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***Abstract*—The right hemisphere (RH) was reported to play a significant role in metaphor comprehension. However, not all studies found a right hemisphere advantage in processing figurative language using brain imaging methods. Therefore, the current study was designed to explore the right hemisphere recruitment with Event-related potentials (ERPs) and source-localization algorithms (sLORETA) by comparing metaphors selected from different language contexts (in and outside literature) and literal expressions. Based on the ERPs results, significant differences were presented during the N400 time window. The waveform of literary metaphors was significantly negative than the other two language conditions, indicating more efforts in retrieving conceptual knowledge. Comparing source localization solutions revealed that both the left and right hemispheres were activated in processing metaphors in and outside literature. Although literary metaphor, which was seen as more novel and unfamiliar, elicited stronger activation in the right hemisphere during the N400 time window, no significant differences were indicated.**

Keywords—metaphor, Event-related potentials (ERPs), N400, hemisphere involvement

I. INTRODUCTION

It has been well established that the N400 component, a negative-going waveform that peaks around 400ms after stimulus onset, is one of the most critical ERP components in metaphorical language processing. The N400 component is proven to be related to world knowledge violations and the semantic integration process [1]-[3]. Many researchers indicated that metaphorical language was more challenging to process than literal statements by providing evidence of larger N400 amplitudes for metaphors. Others reported a graded waveform of N400 component, with novel metaphors eliciting the largest amplitude of N400, conventional metaphors the second, and literal expressions the smallest [4]-[6], suggesting that the neural responses to a specific type of language material are associated with the complexity of conceptual mapping and integration operations. Although the N400 component has been well studied over recent years, especially in figurative language processing, few studies have discussed the differences in neural responses for metaphors in and outside literature from the perspective of temporal and spatial domain.

Many neuropsychologists proposed that the comprehension process of metaphors was different from other language abilities to some extent. Different brain regions were hypothesized to function in a specific phase of language processing, and the critical role of right hemisphere (RH) was discussed a lot. According to previous patient studies, left hemisphere-damaged (LHD) patients still have abilities to comprehend metaphorical meaning of adjectives. In contrast, right hemisphere-damaged (RHD) patients could only decode the literal meaning of the same content [7], [8]. To this end, the right hemisphere theory claimed that left hemisphere was responsible for literal meaning comprehension, while the right hemisphere specializes in non-literal meanings such as metaphors and idioms. The right hemisphere's role in language processing was also supported by the behavioral, patient and fMRI studies [9]-[11]. However, not everyone reported a right hemisphere advantage in metaphor processing. Through fMRI, some researchers [12]-[14] found that the left hemisphere, including the left temporal gyrus, left inferior parietal gyrus, was more active for metaphorical language. These discrepancies may result from the characteristics of the stimuli and the context they were extracted.

As a result, the current study aims to explore the cognitive and neurophysiological underpinnings of metaphors extracted from different contexts by exploring the temporal dynamics and the origin of a specific ERP component (e.g. N400 component) as electrophysiological responses elicited by visual stimuli. Primarily, we intend to explore if there exists an N400 effect for literary metaphors, which were claimed to be more novel, striking, and difficult to interpret than metaphors outside literature [15], through the method of ERPs. More specifically, literary metaphors are predicted to evoke larger voltages of N400 because they appear to be more irrelevant in meaning

and should be more challenging to collect information for meaning integration [5], [16]. Secondly, we used source-localization algorithm to investigate hemispheric recruitment in metaphorical language processing by comparing metaphors in and outside literature and literal expressions.

Considering that some primary responses to semantic processing always occur within 500ms after stimulus onset, the temporal signals that could reflect the changes of neural activities can help to detect the neural responses related to a particular stage of metaphor processing and examine whether the right hemisphere (RH) is activated during that phase [17]. With the advantage of high temporal resolution, ERPs are especially well-suited for metaphorical language comprehension studies. Furthermore, source-localization algorithms could be applied to trace the origin of the ERP components. Therefore, the standardized low-resolution brain electromagnetic tomography (sLORETA) is used to present the three-dimensional distribution (3D) of electric neuronal activity from EEG, indicating the locations of the underlying source processes with low error [18]-[20].

