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Neural Correlation of Relation Information-evidence from ERP

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Abstract

Central-parietal N200 is an ERP component that associates with orthographic processing in Chinese word recognition. Studies have shown that it may be related to the early processing of morpheme structures. Compound words can be regarded as the smallest unit of morpheme combination, the recognition process can be analogous to the comprehension of the sentence, including combining constituent morphemes. This process includes grammatical combinations and semantic combinations. Studies have found that the semantic combination takes place during the N400 time-window. Generally speaking, the grammatical combination should occur before the semantic combination, so does the structure priming that occurred during the N200 time-window represent grammatical combination? We explored this issue by using Chinese coordinative compounds and ERP technology. We found that there is a significant grammatical structure priming effect in the processing of Chinese compound words. This effect occurs in the early stage of word processing, that is, the N200 period. Combined with the previous research, the semantic relation priming occurred in the N400 window, indicating that the grammatical combination did appear before the semantic combination, and outlined the time course of the effect of relation information.

Keywords: Compound words • Grammatical composition • Structure information • ERP

Introduction

The debate surrounding morphemic complex words centres on whether they are mentally represented as holistic units or decomposed into individual morphemes in the mental lexicon. Extensive research employing diverse methods has yielded three predominant theoretical models [1-6]. The full-listing models contend that compound words are stored and accessed as singular units, while the decomposition model posits that they are dissected into constituent morphemes for representation. In contrast, the hybrid model reconciles these perspectives, proposing that both forms of representation coexist.

Recent studies utilizing EEG and MEG have uncovered evidence that manipulating the morphemic characteristics of compounds influences early electrophysiological responses, bolstering support for the decomposition model [3,7-9]. For instance, the central-parietal N200 component has been implicated [9].

This accumulating evidence aligns with the notion that storing multi-morpheme words in a decomposed format within the mental lexicon offers a more efficient means of combining them to express novel concepts when necessary [10]. Particularly in written Chinese, which employs a meaning-based spelling system, word formation involves a combination operation. Thus, it is unsurprising that evidence supporting decomposition storage has emerged in studies utilizing Chinese as their primary material p [11].

In a study by Zhang, et al. [9], subjects were presented with a series of two-character real and pseudo words, and they were asked to distinguish between them. Depending on the relationship between prime-target word pairs, they defined four conditions:

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1. Control Condition: In this condition, the prime and target words were entirely unrelated (e.g., meaning coin-weak).
2. Whole Word Repeated Condition: Here, the prime and target words were identical (e.g., meaning thinking-thinking).
3. First Character Repeated Condition: In this condition, the first character of the prime and target words was the same, but the second character was different (e.g., meaning honor-splendor).
4. Last Character Repeated Condition: In contrast, the second character of the prime and target words was identical, while the first character differed (e.g., meaning fluency-mutual benefit).

Comparing these conditions to the control condition, it was observed that the amplitude of the N400 component decreased in the three repeated conditions (2, 3, and 4). However, a noteworthy finding was that across all conditions, a negative waveform emerged approximately 200 ms after the stimulus onset. Given its broad distribution across frontal, middle, and parietal brain regions, this component was termed the "central-parietal N200."

In contrast to the reduction in N400 amplitude during repeated conditions, the N200 amplitude significantly increased under repetition. This enhancement effect was more pronounced in whole-word repetition conditions compared to partial repetition conditions. Specifically, when the morphological similarity between the prime and target was highest, the magnitude of the N200 repetition effect was greatest. Conversely, when the morphological similarity between the prime and target was lower, the extent of the N200 repetition effect was diminished. This outcome provides direct evidence that the N200 component reflects orthographic processing.

The character experiment also found, the repetition effect of N200 also exists on both pseudo and non-character, but the magnitude is smaller than that of real character. These two types of stimuli are also composed of radicals. They all triggered N200, just like real characters, indicating that the radicals in the three types of stimuli above mentioned can elicit N200. That is, N200 reflects the processing of the radicals, and this processing does not depend on its location.

