Different word order evokes different syntactic processing in Korean language processing by ERP study*

Kyung Soon Shin\(^a\), Young Youn Kim\(^b\), Myung-Sun Kim\(^c\),
Jun Soo Kwon\(^{a,b,d}\)†

\(^a\)Interdisciplinary Program in Cognitive Science, Seoul National University, Seoul, Korea
\(^b\)Institute for Neuroscience, Seoul National University College of Medicine, Seoul, Korea
\(^c\)Department of Psychology, Sungshin Women’s University, Seoul, Korea
\(^d\)Department of Psychiatry, Seoul National University College of Medicine, Seoul, Korea

The goal of the present study is to investigate the Korean language processing by the event-related potentials (ERPs) during the congruent and incongruent conditions with semantic, syntactic and combined. The stimuli were presented visually, 180 of the sentences ended with an expected word (congruent condition), 60 with semantic condition, 60 with syntactic condition and 60 with combined condition to 15 participants. The semantically incongruent condition has shown the N400, which was distributed in right fronto-central region, to the previous semantic studies administered with Indo-European (IE) languages. In syntactically incongruent condition, the P600 is followed by N400 component but no early left anterior negativity (ELAN) was detected which was caused by the structure difference. Doubly incongruent sentences evoked N400 and P600 components with faster latency and higher amplitude than syntactic conditions. The differences suggest that the syntactic integration is affected by the semantic processing, however, the semantic structure is independent of syntactic context in the absence of semantic anomalies.

**Keywords:** Sentence processing; N400; P600; ELAN; event-related brain potentials

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†Corresponding author, Email: kwonjs@plaza.snu.ac.kr

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1. Introduction

Event-related brain potentials (ERPs) have been widely used to investigate the neurophysiological mechanism of human language. Previous ERP studies of semantic and syntactic processing have generally used a “violation paradigm” to identify indexes of different temporal stages of processing. ERP studies concerning language process have been reported to have three language-associated ERP components. The three major components are: N400, early left-anterior negativity (ELAN)/left anterior negativity (LAN), and P600 components (Hagoort et al., 1993, Kutas and Hillyard, 1980, Osterhout and Holcomb, 1992, Osterhout, 1994).

Kutas & Hillyard (1980) presented sentences with unusual endings and found a negative peak around 400 msec (ms) post-stimulus to the unexpected or incongruent ending word. It is observed that the N400 may be an ‘electrophysiological sign of the “reprocessing” of semantically anomalous information’. A large portion of researches have replicated this study, and extended the initial findings to different modalities and paradigms (Anderson and Holcomb, 1995, Hahne and Friederici, 2002, Osterhout et al., 1997).

The ELAN/LAN component is observed over left anterior electrode sites between 100-250 ms after stimulus onset. Studies about language processing have shown ELAN components in a syntactically inappropriate sentence processing (Friederici, 1995, Hahne and Friederici, 1999, Neville et al., 1991) even in MEG study (Friederici et al., 2000). Some researchers reported that the ELAN/LAN components were elicited at the latency of various time windows; 125 ms, between 300 and 400 ms and 550 ms (Gunter et al., 1997, Neville et al., 1991, Rosler et al., 1993). In case of later negative activation on syntactically incongruent sentence the component might be regarded as an N400 component of semantically anomalous sentence. With respect to this finding, Rosler and his colleagues reported that the syntactically incongruent sentences has a difficulty in lexical or semantic processing which causes the negative-positive compounding in a syntactically incongruent condition (Rosler et al., 1993). The P600 component was elicited when the syntactically inappropriate sentences were presented in response to a host of morphosyntactic and syntactic violation. This has been replicated in many

There are many researches on the integration of the semantic and syntactic information process in the brain (Ainsworth-Darnell et al., 1997, Gunter et al., 1997, Osterhout and Nicol, 1999, Friederici et al., 1999, Hahne and Friederici, 2002). Ainsworth-Darnell et al. (1997) reported that semantically incongruent words showed an N400 effect and syntactically incongruent words revealed a P600 effect. Moreover, doubly incongruent words elicited both the N400 and P600 components. According to Gunter et al. (1997), the P600 response to doubly incongruent words was reduced in amplitude, relative to the P600 elicited by syntactically incongruent ones. Osterhout and Nicol (1999) reported that both N400 and P600 components were found in the doubly incongruent condition with smaller N400 and P600 peaks. The subsequent experiment from Friederici et al. (1999) showed N400, P600 and ELAN components in each condition. However, doubly incongruent conditions elicited the same pattern of ERPs as the syntactic violation alone, not evoking an N400. Hahne and Friederici (2002) replicated this previous study by auditory stimuli on the same results with the visual stimuli.