II. MATERIALS AND METHODS

A. Subjects

Forty-eight students at Dalian University of Technology (Liaoning Province, China) volunteered to participate in this study. All the subjects are native Chinese speakers without reading disabilities or neurological disorders. Before the formal experiment, the researcher obtained written informed consent from each subject. Furthermore, this study was approved by the Research Ethics Committee of Dalian University of Technology. The data of forty-two subjects (18 male, 24 female), with an average age of 22.43, were finally used due to the low number of correct trials (n=4) and noisy EEG data (n=2) of another six subjects.

B. Materials

The experimental stimuli in the present study consist of three groups (150 pairs of words or phrases), with natural words or phrases from modern Chinese lyrics for literary metaphor, the original content from Chinese newspapers and magazines for nonliterary metaphors and literal expressions (LM=Literary Metaphors; NL=Nonliterary Metaphors; LE=Literal Expressions). Meanwhile, another 50 pairs of stimuli, which are non-related in meaning, were created as fillers. Before the formal experiment, three pilot studies were designed to test the materials' relatedness, figurativeness and familiarity. Literary metaphors are less familiar and seen as more novel than nonliterary metaphors and literal expressions.

A priming task with the structure of stimulus 1 (prime) to stimulus 2 (target) was used. For instance, "一张那个金黄的心(A golden heart)" --- "九月(September)" / "冬季(Winter)". The subjects were asked to decide whether Stimulus 1 was accurately described by Stimulus 2 or not. Moreover, all the experimental stimuli were presented in a pseudo-randomized order, so that all the stimuli of the same category would not be displayed consecutively.

C. ERPs and SLORETA

MATLAB 2019b was employed in the present study to analyze the ERPs data. Firstly, the individual correct trials whose amplitudes were out of range (max>75μv, baseline max>30μv) were rejected, and the baseline 200 ms before stimulus onset was subtracted from the waveforms. Secondly, all the trials were averaged across blocks for each subject. There were a total of 1185 trials across 42 subjects for each condition. Based on the topographic activations, fifteen electrodes were selected for N400 analysis. The values of N400 latency were calculated as the time of maximum amplitude within the N400 time window [21].

The significance level $p<0.05$ was applied in the current study. The research results were described under the 2-tailed condition. One-way repeated-measures analysis of variance (ANOVA) with three language conditions was employed to examine if literary metaphors elicit a stronger N400 effect than others. Besides, the correlations between behavioral performance and ERP responses were calculated by the Pearson Correlation Coefficient to detect the relationship between behavioral performances and electrophysiological measures within different language conditions.

Moreover, the ERPs results of the N400 component were analyzed through of sLORETA. Voxels with significant differences ($p<0.05$, corrected for multiple comparisons) between different language conditions were located concerning the MNI-brain and Brodmann areas by the sLORETA software.

III. EXPERIMENTAL RESULTS

A. Behavioral Results

The multiple comparison tests (Tukey's HSD) revealed significant differences for the accuracy of three language conditions ($F(2, 123)=161.23$, $p<0.01$, $\eta_p^2=0.72$), with the accuracy of literary metaphor (mean=0.6843, SD=0.1210) significantly lower than that of nonliterary metaphor (mean=0.9529, SD=0.0428) and literal expression (mean=0.9452, SD=0.0424). In contrast, the response time for literary metaphors (mean=756.33, SD=489.92) was significantly longer than that of nonliterary metaphors (mean=639.93, SD=334.41) and literal expressions (mean= 644.06, SD=349.47). A significant effect for language conditions were presented by analyzing the response time in correct trials with one-way ANOVA ($F(2, 4287)=39.48$, $p<0.01$, $\eta_p^2=0.02$).

