

Auditory Evoked Field Responses in the Left Hemisphere to Morphosyntactic Violations in Korean Sentence

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ABSTRACT

To investigate multiple cortical regions associated with syntactic processes at the sentence level, auditory evoked field responses to morphosyntactic violations were measured over the left hemisphere of seven subjects. Subjects were asked to judge the acceptability of the final verb in verb-ending Korean sentence. Measured field data were transformed to the fields that would be detected on a standard sensing plane and averaged across subjects in different violation conditions. In the grand average data, we found distinct features at latencies of 400 ms and 600 ms, which seem to be specific to morphosyntactic processes. Equivalent current dipoles (ECDs) plotted on a standard brain indicate the inferior frontal region and the superior temporal gyrus for 400 ms component, and the middle temporal gyrus for 600 ms component. Our MEG study localized the distinct cortical regions involved in syntactic processes, which may be reflected in LAN and P600 of ERP.

KEY WORDS

Auditory evoked fields, Morphosyntactic, Sentence comprehension, LAN, P600, Grand average

INTRODUCTION

Previous ERP studies revealed the specific temporal components such as LAN and P600 that are correlated with syntactic processes in sentence comprehension, and brain imaging studies suggest several cortical areas specific to syntactic processes of auditory sentence [Friederici, 2000A]. However, only a few MEG studies reported the relevant areas for the temporal components of ERP [Knösche, 1999] [Friederici, 2000B], and it still remains unclear which cortical areas revealed by the imaging studies are responsible for the specific ERP components.

The purpose of the present study is to seek the activated regions that are responsible for the temporal components elicited by syntactic violations in an auditory sentence, where the verb was changed in morphosyntactic manner in a verb-ending sentence. As an experimental language, we used Korean, which has a subject-object-verb order structure, ending with a verb. The thematic role of nouns, such as nominative, dative, and accusative, is assigned by postpositional particles attached to the nouns

- (a) 아이가 정원에서 나무를 꺾었다
(A child in the garden the branch of a tree broke)
NOM ACC V
- (b) 아이가 정원에서 나무를 꺾었다
(A child in the garden the branch of a tree was broken)
NOM ACC V

Figure 1. Examples of Korean sentence in (a) correct, (b) morphosyntactic violation conditions.

as case markers. Thus, in Korean, the thematic role of a noun can be determined without considering the subcategorization information of the used verb, and the word order in a Korean sentence is relatively free compared with that in English. In addition, the properties of verb, such as tense, voice, and sentence type, are defined by adding or deleting the morphological affixes following the verbal stem. In a sentence, there are several 'Eojeol's which are composed of several morphemes or words but is shorter than a phrase (Fig. 1). Eojeol is the main component of meaning in a Korean sentence. Therefore, morphological changes of a verb, in an inappropriate manner, can introduce an error in a sentence and neural activities in response to such a violation can be measured as the response elicited by the verb, which is located at the last Eojeol.

METHODS

Seven healthy, right-handed adults (mean age 29 years, range 24-40 years) participated in this study after giving informed consent. All subjects were males and native speakers of Korean with no known hearing deficit and no history of neurological diseases.

A set of 109 sentences was constructed in a verb-ending structure. All sentences consisted of four Eojeols. The final Eojeol is a three-syllable word, in which the first syllable is the verbal stem representing the meaning of the verb and the second syllable represents the tense and the voice. The last one is a descriptive ending. Since all sentences contained a noun marked as accusative prior to the verb, the final verb should be made active. Morphosyntactic violation was generated by a morphological change of the second syllable of the final verb in the correct sentences. Therefore, the Eojeols in each incorrect sentence were identical to those in their correct counterpart except for the final verb, which contained a morphosyntactic violation. A total of 218 sentences, consisting of canonical and violated sentences, pronounced by a female speaker were recorded and were digitized.

The sentences were applied monaurally in a random order to the right ear of each subject and the subjects were asked to judge whether the final verb was adequate with respect to the preceding context of the sentence. MEG responses elicited by the verb were measured over the left hemisphere, covering the temporal region and a part of the frontal region, using a 40-channel SQUID system. Since this system measures two orthogonal field components (B_x and B_y) parallel to the bottom of the flat-tip dewar, the magnetic field map of the tangential components has an amplitude peak just above the dipolar source current [Kwon, 2002].

Since MEG recordings were obtained in a limited area of 100 mm x 100 mm and the recording area was different between subjects, measured fields were transformed into the fields that would be detected in a common sensing plane. To do this, hypothetical ECDs that could explain the measured fields were estimated within a spherical conductor by minimum norm estimation. Then, the root mean square of the transformed fields within a 50 ms period in different violation conditions was used for statistical analysis (ANOVA). Finally, the transformed fields were averaged over all subjects to obtain the grand average fields [Kwon, 2004]. Localization of single ECDs was carried out for prominent peak components of the grand average fields to find the mean location of the activated areas over multiple subjects. The obtained ECD locations were registered on a standard brain image.

RESULTS

Compared with correct conditions, the grand average waveform of the evoked responses to morphosyntactic violation conditions exhibited two prominent features at 400 ms and 600 ms and ANOVA tests of the rms fields across all channels revealed significant differences in the time window of 400-450 ms ($F_{1,6}=7.17$, $p=0.037$), 550-600 ms ($F_{1,6}=6.57$ $p=0.043$) and 600-650 ms ($F_{1,6}=11.8$ $p=0.014$).