According to Lehmann (1973), Korean language is different from Indo-European languages in that object precedes verb, so the sentence is composed of Subject-Object-Verb (SOV) in Korean. Compared with English, the syntactic structure building is not completed until the final word, verb comes in the Korean sentence.

The goal of the present study is to investigate the neural activities associated with the Korean language comprehension, in order to expand our understanding of the semantic and syntactic processing and their compositional processing of the natural language. In addition, it is aimed to figure out whether the different syntactic structure causes different syntactic processing or not. To answer these questions, the compositional processing of semantic and syntactic processing should be studied. Moreover, in order to find the source of each processing, it will be followed topographic map with multichanneled electroencephalogram (EEG).
2. Experiment

2.1. Participants

Fifteen right-handed undergraduate and graduate students (7 males and 8 females) with a mean age of 24.0 participated. None of the subjects had previous experience of ERP experiments or history of medical, neurological or psychiatric disorders. All subjects were native speakers of Korean and had normal or corrected to normal vision and were right handed. They were administered the Korean version of the Annett Handedness Questionnaires (Annett, 1970) and the Korean version of the Wechsler Adult Intelligence Scale to determine the IQ (K-WAIS: Yum et al., 1992) prior to ERP recording. After a complete description of the intended study, written informed consent was obtained. Subjects were paid for their participants.

Table 1. Examples of stimulus sentences of the four experimental conditions

<table>
<thead>
<tr>
<th>Types</th>
<th>Subject</th>
<th>Adverb</th>
<th>Object</th>
<th>Berb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely correct</td>
<td>Geuneun</td>
<td>ojeon-e</td>
<td>yeongh wa-reul</td>
<td>bo-assda watch-PST-DEC</td>
</tr>
<tr>
<td>condition</td>
<td>He-NOM</td>
<td>in the morning</td>
<td>the movie-ACC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>He wat ched the movie in the morning.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semantically incongruent</td>
<td>Geuneun</td>
<td>eoje</td>
<td>sin bal-eul</td>
<td>meog-eoss-da eat-PST-DEC</td>
</tr>
<tr>
<td>condition</td>
<td>He-NOM</td>
<td>yest erday</td>
<td>a pair of shoes-ACC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*He ate a pair of shoes yesterday.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactically incongruent</td>
<td>Geuneun</td>
<td>bulkkeun</td>
<td>jumeog-eul</td>
<td>jwipsida clench-PRES-EXH</td>
</tr>
<tr>
<td>condition</td>
<td>He-NOM</td>
<td>firmly</td>
<td>his fist-ACC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*He let us clench his fist firmly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doubly incongruent</td>
<td>Geuneun</td>
<td>jo-yonghi</td>
<td>ib-eul</td>
<td>neomgima tum-PROM</td>
</tr>
<tr>
<td>condition</td>
<td>He-NOM</td>
<td>silently</td>
<td>his mouth-ACC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*He will tum his mouth silently.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The abbreviations are used as follows: 
NOM-nominative case marker; ACC-accusative case marker; PST-past tense morpheme; PRES-present tense morpheme; DEC-declarative; EXH-exhort ative; PROM-promissive.
2.2. Materials
The 180 transitive verbs and rest of words are selected from “The Frequency of Modern Korean Vocabulary” in the 30-70 percentiles cumulative frequency range according to the Institute of Language and Information Studies (1998). Three hundred sixty sentences consisted of four words with the pattern of subject-adverb-object-verb with an active voice to create a clear phrase structure and selectional restriction violations (Table 1). Four different types of sentences were presented; correct condition, semantically incongruent condition, syntactically incongruent condition and both semantically and syntactically incongruent condition. The stimuli sentences consisted of 180 correct sentences, 60 semantically incongruent sentences, syntactically incongruent sentences and doubly incongruent sentences.