After learning and using the real characters, its components' positional relation has a pre-existing representation in the brain. In contrast, the positional relation between radicals of the pseudo and non-character has no pre-existing representation in mind. The N200 effect of real characters is greater than that of pseudo-characters and non-characters, which suggests that this effect reflects not only the processing of radicals but also the access to the prior representation of the positional relation of radicals [12].

Combining single characters to form two-character words may be similar to combining radicals to create single-characters. Both single-character and double-character words can elicit N200 responses, but the amplitude of N200 elicited by double-character words is more robust than single characters. It may be because the N200 response to a double-character word is a superposition of that of its two constituents. Du, et al.'s research adopted a delayed repetition priming paradigm and included two conditions: The whole word repetition condition (meaning manager-manager) and the constituents repetition condition (the former is a pseudo word and the later means nurse). They found the N200 effect of the whole word repetition condition is more significant than that of the constituent repetition condition [13].

However, the morphemes contained in them are the same, which suggests that this effect may reflect the access to the pre-existing representation of the relation between morphemes in addition to the representation of themselves [14].

Zhang's research found that N200 may reflect the processing of visual word representation at the level of orthography. The above inference shows that N200 is also very sensitive to the relation between the components or morphemes of single or double-character words. Relations of multi-morpheme words can be divided into grammatical and semantic relations [15,16]. At the grammatical level, unlike the compound words in Indo-European languages, modifier-noun is the dominant structure. There are five grammatical structures in Chinese. For example, subordinate (e.g., meaning pheasant), which corresponding to modifier-noun structure in English; coordinative (e.g., meaning lights); verb-object (e.g., meaning school opens); supplement (e.g., meaning extended); subject-predicate (e.g., meaning earthquake). Among them, the coordinative structure is unique. Unlike other types, there exists no dominant morpheme (the head). Its two constituents play the same role in the semantic contribution to the whole word. In languages where the subordinate is the only structure, only the effect of semantic relation could be checked. For example, Gagne discovered semantic relation priming in compound words with modifier-noun structure; that is, the target word can be facilitated by the prime word with the same semantic relation. For example, the participant would feel student vote (vote by a student) is easier to understand than student car (car of a student) if they have just watched student accusation (accusation by a student) [17-19]. But in Chinese, we find that both grammatical and semantic relations play an important role in compound word processing [15,16,20]. Except for semantic relation priming, we also found grammatical structure priming; that is, the target can be facilitated by the prime with the same grammatical structure. For example, if the participants have just watched (wind and rain, meaning storm), they will feel that (wind and snow, meaning blizzard) is easier to understand than (meaning wind direction). And the existing research has proved that the semantic relation works in the semantic window [20]. Could the structural effect reflected in the N200 period be a grammatical relation? Theoretically, the grammatical structure defines the grammatical relation between morphemes. Although it does not explain their thematic relation, the grammatical structure is the basis for establishing a semantic relation between the two morphemes [21]. In other words, the recognition of grammatical structures must precede the more subtle semantic relations. We will design experiments below to test this hypothesis, whether grammatical combination occurs before the semantic combination.

Up to now, two studies have examined the ERP responses elicited by the grammatical structure of Chinese two-character words. Chung, et al.'s study on Chinese coordinative compounds found that when the SOA is 57 ms, there is a grammatical, structural effect on P250 [22]. Research by Gu, et al. found a pure grammatical structure effect in the early stage of Chinese visual word recognition, P2a (150 ms-180 ms) may reflect this process [23]. But observing their ERP results, it is not difficult to find a noticeable N200 wave, and there is a significant priming effect of grammatical structure on N200. But it was ignored in both studies.

Based on the accumulated evidence above mentioned, to verify whether the grammatical structure effect occurs during the N200 period and whether this effect occurs before the semantic relation effect, we designed the following experiment. We used a sense-nonsense judgment task and a priming paradigm; EEG was recorded at the same time. We set three conditions (see Table1):

Table 1. Examples of experimental materials.

