners (L1 subject – Signa, GE Medical Systems, Milwaukee, WI, USA, repeat time (TR) = 36 ms, echo time (TE) = 8 ms, flip angle = 30 degrees, slice thickness = 1.5 mm, matrix = 256 x 256 pixels, field of view (FOV) = 260 mm x 260 mm, L2 subject – Intera, Philips Medical Systems, Best, The Netherlands; TR = 20 ms, TE = 2.9 ms, flip angle = 30 degrees, slice thickness = 1.5 mm, matrix = 256 x 256 pixels, FOV = 260 mm x 260 mm).

3. Results

A prominent neuromagnetic field component, peaking at around 150 ms after the onset of the critical word (“SF-M150”) in the incorrect condition *NP(b), was elicited from both hemispheres of L1 and L2 speakers, as shown in Fig. 1. No such component was observed for any other condition in either group.

RMS evoked field amplitudes for two subject groups (L1 and L2 speakers) and four conditions (left hemisphere (LH): correct and incorrect conditions; right hemisphere (RH): correct and incorrect conditions) were compared by a two-way repeated-measures ANOVA. For the CF(a)/*NP(b) conditions, the group by condition interaction ($F_{(3,24)}=0.72$, $p=.55$) and the main effect for groups ($F_{(1,8)}=0.42$, $p=.53$) were not statistically significant, respectively, but the main effect for conditions was significant ($F_{(3,24)}=10.93$, $p=.0001$). A one-way repeated-measures ANOVA revealed that the condition differences were statistically significant ($F_{(3,27)}=11.28$, $p<.0001$), and Fisher’s Least-Significant-Difference (LSD) multiple comparisons of conditions showed that the magnetic strength of the early response to *NP(b) was significantly larger than that to CF(a) within each hemisphere in

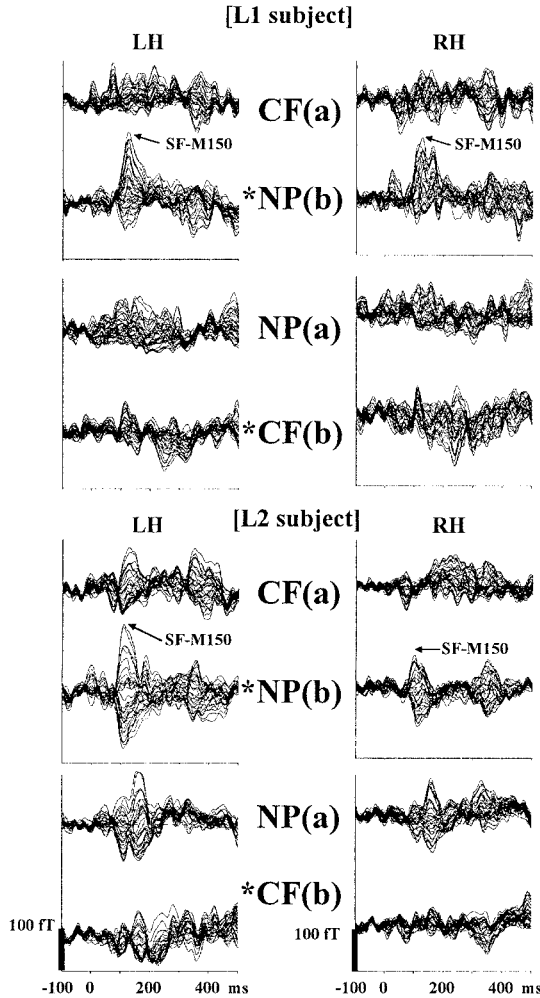


Fig. 1. 74 MEG channels are overlaid from the left and right hemispheres on the ordinate axis. Responses to correct sentences (CF(a), NP(a)) and incorrect sentences (*NP(b), *CF(b)) for a representative subject of each group are shown for each stimulus condition. Only the responses to *NP(b) for the L1 and L2 subjects have a prominent peak at approximately 150 ms.

both subject groups ($p<.01$) (see Fig.2). For the NP(a)/*CF(b) conditions, the group by condition interaction ($F_{(3,24)}=2.18$, $p=.12$), and the main effects for groups ($F_{(1,8)}=0.18$, $p=.68$) and for conditions ($F_{(3,24)}=0.26$, $p=.85$) were not statistically significant.

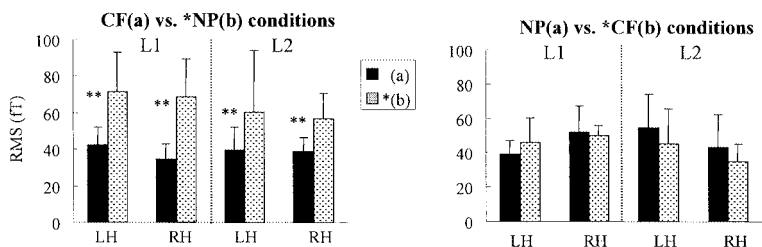


Fig. 2. Peak RMS field amplitudes (magnetic field strength) of an early syntactic response averaged across subjects for the CF(a)/*NP(b) and NP(a)/*CF(b) conditions within a subject group for each hemisphere [Error bar = 1 SD]. The RMS field values in both hemispheres of L1 and L2 subjects are statistically larger in the incorrect condition *NP(b) than in the correct condition CF(a) [$** p<.01$].