2.3. Correctness judging task
Participants were asked to judge whether sentences make sense or not by pressing one of two mouse buttons. Response fingers were counterbalanced across subjects.

The stimuli were presented in foveal vision on a computer monitor with an exposure duration of 300 ms, subtending a vertical visual angle of 2.29° and a horizontal visual angle of 3.43°, by an interstimulus interval of 600 ms with 2100 ms interval following the last word of the sentence. Prior to the experimental session, all participants trained a block to ensure that they understood the task perfectly.

2.4. ERP recordings
Electroencephalographic (EEG) activities were collected using a 128-channel Quik-cap system (Neuroscan, El Paso, TX, USA) in the electrically shielded and noise attenuated room. One hundred and twenty-eight scalp sites were recorded, and all of the scalp electrodes were referenced to linked electrodes placed on the left and right mastoid processes. Eye movements and blinks were monitored by a horizontal EOG, expressed as a differential recording between two electrodes placed at the outer canthi of the left and right eye, and a vertical EOG (vEOG), which is the difference of two electrodes placed at locations directly above and below the left eye. Impedance of scalp electrodes was maintained at 5 kΩ or less.
During the experiment the EEG was continuously recorded with a sampling rate of 1000 Hz. After the completion of data collection, the EEG was segmented into 1500 ms epochs, including a 100 ms prestimulus baseline. The baseline was corrected separately for each channel according to the peak amplitude of the EEG over the 100 ms period that preceded stimulus onset. Those EEG epochs that contained amplitudes exceeding $\pm 100 \mu V$ at any EEG or electrooculogram channel were automatically excluded from the averaging. The EEG epochs were then averaged for each subject and each stimulus presentation condition (correct sentences, semantically incongruent sentences, syntactically incongruent sentences, doubly incongruent sentences).

The averaged waveforms of ERPs were digitally filtered with a bandpass between 1 and 15 Hz. Only the EEGs of the correct responses, i.e. correctly judged words in the sentence correctness judge task, were subjected to the statistical analysis.

2.5. Statistical analysis

For every subject, statistical analyses were executed on the peak amplitude of 21 electrode sites (Fz, F3, F4, F7, F8, FCz, Cz, C3, C4, T7, T8, CPz, Pz, P3, P4, P7, P8, POz, Oz, O1, and O2) within ELAN (100-200 ms), N400 (300-500 ms) and P600 (500-700 ms) time windows determined by visually inspecting individual and grand averaged waveforms. The amplitude and latency of each interval in three time window were calculated and analyzed by means of mixed design ANOVA, repeated measures with electrode sites (21 sites) and sentence condition (correct, semantically incongruent, syntactically incongruent and doubly incongruent conditions) as within-subjects factors. Left (F3, F7, C3, T7, P3, P7 and O1) and right (F4, F8, C4, T8, P4, P8 and O2) were calculated for laterality and frontal (Fz, F3, F4, F7, F8 and FCz), central (Cz, C3 and C4), parietal (Pz, P3, P4, P7, P8 and POz), occipital (Oz, O1 and O2) and temporal (T7 and T8) lobes were analyzed for regional effect by a two-way repeated measure ANOVA. It was analyzed the laterality using a two factor ANOVA, with sentence condition and hemispheric laterality (left, midline and right) as within-subjects factors. A regional effect with sentence conditions and regions (frontal, central, parietal, occipital and temporal) as within-subjects factors were analyzed.

Huynh-Feldt corrections for multiple comparisons were applied when
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Fig. 1. Grand averaged ERPs for the critical word. A: correct condition (solid line) vs. semantically incongruent condition (dotted line). B: correct condition vs. syntactically incongruent condition. C: correct condition vs. doubly incongruent condition.
appropriate, and the corrected $p$ value was reported. Reaction time and hit rates were also subjected to ANOVA, repeated measures, and mixed design.

