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Electrophysiological difference between the representations of causal judgment and associative judgment in semantic memory

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ABSTRACT

Causally related concepts like "virus" and "epidemic" and general associatively related concepts like "ring" and "emerald" are represented and accessed separately. The Evoked Response Potential (ERP) procedure was used to examine the representations of causal judgment and associative judgment in semantic memory. Participants were required to remember a task cue (causal or associative) presented at the beginning of each trial, and assess whether the relationship between subsequently presented words matched the initial task cue. The ERP data showed that an N400 effect (250–450 ms) was more negative for unrelated words than for all related words. Furthermore, the N400 effect elicited by causal relations was more positive than for associative relations in causal cue condition, whereas no significant difference was found in the associative cue condition. The centrally distributed late ERP component (650–750 ms) elicited by the causal cue condition was more positive than for the associative cue condition. These results suggested that the processing of causal judgment and associative judgment in semantic memory recruited different degrees of attentional and executive resources.

1. Introduction

Knowledge about causal relations (e.g., virus–epidemic) is fundamental to human cognition (Blakemore et al., 2001; Fugelsang & Dunbar, 2009). Indeed, the ability of using causal knowledge to plan, act and reason is very important for an individual's success in real life. Recent studies have begun to explore the processing of causal relations in a variety of areas, such as causal perception, causal learning and causal inferences in text processing (see a review for Fugelsang & Dunbar, 2009). These studies suggested that some types of causal relations present in the environment may be immediately apparent through perceptual causation (Michotte, 1963), whereas other types of causal relations are likely learned through observation (Fugelsang & Dunbar, 2009). An important avenue for understanding causality is to explore how stored causal relations are represented and accessed in semantic memory.

Semantic memory is described as our long-term repertoire of information about categories/features and the complex semantic relations between them (Tulving, 1972). Although previous studies have explored these semantic relations, most of them focused on taxonomic and thematic relations (Chen et al., 2014; Estes, Golonka, & Jones, 2011). Recent studies have begun to explore the representation of causal relations stored in semantic memory. For example, when participants were required to report the existence of causal relations, the reaction times (RTs) of the word pairs presented in cause–effect order were shorter (e.g., *spark* prior to *fire*) than vice versa (*fire* prior to *spark*). However, such RT advantage was not observed when participants were required to verify the existence of an associative relation (Fenker, Waldmann, & Holyoak, 2005).

Following this, these researchers also investigated the neural basis of causal relations via fMRI (Fenker et al., 2010; Satpute et al., 2005). For example, Satpute et al. (2005) found that causal judgments, in contrast to associative judgments, recruited greater activation in the left dorsolateral prefrontal cortex and the right precuneus related to working memory and reasoning. Recently, Fenker et al. (2010) requested participants to determine whether the word pair was consistent with task cue (causal or associative) shown at the beginning of each trial in one task, and asked them to assess whether the word pair was causally related or non-causally associated in another task. The results found that the evaluation of causally related words, as well as causal task cue, engaged a mesolimbic and mesocortical circuitry known to mediate prediction error learning (Corlett et al., 2004; Fenker et al., 2010), suggesting that prediction error processing is involved during the assessments of causality even under conditions when it is not explicitly required to make predictions.

Overall, these studies indicated that the representation of causal judgment was dissociated from associative judgment in semantic memory, and participants appeared to distinguish the roles of cause and effect or bind the relevant events into the 'cause' and 'effect' roles when verifying the causal relations (Fenker et al., 2005, 2010; Satpute

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et al., 2005). However, little is known about the time course of how stored causal relations are represented and accessed, as well as the representation of causal judgment and associative judgment in semantic memory. Event Related Potentials (ERPs) could further our understanding of processing differences affected by stimulus manipulations directly (Luck, 2005). The N400 effect was considered as a potentially good physiological index for exploring this issue.

The N400 component has been shown to be an important component to semantic processing, which is highly sensitive to the strength of semantic relations (Holcomb & Grainger, 2009; Kutas & Hillyard, 1980), as well as different types of semantic relationship, such as thematic vs. causal relations (Kutas & Federmeier, 2011; Paczynski & Kuperberg, 2012). That is, the largest N400 amplitude was evoked by unrelated word pairs, and smaller N400 effect was elicited by semantic word pairs with low associative strength, whereas no significant N400 was found in highly related word pairs (Anderson & Holcomb, 1995; Rossell, Price, & Nobre, 2003). Furthermore, Kuperberg, Paczynski, and Ditman (2011) found that the N400 was smallest for directly causal relations, greater for indirectly causal relations, and greatest for noncausal relations, while keeping semantic association constant across conditions (Kuperberg et al., 2011).

Based on the above analysis, the main goal of our work is to examine the electrophysiological difference between the representations of causal and associative judgments in semantic memory via ERPs. Participants were presented with a task cue (causal or associative) at the beginning of each trial, and required to assess whether the relationship between subsequently presented words matched the initial task cue. If the processing of related words was different from unrelated words, larger N400 effect should be elicited by unrelated words than for related words. Furthermore, processing differences between causal judgment and associative judgment should also be found, because they involved different degrees of attentional and executive resources (Fenker et al., 2010; Fugelsang & Dunbar, 2009; Satpute et al., 2005).