The peak latency of the early syntactic responses was also compared by a two-way (group by condition) repeated-measures ANOVA. No significant difference was observed for either the CF(a)/*NP(b) conditions or NP(a)/*CF(b) conditions: CF(a)/*NP(b) – $F_{(3,24)}=0.65$, $p=.59$ for the interaction, $F_{(1,8)}=0.93$, $p=.36$ for the main effect of groups, $F_{(3,24)}=0.83$, $p=.49$ for the main effect of conditions; NP(a)/*CF(b) – $F_{(3,24)}=0.35$, $p=.79$ for the interaction, $F_{(1,8)}=1.91$, $p=.20$ for the main effect of groups, $F_{(3,24)}=2.19$, $p=.12$ for the main effect of conditions). The mean latency of the early syntactic component elicited by the incorrect condition *NP(b) for L1 subjects was 155.14 ± 28.44 ms in the LH and 162.81 ± 30.28 ms in the RH, and for L2 subjects 139.58 ± 26.01 ms in the LH and 144.68 ± 31.98 ms in the RH (no statistical difference between the LH and the RH in each group).

Source analysis of the SF-M150 component in the incorrect condition *NP(b) showed that for a representative L1 subject, a single source was identified in the superior temporal sulcus in each hemisphere (LH – fit intervals: 114.24 to 162.23 ms, an unexplained residual variance (RV): 9.05%; RH – fit intervals:

127.68 to 158.40 ms, RV: 9.84%), as displayed in Fig. 3. For a representative L2 subject, a single source was estimated to be in the lateral fissure in each hemisphere (LH – fit intervals: 114.24 to 144.96 ms, RV: 8.68%; RH – 83.52 to 141.12 ms, RV: 5.06%). All sources were estimated by an in-house radiologist.

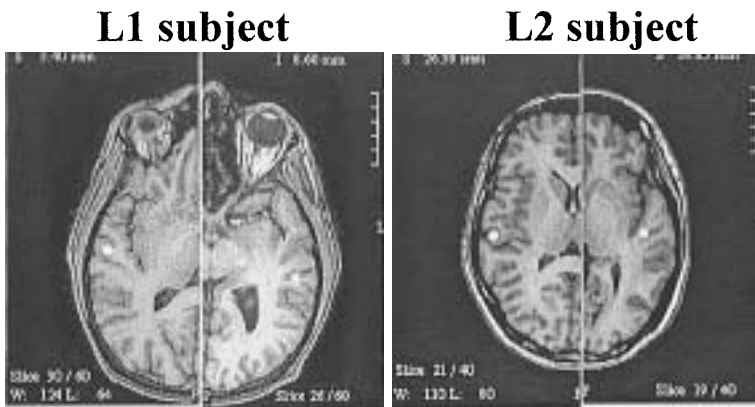


Fig. 3. Estimated source localizations of SF-M150 elicited by the incorrect condition *NP(b) for a representative subject in each group. A single source is identified in the temporal regions in the vicinity of the auditory cortex for both groups.

4. Discussion

The results showed that a prominent magnetic component was elicited by NP-raising violations in the incorrect condition *NP(b) in both hemispheres of L1 and L2 subjects. The magnetic strength in the incorrect condition *NP(b) was significantly larger than in the correct condition CF(a) in each hemisphere, with no hemispheric difference being observed in the *NP(b) condition. On the contrary, the case filter violations did not evoke the SF-M150 component in either group. The difference of this evoked response may be attributed to the structural difference; NP-raising violations related to movement appear strong enough to elicit a prominent magnetic field response, whereas case filter violations may be thought of as breaking a weaker rule and thus not eliciting a strong response.

The current finding is the first report of the early syntactic response observed in each hemisphere of both L1 and L2 speakers. In my previous MEG study, however, only the left-hemisphere activation was seen in L2 learners in response to c-selection violations of English infinitives [4]. The hemispheric discrepancy between my two MEG studies might reflect differences in the

structures' error gravity and the processing level of L2 learners with respect to gerunds/infinitives; NP-raising violations could be considered stronger and more salient such that it is easy for L2 learners to process them and both hemispheres are thus recruited in syntactic error processing, while violations of infinitives are less salient for L2 subjects and only elicit a weak LH response. The overall results of my previous [3,4] and current studies suggest that the elicitation of the SF-M150 component may depend upon "locality constraints" at a syntactic level in that an early syntactic response is generated by a neuronal mechanism responsible for local (phrase-internal) processing.

The peak latency of an early syntactic response in the incorrect condition *NP(b) was 158.98 ± 29.36 ms averaged over both hemispheres for L1 subjects, and 142.13 ± 29.00 ms for L2 subjects. Hence, this component was labeled the SF-M150 [3]. This 150-ms peak latency was in accord with three previous MEG studies [3,4,11]. Furthermore, the source localizations of the SF-M150 component revealed that the temporal regions in the vicinity of the auditory cortex in each hemisphere of both representative L1 and

L2 speakers were predominantly activated in syntactic error processing. This finding is in line with the previous MEG results [2,3,4,11].

5. Conclusion

The present study investigated whether English NP-raising and case filter violations would elicit the SF-M150 component in both L1 and L2 subjects. The results revealed that such an early response was elicited only by NP-raising violations, but in both hemispheres of both L1 and L2 speakers. We suggest that NP-raising violations are more salient than case filter violations and thus give rise to an SF-M150 neuronal event. Low-advanced L2 learners may possess similar pre-attentive neuronal mechanisms as L1 speakers for syntactic parsing of strong movement-related violations such as NP-raising violations. MEG recording of the SF-M150 appears to index both linguistic salience of syntactic violations and potentially the acuity of L2 learners. Future studies could identify a syntactic error gravity threshold that distinguishes individual L2 speakers from L1 counterparts. This study in a field of linguistic neuroscience highlights the utility of

employing imaging modalities capable of high temporal (1 ms) resolution like MEG.

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