3. Results

3.1. Behavioral findings

The hit rate for each correct, semantically incongruent, syntactically incongruent, and doubly incongruent condition are 95.9% (S.D. = 2.0), 97% (S.D. = 2.8), 95.9% (S.D. = 2.3), and 99% (S.D. = 1.5), respectively. A one-way ANOVA performed on the reaction time data revealed significant main effects of the sentence type $[F(3,42) = 13.960, P < 0.001]$. The data shows that the mean reaction time for doubly anomalous condition (Mean = 932ms, S.D. = 195.1) is the shortest among the conditions. The mean reaction time of correct condition was 1032.6 ms (S.D. = 174.7), semantic condition was 1055 ms (S.D. = 235.9) and syntactic condition was 1044 ms (S.D. = 198.5).

3.2. Event-related potential data

The semantically and the syntactically incongruent sentences have a significant difference to the correct sentence (Fig. 1A, B). Not in accordance with the study of language processing, the N400 is elicited in the doubly incongruent condition (Fig. 1C). No ELAN component is seen on the ERP data of the syntactically and the doubly incongruent sentence processing of this experiment. As expected, correct sentences extracted smaller N400 and P600 than all the incongruent conditions. The semantically incongruent condition elicited larger amplitude than the correct sentences to negative aspects at around 400 ms. The syntactically incongruent sentences showed the N400 and P600 components but no ELAN component was detected. In the doubly incongruent condition, the P600, N400 and no ELAN components were shown like syntactic condition with higher amplitude and faster latency with the same time windows.

3.2.1. Visual Inspection

Grand-averaged waveforms in the semantically incongruent condition clearly elicited N400 component begins with around 300 ms and lasts on 500 ms (Fig. 1A). The semantically incongruent sentences elicit the most activation
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in right frontal lobe (Fig. 2A). The early time window (100-200 ms) in the syntactic condition revealed neither main effect nor interaction of conditions with the N400 component followed by P600. However, unlike the studies about language processing, ELAN component was not detected in the syntactically incongruent condition. The activation in the fronto-central region is observed during syntactic processing as in Fig. 2B. The doubly incongruent condition has two different time windows (300-500 and 500-700 ms) to detect the significant ERP components. Both the N400 and P600 components were found in the doubly incongruent sentence condition without ELAN component. Doubly incongruent condition has the nearly same data pattern

Fig. 2. Topographic map of N400 and P600 components on each condition at the frontal region on the FCz site with each grand averaged ERPs for each condition. A: semantically incongruent condition elicited N400 component and peaked at 401 ms. B: syntactically incongruent condition evoked N400 and P600 component and activated at 420 ms and 586 ms respectively. C: doubly incongruent condition peaked at 403ms and 532ms for each N400 and P600 component.
with the noticeably higher amplitude and faster latency compared with the syntactic incongruent condition. The three dimensional topographic map shows the activation was detected in fronto-central region in case of the P600 component (Fig. 2C). In terms of the N400 component, it is distributed over the right frontal lobe as the semantic condition (Fig. 2C).

3.2.2. Statistical Analysis

ANOVA's on mean amplitude between 300 and 500 ms revealed a main effect for sentence conditions \[F(3,42) = 35.293, P < 0.001\], electrode sites \[F(20,280) = 11.158 , P < 0.001\] and reliable interaction between sentence conditions and electrode sites \[F(60,840) = 2.535, P < 0.015\]. When N400 amplitude analysis was performed on midline sites (7 sites), significant main effects of sentence conditions \[F(3, 42) = 33.031 , P < 0.001\], and electrode sites \[F(6, 84) = 15.906, P < 0.001\] were obtained. There was no main effect for sentence condition in latency with 300-500 ms time interval. No significant interaction in sentence conditions and electrode sites was observed. It showed the most negative N400 amplitude at Fz and the least at T7, for semantically incongruent conditions.

