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Research report

The temporal dynamics underlying the comprehension of scientific metaphors and poetic metaphors

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ABSTRACT

The neural mechanisms underlying the processing of novel metaphors created from poetic contexts have been investigated in previous experiments. Considering the different attributes of metaphors, the current study compared the temporal dynamics for processing two kinds of novel metaphors with event-related potentials (ERPs): scientific metaphors and poetic metaphors. Amplitudes of the N400 (350–450 ms) were similar for scientific metaphors and poetic metaphors. Within the LPC window (550–850 ms), ERPs associated with these two kinds of novel metaphors were observed every 100 ms in three successive subwindows. We found that due to a sustained late negativity overlapping in time and space with the LPC scientific metaphors seemingly elicited the least positive LPC throughout. More importantly, with the passage of time, the LPC waveforms for scientific metaphors diverged from those for poetic metaphors and conventional metaphors while LPC waveforms for poetic metaphors converged with those for conventional metaphors. The reported results indicate the possible different time courses for processing novel metaphors with different contextual structures and different functions. And the findings are compatible with recent brain imaging studies and complement them by adding such new dimensions as the temporal dynamics and the properties of novel metaphors.

1. Introduction

Metaphors come in a wide variety of forms with various contexts. Apart from their use in basic linguistic communication, metaphorical models play an important part in communicating new discoveries in scientific theories. By means of metaphors the structures from one conceptual domain are mapped to another, thus making it possible to understand one type of experience by means of another. Conceptual metaphors facilitate both productive and pernicious analogical reasoning. Their conscious and explicit use in analogical reasoning has been demonstrably helpful and productive in disciplines ranging from physics (Ceroni, 2014) and chemistry (Lancor, 2014) to biology (Volanschi and Kubler, 2011). For example, the model of atom proposed by Niels Bohr in 1913 explains the structure of atom by an analogy with the solar system in which there is a central nucleus around which revolve planets—electrons. Metaphor can be regarded as a part of analogical reasoning because comprehension of metaphor is ruled by analogical thinking (Wolff and Gentner, 2011). The processing of metaphor requires analogical mapping of different levels of similarity, such as the attributes of objects or the relationships between objects, from a source domain to a target domain (Holyoak, 2012). The imaginative description of conceptual relations stimulates the scientific research process, providing the basis for new discoveries.

Obviously, like poetic metaphors, scientific metaphors are also novel representing creative conceptual mapping between the target and source domains. However, up till now, most ERP studies of metaphor comprehension have chosen metaphors from literary works, identified here as poetic metaphors, as the novel ones. Actually, metaphors from other creative contexts, such as natural science terms, have been overlooked. In fact, although scientific metaphors and poetic metaphors are both creative and unfamiliar compared to conventional metaphors, the former has its unique properties. Firstly, the contextual structure of scientific metaphors is more complicated covering two different contexts. For example, in the sentence “染色体是姐妹 *Chromosomes are sisters”*, the source *(*姐妹 *sister)* is from the daily context while the target *(*染色体 *chromosome)* is from the scientific context. In contrast, for poetic metaphors (e.g. 女孩是草莓 *The girl is a strawberry*), both the source (草莓 *strawberry*) and target (女孩 *girl*) are from the daily context. So, when the two semantic domains are integrated, more difficulties should be caused by this complicated contextual structure of scientific metaphors. Secondly, the main function for poetic metaphors is to arouse a sort of emotional echo in

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the readers' minds whereas the main function for scientific metaphors is to stimulate a sort of epiphanic understanding of a new knowledge by triggering analogical reasoning. Accordingly, we hypothesized here that processing these two kinds of novel metaphors might show different time courses. Therefore, the aim of the present study is to distinguish two different kinds of novel metaphors in the ERP experiment by observing their possible different processing mechanisms.

A few models have proposed distinct operations. According to the graded salience hypothesis (Giora, 1997), it is the salience that determines the precedence of access. The salient meaning is always processed first and context can make either the figurative or the literal meaning more salient. Thus, when a novel or unfamiliar metaphor is encountered, the salient meaning is the literal one, and the figurative meaning is inferred later by the context. However, for conventional metaphors the figurative meaning is commonly more salient than the literal one, thus the figurative meaning is mostly accessed first. According to the structural-mapping model (Bowdle and Gentner, 2005), a more rapid and less computationally costly categorization is involved in understanding conventional metaphors because there is an existing metaphorical category. But a slower and more costly comparison is elicited between partially isomorphic conceptual structures of the target and source when comprehending novel metaphors after determining that the literal meaning cannot be sensibly applied. Based on these two models, we could predict that firstly when processing scientific and poetic metaphors, an initial categorization attempt might fail in lack of a well-defined category and a comparison process might be elicited. Secondly, for scientific and poetic metaphors, the salient meaning should be the literal one because they are both unfamiliar. But as time goes by, processing scientific metaphors might tend to be even more difficult due to its complicated contextual structure and knowledge-understanding reasoning at the later stage.