Condition	Semantic relation	Grammatical structure	Examples (prime-target)
S	same	same	warehouse-friend
D	different	same	day and night-friends
N	different	different	bookstore-friend
Note: The prime and target sharing the same grammatical structure and the same semantic relation (condition S);The prime and the target have the same grammatical structure but different semantic relation (condition D); The prime and the target has no relation; that is, both the grammatical structure and semantic relation are all different between them (condition N).			

1. The prime and target sharing the same grammatical structure and the same semantic relation (condition S); for example, (warehouse-friend), they both belong to coordinative in grammatical structure and synonymous combination in semantic relation;
2. The prime and the target have the same grammatical structure but different semantic relation (condition D). For example, (day and night-friends), they all belong to coordinative in grammatical structure. But in semantic relation, the previous one belongs to antonymous combination, while the latter belongs to synonymous combination;
3. The prime and the target has no relation; that is, both the grammatical structure and semantic relation are all different between them (condition N), for example, (bookstore-friend), where the prime belongs to subordinate structure, the target belongs to the coordinative structure.

If N200 reflects the effect of grammatical structure, then N200 should distinguish words with different grammatical structures. We expect that the N200 amplitude of the N condition will be significantly different from the S and D conditions. The prime of the S and D conditions share the same grammatical structure with the target, whereas N's prime condition has a different grammatical structure from the target, reflecting the grammatical structure priming. Given the previous discovery that the semantic relation priming occurs on N400, compared with two compound words with different semantic relations, compounds with the same semantic relation have a more substantial priming effect between each other. We expect that the S condition's N400 amplitude will be smaller than that of the D condition, reflecting the semantic relation effect (relation priming). If the results meet our expectations, the grammatical structure effect occurs in the N200 period, and the semantic relation effect occurs in the N400 period. Then we would specifically outline the structural information's time course; that is, the grammatical combination occurs before the semantic combination.

Methods

Participants

27 healthy college students volunteered to participate in this experiment. All of them were right-handed, aged between 18-25 years (average 22.7 years), they were native Chinese speakers, and their vision or corrected vision was normal. All subjects read and signed the informed consent form following a research protocol approved by the IRB board of Xiamen University before the experiment, and all methods were performed in accordance with the relevant guidelines and regulations.

Stimuli and procedure

The critical target words include 108 coordinative compounds, and each target word has three primes corresponding to the three conditions. According to the word frequency dictionary of Cai, et al. [24], the average word frequency of the target word is 1.77. The word frequencies of the three groups of priming words were matched (S: 1.74; D: 1.68; N: 1.72). The fillers contain the same number of 324 prime and target word pairs. The prime is a real word, and the target is a pseudo-word composed of two real characters. Key and filler word pairs are all divided into three parts, forming three versions. Each version contains 108 key word pairs and 108 filler word pairs. Each target word appears only once in each version, and its corresponding three primes appear in the three versions, respectively. Each participant was assigned to one version for a test.

The experiment adopts a sense-nonsense judgment task of priming paradigm and a self-paced stimulus presentation method. Participants face the screen with a distance of about 0.7 m. The index finger of the left and right hand is placed on the F and J keys of the keyboard, respectively, with both eyes looking at the fixation in the screen's center. Each trial starts with a "Ready?" presented in the center of the screen. When the subject was ready, he/she pressed the Q key and a two-character word appeared. The subject judged whether the word was meaningful or not by press the corresponding key as quickly as possible. Press F for sense, J for nonsense. After the subjects responded, the words "Ready?" appeared on the screen again. When the subjects are ready, they press the Q button to start the next trial. Two adjacent trials were a group, with the first presenting the priming word and the second presenting the target word, but this was not told to the subjects. A self-paced presentation was taken to give participants enough preparation time to ensure that they can fully understand each word.