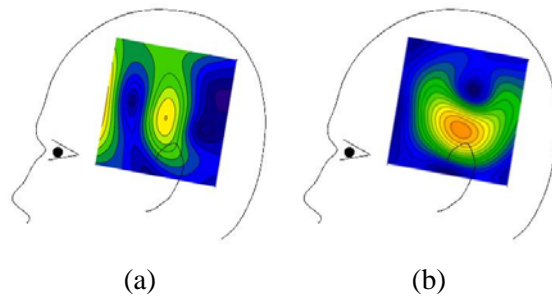


Figure 2. Grand average of the field distribution of (a) 400 ms and (b) 600 ms components in morphosyntactic violation condition.

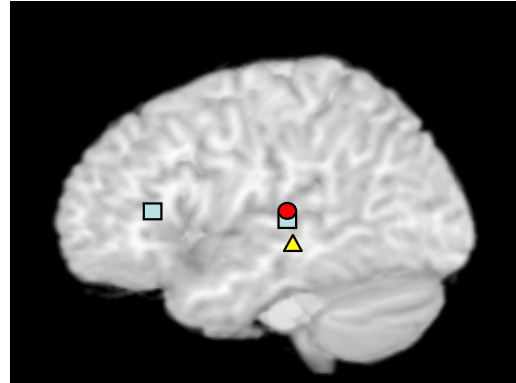


Figure 3. ECD localization results.

Paired t-tests between the two conditions in the responses at each channel revealed significant differences in the anterior (400 ms) and inferior central (600 ms) regions of recording area. In Fig. 2, (a) and (b) show the grand average field distribution of 400 and 600 ms components in morphosyntactic violation condition. Here, the color scale in (a) and (b) was normalized by the maximum field of 50 and 95 fT, respectively; the yellow region indicates the maximum. The contour pattern of 400 ms component indicated major activations in two regions within the recording area, i.e., the anterior part where a significant difference was observed in the waveform, and the central part. Using the grand average field distribution of Fig. 2, these two activations were localized at (5.2, 5.8, 5.3) cm in the head coordinates with a goodness-of-fit of 86.6 % and (-0.6, 5.6, 4.9) cm with a goodness-of-fit of 88.5 %, respectively. The field pattern of 600 ms component indicated an ECD in the region slightly inferior to the auditory cortex, and a posteriorly directed dipole was obtained with a goodness-of-fit of 95.7 % at a site of (-0.8, 5.2, 3.8) cm.

The ECDs plotted on a standard brain crudely indicate the left inferior frontal gyrus and the superior temporal gyrus for 400 ms component (square) and the middle temporal gyrus for 600 ms component (triangle), respectively, as can be seen in Fig. 3. Here, circle indicates the source of N100m by 1 kHz tone stimulus.

DISCUSSION

The purpose of this study is to specify common areas of the neural activity across subjects, which are responsible for temporal components in sentence-level syntactic processing. Here, a morphosyntactic violation was generated by a morphological change of the second syllable of the verb, which altered an active verb, for example, *broke* to a passive verb *was broken* in a verb-ending sentence (Fig. 1). In this manner, we observed clear peaks at latencies of 400 and 600 ms in the grand average waveform of the responses to a syntactic violation compared to the correct condition. An ERP component of LAN at 300-500 ms was evoked by the morphologically incorrect form of the verb [Rösler, 1993] [Gunter, 1997]. The scalp topography of LAN indicates a negativity in the left anterior region. In a PET study to disentangle grammar from semantics using pseudo sentences, it was shown that morphosyntactic processing is subserved by the left inferior frontal gyrus [Moro, 2001]. From these facts, the localized activity in the inferior frontal region seems to correspond to the response of LAN that reflects the processing of syntactic anomalies.

As to the other activity at 400 ms localized around the auditory cortex, it is inferred that this may reflect semantic incongruence. That is, it is difficult to integrate the passive verb *was broken* with the previous subject noun phrase *child*, semantically or pragmatically. Previous MEG studies indicated the superior temporal region around the auditory cortex for the neural generator of N400 that is elicited by

semantic anomaly [Mäkelä, 2001]. Therefore, the 400-ms component with the temporal source around the auditory cortex seems to correspond to N400, which reflects semantic processing. Following the 400-ms component, a prominent response was found at around 600 ms and is assumed to reflect processes of syntactic repair/reanalysis as P600 of ERP. The field distribution and ECDs plotted on a standard brain suggest that the left inferior frontal and the left superior temporal regions are responsible for the 400 ms component and the left middle temporal region, inferior to the auditory cortex, for the 600 ms component. These results are consistent with previous studies that reported an involvement of the left inferior frontal and temporal regions in syntactic processes of auditory sentence comprehension [Friederici, 2000A].

In summary, the results of the present MEG study indicate distinct cortical activities occurring in different latency periods during the comprehension of auditory sentences, i.e., in the inferior frontal region, the temporal area around the auditory cortex, and its inferior region around the middle temporal gyrus. Measurements were made, however, over the left hemisphere with limited coverage of sensors. Extending the measurement to the whole cortex would be a subject of further study.

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