Electrophysiological recordings can help improve our understanding of the time course of metaphorical expressions processing by providing measures of brain activity with very high temporal resolution. Event-related potentials (ERPs) can be effective in measuring processing effort from conceptual mappings and have been used to explore the time course of metaphor processing and, specifically, to study the different processing of novel and conventional metaphors (Arzouan et al., 2007a, 2007b). Qualitative differences in the amplitudes, latencies, and topographies of ERPs can inform us more about the underlying cognitive processes in conventional and novel metaphor processing.

Most of the ERP researches on metaphor comprehension have focused on two particular ERP components: the N400 and the late positive component (LPC). The amplitude of the N400 has been shown to vary systematically with the processing of semantic information and can be thought of as a general index of the ease or difficulty of retrieving stored conceptual knowledge associated with a word (Kutas and Federmeier, 2000). Retrieval difficulty is dependent on the stored representation itself (word class, frequency, etc.) and on retrieval cues provided by immediate and discourse context (Kutas et al., 2006). Increased N400 amplitudes have repeatedly been reported for novel metaphors compared to conventional metaphors and literal expressions (Arzouan et al., 2007a; Grauwe et al., 2010; Lai et al., 2009; Rutter et al., 2012). The graded N400 difference suggests that processing difficulty associated with figurative language is related to the complexity of the underlying mapping and integration operations.

The LPC has been observed in connection with the N400 effect in semantic tasks (Bouaffre and Faita-Ainseba, 2007) reflecting sentence-level integration or reanalysis (Friederici, 1995; Kaan et al., 2000) and memory retrieval processes (Paller and Kutas, 1992; Rugg et al., 1995). The LPC should be an index of the integration of one concept with others that results in the creation of a whole meaning for words (Juottonen et al., 1996). The LPC effect represents greater semantic integration costs (Neville et al., 1993; Stuss et al., 1988). Regarding processing stages later than the retrieval of the semantic information of words, findings in the literature are less consistent. Some researches reported larger LPCs for endings of metaphorical sentences, compared to literal endings (Coulson and Van Petten, 2002). This was interpreted as reflecting recovery and integration of additional material from semantic memory. In contrast, smaller LPCs for metaphorical meanings, especially novel metaphorical meanings, have also been reported implying a possible late negativity suggesting further attempts to integrate meaning in a figurative context (Arzouan, Goldstein and Faust, Arzouan et al., 2007a, 2007b). Some other studies did not find significant LPC differences between literal expressions and conventional metaphors, or between conventional and unfamiliar metaphors (Pynte et al., 1996).

So, what we are interested here is whether the time course for processing scientific metaphors is different to that for processing poetic metaphors both being novel compared to conventional metaphors. We used event-related potentials (ERPs) in order to unravel the temporal dynamics underlying the comprehension of scientific metaphors and poetic metaphors. Our predictions are as follows. For the N400, if the amplitude of the N400 indexes how easy or difficult the stored information of a word could be retrieved (Kutas and Federmeier, 2000), there should be very little N400 difference between the scientific and poetic conditions because both are unfamiliar to participants and similarly difficult to be processed. The N400s should be more negative in the above two conditions than the conventional one, because novel metaphors cost more in conceptual mapping. And both conventional and novel metaphorical expressions should show some N400 due to an initial stage of structural alignment for conceptual mappings. For the LPC window, it is more complicated and exploratory. Because scientific metaphors and poetic metaphors have different contextual structures and late reasoning processes, these two categories of metaphors should show different LPCs or late negativities. If the LPC reflects the level of difficulty in integrating additional material from semantic memory, bigger LPCs should be elicited by scientific metaphors than poetic ones. Accordingly, the LPC amplitudes would be larger for scientific metaphors and poetic metaphors than for conventional metaphors. However, if a late negativity is elicited overlapping in space and time with the LPC, larger amplitude of the late negativity and reduced amplitude of the LPC should be expected for scientific metaphors.

In sum, the current study is the first to differentiate how during conceptual expansion the processing involved in one kind of novel metaphors differs from that of another kind. Moreover, the present study divided the time window for the LPC into three epochs in order to observe the time course of processing these two kinds of novel metaphors more clearly (See the Stimuli part for details).

2. Results

2.1. Behavioral results

For the purpose of this analysis we calculated for each participant mean reaction times for correct trials only, and accuracy rates for each sentence type. A repeated-measures ANOVA revealed significant effects of condition for both reaction times [$F(3,48)=5.92$, $p=.014$, $\eta_p^2=.27$] and accuracy rates [$F(3,48)=33.56$, $p<.001$, $\eta^2{}_p=.68$]. For reaction times, Bonferroni's post hoc analyses ($ps<.05$) indicated that reaction times were shorter for both literal expressions ($M=421.15$, $SD=140.45$) and conventional metaphors (M=453.47, SD=171.03) as compared to poetic metaphors ($M=556.44$, $SD=176.94$) and novel metaphors ($M=561.21$, $SD=208.18$). The difference between reaction times for poetic metaphors and scientific metaphors, and the difference between literal expressions and conventional metaphors were not significant. For accuracy rates, Bonferroni's post hoc analyses ($ps<.05$) indicated that accuracy rates were significantly lower for scientific metaphors ($M=.80$, $SD=.051$) and poetic metaphors ($M=.88$, $SD=.062$) than for conventional metaphors ($M=.94$, $SD=.068$), and literal expressions ($M=.98$, $SD=.024$). The difference in accuracy rates between scientific