EEG recordings and data analysis

Neuroscan system was used to record EEG from the scalp using a 64-lead Ag/AgCl electrode cap, where the electrodes were placed following an extended 10-20 system. The bandpass filtering range is 0.1 HZ-70 HZ, and the sampling rate is 500 HZ. The contact resistance between all electrodes and the scalp is less than 7 kΩ. The electrode for recording the vertical EOG is located below the left eye and above the left brow bone, and the electrode for recording the horizontal EOG is located on the left and right lateral orbital rim. Taking the tip of the nose as a physical reference, the original EEG was recorded continuously and was re-referenced offline to the mean of the bilateral mastoids. EEGLAB 14.1.1 was used for data analysis. Epochs were computed from 200 ms before to 800 ms after the stimulus onset, and the baseline correction was made between -200 ms-0 ms. The offline bandpass filtering was applied between 0.1 Hz-30 Hz, and independent component analysis (ICA) was used to remove ocular artifacts. Incorrect responses and responses with amplitude greater than ± 75 μv are excluded from the superimposed average. The number of trials rejected due to artifacts is less than 6%.

Results

Behavioral results

We use the LmerTest package of R software to fit a mixed-effects model with logarithmic response time as the dependent variable, conditions as a fixed factor, and subject and item as a random factor [25-27]. The results show that the main effect of the conditions is significant, F(2,1776)=5.36, p<0.005; and the difference between S, D condition and N condition is significant, that is, the average response time of all subjects under S and D condition is significantly slower than that of N condition (S vs. N: 857 vs. 800 ms, t(1776)=2.41, p<0.01; D vs. N: 874 vs. 800 ms, t(1776)=3.12, p<0.001). There is no significant difference between S and D condition (857 vs. 874 ms, t(1776)=-0.71, p>0.1). The accuracy rate of all conditions has reached above 99%, the ceiling effect has appeared, and no significant difference was found between all the conditions.

EEG results

Figure 1 shows the average EEG response on the representative electrodes using different colors for the three conditions. S, D, and N conditions all elicited a clear N200 response, the peak of about 200 ms after the stimulus's onset. It was widely distributed, especially in the frontal and parietal regions. We can see that the amplitude of the S and D conditions are not different from each other, but both are significantly lower than that of the N condition. Take a 150 ms-250 ms time window and calculated the mean amplitude of 9 electrodes (FC1, FCz, FC2; C1, Cz, C2; CP1, CPz, CP2) to confirm the abovementioned observation statistically (One-way ANOVA showed a significant effect of condition, F(2,50)=3.1, p<0.05. Post-hoc pairwise comparison results: S vs. N: 3.57 vs. 2.79 μv, t(50)=1.92, p=0.06; D vs. N: 3.73 vs. 2.79 μv, t(50)=2.33, p=0.02; S vs. D: 3.57 vs. 3.73 μv, t(50)=-0.42, p>0.5).

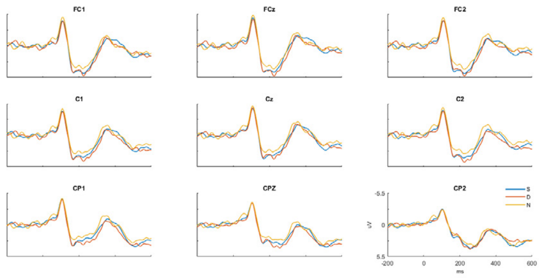

Figure 1. Grand average ERP waveforms for all conditions in 9 representative electrodes

The target word of the three conditions also elicited clear N400, which is widely distributed, but more prominent in the frontal and parietal lobe, according to the general characteristics of N400 reported in the literature. We took a 330 ms-430 ms time window and calculated the mean amplitude of 9 electrodes (FC1, FCz, FC2; C1, Cz, C2; CP1, CPz, CP2). Statistical analysis showed that condition had no main effect (F(2,50)=0.30, p>0.5), and there was no significant difference on N400 between the three conditions (S vs. N: -0.54 vs. -0.31 μv, t(50)=-0.41, p>0.5; D vs. N: -0.10 vs. -0.31 μv, t(50)=0.36, p>0.5; S vs. D: -0.54 vs. -0.10 μv, t(50)=-0.77, p=0.45).