Within the 500-700 ms range, main effect between sentence conditions \[F(3,42) = 7.024 , P < 0.002\], electrode sites \[F(20,280) = 10.243 , P < 0.001\] and interaction between sentence conditions and electrode sites were observed \[F(60,840) = 2.568, P < 0.008\]. When the P600 amplitude analysis was performed on midline sites (7 sites), significant main effects of sentence conditions \[F(3,42) = 7.299 , P < 0.001\], and electrode sites \[F(6,84) = 13.040 , P < 0.001\] were obtained. The interaction between sentence conditions and electrode sites was observed \[F(18,252) = 2.527 , P < 0.04\]. The main effect for electrode sites \[F(20,280) = 2.608 , P<0.012\] was significant with respect to the latency on 500-700 time window and the some trend on the main effect of the sentence condition was found \[F(3,42) = 2.661 , P < 0.06\]. No significant interaction in sentence conditions and electrode sites was observed. It was showed that the most positive P600 amplitude at Fz and the least at P7, for the syntactically incongruent condition.

There were significant main effects for hemispheric laterality for the N400 \[F(2,28) = 5.058 , P < 0.013\] and P600 \[F(2,28) = 9.447 , P < 0.001\] and sentence conditions for the N400 \[F(3,42) = 35.293 , P < 0.001\] and P600
The significant interaction between hemispheric laterality and sentence conditions for N400 \([F(6,84) = 3.685, P < 0.003]\) and P600 \([F(6,84) = 2.841, P < 0.028]\) was found. It implied that the difference exist performing task in hemispheric laterality.

With the time range of 300-500 ms, the main effects for the scalp regions \([F(4,56) = 14.368, P < 0.001]\) and sentence conditions \([F(3,42) = 36.431, P < 0.001]\) were discovered significance. The significant interaction between scalp regions and sentence conditions for N400 \([F(12,161) = 2.641, P < 0.04]\). In the 500-700 ms time window, the main effect for the scalp regions \([F(4,56) = 14.128, P < 0.001]\) and sentence conditions \([F(3,42) = 7.546, P < 0.001]\) were discovered significance. The interaction between the scalp regions and sentence conditions \([F(12,168) = 3.211, P < 0.011]\) were significant. The regional effect was differentially observed in all conditions.

4. Discussion

This experiment was focused on the Korean language processing, which has both similarity and dissimilarity to IE languages with the electrophysiological method; ERPs. More specifically, the relation between semantic and syntactic processing, and additionally each processing were aimed to be detected. This experiment provides several important pieces of information in the feature of ERP components elicited by Korean sentence stimuli.

The N400 is regarded as a neurophysiological index of the semantically incongruent condition. This condition evokes a clear N400 component, which was distributed over a centro-parietal lobe with 400 ms time window. Words that occur in late-sentence positions show smaller N400 than the words located in earlier sentence positions because the former ones can take an advantage from a larger exposure to the ongoing sentence context (van Petten, 1995). In this study, the semantically incongruent condition shows a similar waveform and latency but the topography is different from the previous semantic studies administered with IE languages (Kutas and Hillyard, 1980, Kutas and van Petten, 1994, Oterhout and Holcomb, 1995).

Some researchers regard P600 as a family of P300 effect and called P3b, often observed after the reception of any unexpected stimuli (Coulson et al., 1998) and rare events embedded in a sequence processed by the subject.
Others consider that the P600 is one of the language specific ERP components associated with aspects of structural reanalysis, repair and recall of the ungrammatical sentences (Friederici et al., 1996, Friederici and Mecklinger, 1996, Hagoort et al., 1993). The P600 has been found on anomalies of phrase structure, verb subcategorization, constituent movement, agreement, case (Osterhout et al., 1997) and subjecacy, and specificity (Neville et al., 1991). Unlike previous studies, in this study, N400 component was observed in the phrase structural violation of the syntactically incongruent condition. One of the finding is that the different word order between Korean and IE languages may elicit the N400 component in the syntactically anomalous condition. Korean language has an order of SOV. Since the object is processed prior to the verb, it is difficult to know how many and what types of arguments are required on the verb in a sentence. It reflects a reprocessing of a sentence until the necessary components come. The other expansion is that the sentence is designed to process the meaning after the sentence structure building to check the grammaticality that is revealed the negative potential around 400 ms. According to the morphological point of view, Korean is an agglutinative language in which words are made up of a linear sequence of distinct morphemes and each component of meaning is represented by its own morpheme. When a word is inflected, a word stem and an ending are distinctively divided. A verb comes to the end of the sentence in Korean language; the last word can be detached a word stem and an ending which is separate into a prefinal ending and a final ending. Korean has many types of final ending such as Imperative, Exclamatory, Exhortative, Promissive and Declarative. The errors in syntactically and doubly anomalous sentences were explicitly generated from mismatching the final ending with a subject of the sentence. When the syntactic anomalousness was detected, a semantic reprocessing was conducted with the appropriated information of ‘Person’ and it caused N400 component.