B. ERP Results

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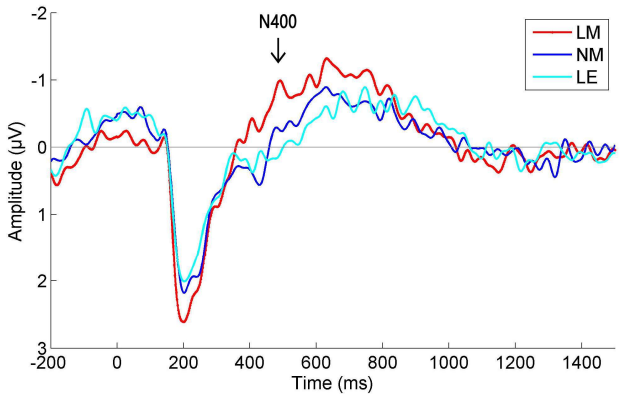
(a)



(b)

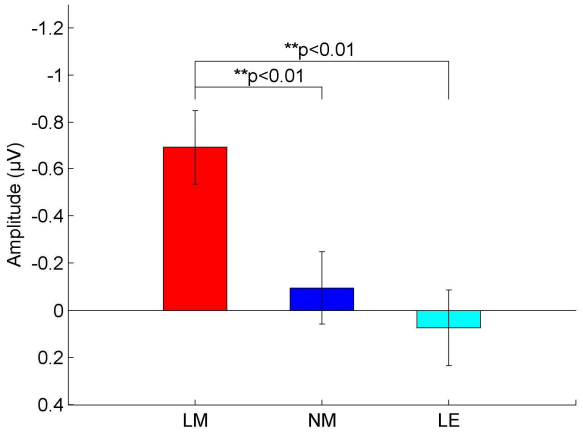
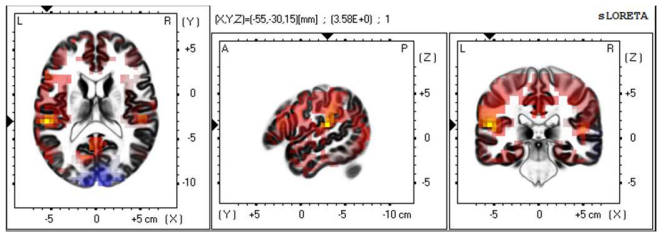


Fig. 1. ERP responses to three stimulus conditions. (a) Grand average ERP of N400 channels. (b) Mean values and standard error of the N400 amplitude in the three conditions.

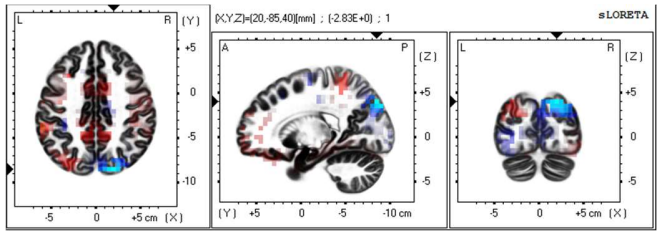
C. SLORETA Results

Based on the ERPs results, sLORETA was applied to calculate the source density. Fig. 2(a) demonstrates that voxels with significant differences between literary metaphor and literal expression were located at Brodmann area 42 ($t=3.5764>t_{0.05}$, $p<0.05$). The analysis tells stronger activation for literary metaphor than literal expression in the left superior temporal gyrus (X=-55, Y=-30, Z=15), which is close to Wernicke's area, at latencies ranging from 350 to 470ms. During the same time window, Fig. 2(b) shows significant differences between nonliterary metaphors and literal expressions at Brodmann area 19 (X=20, Y=-85, Z=40), a visual association area. Literal expressions presented stronger activation than nonliterary metaphors ($t=-2.8341>t_{0.01}$, $p<0.01$) in the right precuneus and parietal lobes. Fig. 2(c) indicates the differences between literary and nonliterary metaphors in the right precentral gyrus and frontal lobe (X=35, Y=-15, Z=50, Brodmann area 6). However, no statistically significant differences were presented between these two language conditions ($t=3.2563>t_{0.1}$, $p<0.1$).

(a)



(b)



(c)

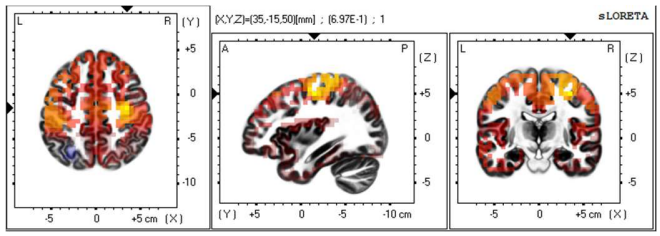


Fig. 2. The results of sLORETA analyses. (a) The comparison of sLORETA images between the literary metaphors and literal expressions at the latencies ranging from 350 to 470 ms ($p<0.05$). (b) The comparison of sLORETA images between nonliterary metaphors and literal expressions ($p<0.05$). (c) The comparison of sLORETA images between the literary and nonliterary metaphors ($p<0.1$).