Discussion

In the behavioral results, the significant difference between S, D, and N condition reflects the effect of grammatical structure and meets our expectations. There is no significant difference between S and D, indicating that the semantic relation information does not play a significant role in recognizing coordinative compounds, which does not meet our expectations.

In the ERP results, the early N200 response was consistent with the behavioral results. There is a significant difference between S, D, and N condition; that is, there is an amplitude reduction in S and D conditions compared with the control conditions. The S and D conditions share the same grammatical structure, but the N condition has a different grammatical structure. This indicates that N200 could distinguish between different grammatical structures. This result replicates Chung and Gu [22,23]. There is no significant difference between S and D conditions in N200. The S and D conditions have the same grammatical structure, but the semantic relation is different. This result shows that the semantic relation does not work in this period.

On N400, there is no significant difference between the three conditions, indicating that grammatical structure processing only affects the early processing stage of word recognition. Semantic relation did not affect N400, which is inconsistent with our previous results [20]. The previous study found that semantic relation works in the N400 window. In the previous research, we used compounds with subordinate structure, but this time coordinative compounds were used. The semantic relation between morphemes in subordinate compounds is more complicated, and each word may carry a lot of relation information. After recognizing the modification relationship between the two morphemes (the process of grammatical combination), calculating the semantic relation between them is also a complicated process.

Unlike coordinative compounds, the semantic relation combination has only two options: Synonymous and antonymous. After the grammatical combination process is completed, the parallel relation between the two morphemes is recognized. And the semantic relation must be one of the two. It is easier to extract the relation information so that the semantic relation may play a smaller role (as shown in Figure 2, but both in behavior (2-b) and ERP (2-a), we can still see the difference between S and D, though it does not reach a significant level). There is research to support this explanation [28]. This study found that during the 200 ms period, the activation of the left anterior temporal cortex is stronger when reading compounds than that when reading monomorphemic words, which may reflect the process of combining morphemes. Between 300 ms and 400 ms, the left posterior temporal cortex's activation is more robust when reading subordinate and verb-object compounds than when reading mono-morphemic words. But within this time window, there are no significant differences between the activation when reading coordinative compounds and when reading mono-morphemic words. It shows that the process of the grammatical combination may occur in the 200 ms period. The mono-morphemic words and compound words show a difference. At the same time, in 300 ms-400 ms, it is the semantic combination process. Coordinative compound words do not have this process, or this process has relatively small effects, so there is no difference between their activation and mono-morpheme words.

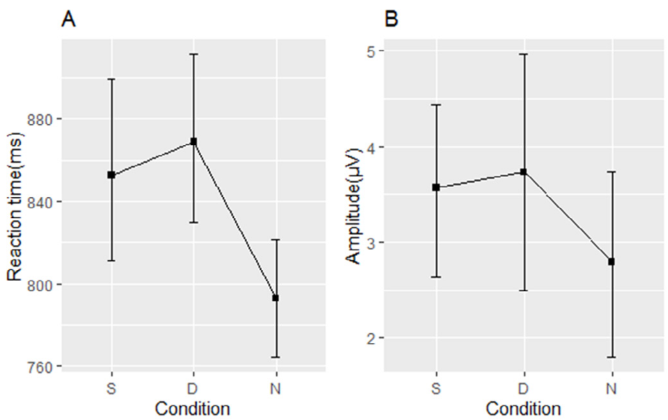

Figure 2. The influence of semantic relations (that is, the difference between S and D) is shown on Reaction time(3-A) and N200(3-B)

Combined with our previous research [21,29], the semantic relation works in the semantic window (N400 period). The results of the present study show that the grammatical structure played a significant role in the N200 period, indicating that the grammatical structure effect takes effect earlier than the semantic relation effect. This is consistent with the research on English Minimal Linguistic Phrases combination [30]. Using magnetoencephalogram technology, they found that LATL and vmPFC are respectively related to the processing of syntactic and semantic combinations. Most importantly, the time of LATL activation (225 ms) precedes vmPFC activation (400 ms), indicating that syntactic combination occurs before semantic combination.