It is recognized the syntactic negative shift as ELAN/LAN with time window of 100-250 ms with a stimulus onset. Rosler and colleagues (1993) research showed LAN component had a maximum peak on 400-700 ms which is distributed in left anterior. This syntactic negative shift can be confused with the N400 component in accordance with their similar time range. However, the LAN with 400 ms negative component has different scalp distribution with the
N400 in semantically anomalous sentences. This LAN component is distributed more left anterior not in accordance with N400 in semantic, which is distributed centro-parietal (Kutas and van Petten, 1994), right central with this present study. According to Friederici (2002), ELAN correlates with rapidly detectable word category errors while the left anterior negativity (LAN) correlates with morphosyntactic errors. The neurocognitive model of auditory sentence parsing by Friederici (2002) showed that the ELAN component concerns the syntactic structure building. So far, ELAN components were detected in the syntactically anomalous conditions (Friederici, 1995, Neville et al., 1991, Osterhout and Holcomb, 1992). However, a matter of a word order may cause the absence of ELAN component. The ELAN component cannot be seen in the syntactically incongruent condition in this study because the structure building is not physically completed until the final word appears.

In the doubly anomalous condition, both N400 and P600 components were detected in this experiment, supported by Osterhout and Nicol (1999), Ainsworth-Darnell et al. (1997) and Hagoort et al. (1993). In the present study, the N400 and P600 components in the doubly anomalous condition shared the components with the P600 in the syntactically anomalous condition and the N400 of the semantically anomalous condition with the same time windows of the doubly anomalous condition. Ainsworth-Darnell et al. (1997) also proposed, the co-occurrence of N400 and P600 components supports the dual processing hypothesis which suggests there are two separate routes for semantic and syntactic process. Their results show that two processors worked out in the brain and elicited two potentials independently.

In the contrary to the long-standing idea of left hemisphere dominance in language processing, right hemisphere is also related to the certain aspects of language processing (Kutas and Hillyard, 1982, Nakagome et al., 2001) as well as left hemisphere. The short presentation of the stimuli causes the activation over the fronto-central region during semantic and syntactic processing.

If the word presented with long duration, it may increase working memory loading. This may cause to activate a posterior than an anterior distribution. Also, the orthographic characteristic may give an effect to the topographic map to activate the right hemisphere more. Takazawa and colleagues (2002) reported that the right hemisphere was predominantly activated in semantic and syntactic processing in Japanese. The study of Chinese language also
showed that the right prefrontal area was strongly activated in the mid latency (300-400 ms) period of Chinese character naming (Liu and Perfetti, 2003). Since the orthographical structure of Korean language requires right-dominant visual processing, as the right hemisphere is specialized for spatial and holistic processing (Kim et al., 2004), the language-related activation in right hemisphere is observed compared to left hemisphere.

With respect to these findings, it is possible to reach some conclusions. Firstly, the semantic processing in Korean is similar to IE languages. The N400 component was evidently shown over the brain in semantically incongruent conditions. Secondly, the syntactically incongruent condition elicited along with N400 and P600 components and without ELAN component. The results suggest that different word order brings about different syntactic processing in the cerebral mechanism. The output feature of the brain mechanism varies according to the word order. That is, the different word order evokes different syntactic processing. Lastly, doubly incongruent condition explicitly showed the N400 and P600 components with much faster latency and higher amplitude compared with syntactically incongruent condition in all aspects. In comparison to semantically incongruent condition, no difference was found in N400 component in doubly incongruent condition. The results suggest that the syntactic integration is affected by the semantic processing, however, the semantic structure is independent of syntactic context in the absence of semantic anomalies.

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