2. Methods

2.1. Participants

Sixteen healthy undergraduate students (eight males) were paid to participate in the main study. All participants were right handed between the ages of 18 and 23, with normal or corrected to normal vision. The study was approved by the local ethics committee. Data from one participant were discarded due to excessive EEG artifacts.

2.2. Stimuli

The stimuli consisted of 120 pairs of 4 character Chinese words in the main experiment. Before the main experiment, however, 150 pairs were initially selected and then normed. That is, 50 causally related (e.g., virus–epidemic, drought–famine), 50 non-causal associatively related (e.g., ring–emerald, glass–window) and 50 unrelated (e.g., door–pinball, grass–fist) word pairs were selected from previous studies (Fenker et al., 2005) and translated into Chinese. Subsequently, eighty-eight healthy undergraduate students (not included in the main study) were recruited and paid to participate in several normative studies to account for the associative strength and the strength of statistical contingency, which might affect the comparison between causal judgments and associative judgments.

At first, 13 evaluated the words in a preliminary phase, in which they marked any words that they had not heard before. Words that were marked by two or more participants were replaced. One word pair (protestants–baptist) was replaced with a new pair (temple–monk) because of the cultural difference.

After this, 29 undergraduates participated in a strength test. Specifically, the causal relation was defined before evaluating as follows: "the event described by the first word caused or was caused by the event described by the second word", while the noncausally associative relation was defined as follows: "meaningful relationship between the two events, but not a causal relation." In this test, the participants were required to rate the causal and associative relatedness strengths of all word pairs on a 7 point scale, where 7 indicated the highest relatedness. For example, in response to the word pair "virus–epidemic", people typically rated the strength as "6" or "7" on the causal relatedness scale, but marked as "3" or "4" in the associative relatedness scale. Whereas, for the word pair "ring–emerald", people typically rated the strength as "2" or "3" in the causal relatedness scale, but "6" or "7" on the associative relatedness scale. Unrelated word pairs such as "door–pinball" were consistently marked as "1" or "2" both on the causal relatedness and associative relatedness scales.

As a next step, another 23 undergraduates participated in an associative strength test for the above 150 word pairs, the order of each word pair was counterbalanced (S1S2 vs. S2S1). In the causal strength test, participants were required to rate the likelihood that the event or object described by the first word caused or be caused by the event or object described by the second word on a 7 point scale, where 7 indicated the highest likelihood (Chen, Roberson, Liang, Lei, & Li, 2014). In the associative relationship test, participants were required to rate the strength of the meaningful relationship between the two items. The unrelated word pairs were also rated on the strength of general associative relationship. For example, the word pair "virus–epidemic", received a typical rating of "6" or "7" on the causally relatedness scale; while the word pair "ring–emerald", received a typical rating of "5" or "6" and "door–pinball" received a typical rating of "1" or "2" on the associatively relatedness scale.

What is more, we conducted a norming task to account for the strength of statistical contingency between our items, as these measures sometimes affect the associative strength between items (Fenker et al., 2005). That is, another 23 participants were presented with the above 150 word pairs on a computer screen using E-prime software, the orders of each word pair were counterbalanced (S1S2 vs. S2S1). All types of related and unrelated word pairs were presented, and for each pair participants were required to estimate that if the object or event described by the first of the two words occurred 100 times, how many times the object or event described by the second word would occur? For example, "if *virus* occurs 100 times, how often does *epidemic* occur?" Participants were required to rate co-occurrence on a scale from 0 to 100, in increments of 10.

On the basis of the results of these norming studies, we selected 40 pairs for our experiments that did not differ in the associative strength and the strength of statistical contingency between the two directions (S1S2 and S2S1). Table 1 shows the mean strengths and standard deviations of the ratings for each condition when analyzed by subjects and by items. At first, for the initial strength test, paired *t* test indicated that causally related pairs were rated significantly stronger on the causal scale ($M = 5.66$, $SD = 0.77$) than on the associative scale ($M = 4.54$, $SD = 1.25$), $t\ (28) = 5.27$, $p < .001$. In addition, associatively related word pairs were rated significantly stronger on the associative scale

Table 1
The mean strengths and statistical frequency and standard deviations over subjects and stimuli.

		Strength				Statistical frequency ratings			
		Over subjects		Over stimuli		Over subjects		Over stimuli	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Causally related	S1S2	5.46	0.76	5.46	0.50	58.15	12.32	58.15	9.60
	S2S1	5.38	0.81	5.38	0.41	57.64	11.52	57.64	9.09
Associatively related	S1S2	5.49	0.88	5.49	0.58	55.82	8.58	55.82	10.06
	S2S1	5.53	0.85	5.53	0.59	55.79	9.29	55.79	11.27
Semantic unrelated	S1S2	1.51	0.25	1.51	0.25	21.27	15.72	21.27	6.24
	S2S1	1.52	0.38	1.52	0.33	20.95	13.67	20.95	6.06