IV. DISCUSSION

This study intends to explore the hemisphere involvement in metaphor comprehension by examining the temporal dynamics and the origin of N400 component in processing distinct language conditions. More specifically, we aimed to testify if literary metaphors would evoke a significantly larger waveform of N400 than other language conditions and the involvement of the right hemisphere during this period.

Consistent with previous findings [5], [6], [22], this study found a negative relationship between the response time and accuracy of correct trials for literary metaphors of each subject. Although it took longer time to accomplish the meaningful judgment task for literary metaphors, the subjects still achieved lower accuracy, proving that literary metaphors were more challenging to comprehend than nonliterary metaphors and literal expressions. In contrast, for the conditions of nonliterary metaphors and literal expressions, the subjects spent similar

time in making a meaningful judgment and achieved almost the same response accuracy. Therefore, the comprehension process for nonliterary metaphors and literal statements was similar, but significant differences were indicated between literary and nonliterary metaphorical materials.

One of the most obvious findings to emerge from this study was that the N400 waveform for literary metaphor was significantly larger than the other two language conditions. The ERPs result is consistent with the behavioral results above, providing evidence that the subjects spent more effort in approaching metaphors in literature, which is considered more striking and irrelevant in meaning [15]. To this end, it was more challenging for the subjects to retrieve conceptual knowledge and construct conceptual mappings in literary metaphor comprehension than in the other two language conditions [23]. Comparatively, no significant differences were presented between the waveforms for nonliterary metaphors and literal statements during the N400 time window, indicating a similar effort in lexical retrieval and semantic integration [24]. Hence, these results proved that the neural correlates of literary metaphor, as one type of novel metaphor, were qualitatively different from nonliterary metaphor and literal expressions, which was in line with recent studies about literary metaphor comprehension [25], [26].

Another important finding was that both left and right hemispheres were activated in metaphor processing, affected by the difficulty of metaphorical language. Firstly, based on the comparison results of source-localization images (see Fig. 2), literary metaphors evoked greater activation than literal expressions in the left superior temporal gyrus (STG), which was proven to be an essential structure in language comprehension [27]. Secondly, literal expressions showed stronger activation in the right hemisphere (BA 19), a visual association area, than nonliterary metaphors. At last, although literary metaphors elicited more activation than nonliterary metaphors in the right hemisphere, no significant differences were presented between the two language conditions. Specifically, both left and right hemispheres were activated in processing metaphors from distinct language contexts.

Previous researchers suggested that the involvement of right hemisphere was decided by factors such as differences in familiarity [28] and complexity [29]. In the current study, the subjects spent a longer reaction time but achieved lower accuracy in the condition of literary metaphor, proving that literary metaphors were more complex and the subjects need to spend more effort in conceptual mapping and semantic integration. Accordingly, the present study was consistent with the research finding of Schmidt and Seger [30], confirming that the difficulty of language materials would result in the engagement of both the left and right hemispheres. This study was approved by the Coarse Coding Hypothesis (CCH), claiming that both hemispheres were involved in semantic activation, integration, and selection. While the right hemisphere is activated in non-selective and widespread semantic context (i.e., coarse coding), the left hemisphere was involved more in the fine coding context, which is more focused and context-relevant [31], [32].

V. CONCLUSION

The present study demonstrated that literary metaphors elicited a significant N400 effect compared to nonliterary metaphors and literal statements. Both the behavioral results and ERPs results supported that metaphors from literary contexts were more complex, and extra effort was required in language processing. This study confirmed that both the left and right hemispheres were engaged in the process of metaphor comprehension. Although literary metaphors were conceived as more novel than nonliterary metaphors, no right hemisphere advantage was displayed in this study. A future study should focus on the investigation of metaphor comprehension on discourse level and the individual differences would be emphasized.

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