Graessner, et al.'s experiments seem to explain this sequence [31]. In a functional magnetic resonance imaging study, they designed a well-controlled two-word paradigm. The phrases differ only along the semantic dimension while maintaining the same grammatical information. Participants listened to meaningful phrases ("fresh apple"), abnormal phrases ("awake apple"), and pseudo phrases ("awake gufel") while performing implicit and explicit semantic tasks. They determined the neural signatures of the different processes involved in the basic semantic composition process: The general phrase synthesis process has nothing to do with the resulting phrase's rationality. It involves a wide range of left hemisphere networks. The front angle gyrus guides more specific combination processing by evaluating the resulting phrases' rationality, which may correspond to the grammatic and semantic composition processes, respectively. The grammatical process is equivalent to the general composition process. As long as the components meet a specific grammatical structure, it can be combined. The semantic process is more detailed, and it is responsible for evaluating the rationality of the composed phrase. If it is reasonable, continue processing, and if it is unreasonable, then exit the processing process. This corresponds to what we found in our experiments that grammatical combination occurs before the semantic combination.

Compared with the previous research, the processing mechanism of coordinative compounds seems to be unique. Firstly, S and D conditions showed no difference in both behaviors and ERP (although the difference trend can be watched in the N200 period). It shows that the semantic relation information has little effect on the processing of coordinative words. Therefore, for coordinative structures, the process of the grammatical combination may be more critical. Unlike other structures such as the subordinate, the grammatical combination comes first, and the semantic combination comes later, which is a serial process [20].

Secondly, although the behavioral results showed grammatical structural effects in the reaction time, the reaction time of S and D conditions was significantly larger than that of N condition. The prime and target words of S and D conditions have the same grammatical structure, while the prime and target words of N condition have different grammatical structure. The results show that although N200 can distinguish different grammatical structures, grammatical structure repetition seems to inhibit compound word processing and the response time is longer than that of the N condition. This is consistent with Sun, et al.'s research [32]. They found inhibitory inter-character semantic similarity effects. That is, the semantic similarity between two morphemes (close or opposite) did not facilitate processing but played a blocking role, contrary to previous studies [33-35]. They interpreted it as, unlike other types of compound words, there exists the head as the dominant morpheme. In the processing of coordinative compound words, an inter-character morpho-semantic verification process exists between the two morphemes, which is quite complicated, so the structural information of the prime word cannot be easily transferred to the target word.

Thirdly, our results further suggest that in the absence of shared morphemes, morpheme structure information can also take effect independently, which challenges the belief that structure information must be bound to specific constituents to work [15,16,18]. We speculate that the reasons may come from:

1. The structural effect itself is very weak. The conditions in our research are relatively few (compared to Cu, et al.'s research), and we fit the mixed-effects model, so the statistical power is relatively large;

2. The material we choose is a more typical example of each structure (because structure priming has a typical effect) [36].

Coordinative compounds are a particular case. Its semantic relations is the simplest among all kinds of combinations, so it composition process may be unique. It is reasonable to speculate that the composition process of the other types of compounds may be more similar to modifier+noun compounds, which is a serial process because there is a dominant morpheme-the head.

Unlike the coordinative compounds, the two constituents play the same role in the semantic contribution to the whole word. This speculation needs to be tested by more experiments in the future.

Conclusion

In this research, we used Chinese compound words as the material to study the time course (including the grammatical structure and semantic structure) of structural information. We found that there is an apparent grammatical structure effect in the processing of Chinese compound words, and this effect occurs in the early stage of word recognition, that is, the N200 period. Combined with the previous research, the semantic relation effect occurred in the N400 time window, indicating that the grammatical combination occurred before the semantic combination and outlined the structural information's time course. Among them, the coordinative structure is unique. Because its semantic relation is relatively simple, there are only two kinds: Synonyms and antonyms, so the effect of the semantic combination is not significant, which is different from other structures with head.

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None.

Conflict of Interest

The authors declare that they have no competing interests.

Data Availability/Availability of Data and Materials

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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