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Automatic processing of taxonomic and thematic relations in semantic priming — Differentiation by early N400 and late frontal negativity

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ABSTRACT

Most current models of knowledge organization are based on hierarchical (plant–pine) or taxonomic categories (animal–plant). Another important organizational pattern is thematic categories, which performs external or complementary roles in the same scenario or event (bee–honey). The goal of this study was to explore the processing of hierarchical categories and thematic categories under automatic processing conditions that minimize strategic influences. The Evoked response potential (ERP) procedure was used to examine the time course of semantic priming for category members with a short stimulus onset asynchrony (SOA) of 300 ms as participants performed a lexical decision task. Six experimental conditions were compared: hierarchical relations (offspring–grandson), internal features (gold–golden), productive relations (bee–honey), script relations (room–tenant), unrelated (star–spoon), and non-word trials (star–derf). We found faster reaction times for related prime–target pairs than unrelated pairs except for productive relations. The ERP data showed that an early N400 effect (200–400 ms) was more negative for unrelated words than for all related words. Furthermore, a frontal negativity (400–550 ms) elicited by productive relations was smaller (more positive) than other related words. We suggest that the smaller frontal negativity in the processing of productive relations indicates their increased salience in knowledge structure compared to less prominent hierarchical relations. Indeed, the allocation of attentional resources and subsequent recruitment of additional memory processing might be two of the hallmarks of thematic relations.

1. Introduction

The ability to use the knowledge stored in semantic memory to plan, act, and categorize is crucial in people's daily lives. The knowledge stored in semantic memory includes information about categories and features, as well as the semantic relationship between them, such as "is used to," "works in," "lives in," "is made of," "is kept in," and "is the outside of" (Murphy & Medin, 1985; Spellman, Holyoak, & Morrison, 2001). Two types of semantic relations can be distinguished in semantic memory. The first is the taxonomic relation that refers to an overlap in the features or the meaning of words, which includes items of the same superordinate category (e.g., mammal, with members such as dog, cat, cow, etc.). Hence, taxonomically related concepts share similar perceptual or functional properties and are represented in conceptual hierarchies or taxonomies (Sachs et al., 2008; Sass, Sachs, Krachb, & Kircher, 2009). The second type is the thematic relation that includes externally or complementary related items within scenarios or events (e.g., bee–honey; Lin & Murphy, 2001), which shares an associative relationship but not perceptual features.

Most behavioral and event related potential (ERP) studies about relationships in semantic memory have mainly focused on the processing of class concepts within the same or different hierarchical levels, such as animal–bird–robin (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Bream, 1976; Tanaka, Luu, Weisbrod, & Kiefer, 1999; Large, Kiss, & McMullen, 2004). For example, Large et al. (2004) found that superordinate categorizations were performed more quickly and were differentiated from basic level categorizations by their amplitude during early visual processing (320–420 ms), whereas subordinate categorizations were differentiated from basic level categorizations by their amplitude and latency at later stages (450–550 ms). The importance and salience of thematic categories has been shown in a broad range of cognitive phenomena, such as similarity, memory and categorization, language, inference and analogy (see review by Estes, Golonka, & Jones, 2011). For example, thematic relations are apprehended faster than taxonomic relations (Gentner & Brem, 1999). Moreover, children with poor reading abilities are less skilled at thematically integrating textual information (Cain, Oakhill, & Elbro, 2003), and

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schizophrenic are more likely to sort items into thematic categories than are normal participants (Doughty, Lawrence, Al-Mousawi, Ashaye, & Done, 2009). These studies suggest that the thematic relations are another important way of organizing semantic knowledge, and the processing of thematic relations seems to be dissociated from the processing of taxonomic relations.

However, there are only a few electrophysiological studies on the dissociation of thematic relations and taxonomic relations (Hagoort, Brown, & Swaab, 1996; Khateb et al., 2003; Maguire, Brier, & Ferree, 2010; Chen et al., 2013). For example, Hagoort et al. (1996) found no significant differences in any ERP effects in healthy adults or in patients with left hemisphere damage when participants were required to listen to thematically related or taxonomically related words in a passive listening task. Patients with right hemisphere damage showed a reduced N400 to taxonomic pairs relative to the control population, but a normal N400 to thematic pairs. Similarly, although Maguire et al. (2010) found no significant differences in any ERP components in a passive listening task, they did find increased theta power for thematically related words and increased alpha power for taxonomically related words. The authors concluded that thematic relations engaged memory processes, while taxonomic relations required additional inhibitory or attention processes. A study by Khateb et al. (2003) recorded EEG when participants were required to judge whether word pairs were related or not. Although no significant differences in the N400 effect were found between thematic and taxonomic relations, an increased stimulus-averaged EEG signal over the left media frontal electrodes was found for taxonomic relations. Furthermore, a significantly larger P600 effect was found for taxonomic relations relative to thematic relations, when participants were required to make "high" or "low" similarity judgments about thematically related, taxonomically related or unrelated words, and (Chen et al., 2013). We suggest that similarity judgments of thematically related words involve a dual process of comparison and integration, rather than a single comparison process like that used for taxonomically related words, and that the additional process makes it easier to judge thematic categories and, thereby, elicits a smaller P600.

It should be noted that previous research about the dissociation between thematic relations and taxonomic relations is limited in many important ways. For example, most previous studies used classical taxonomic relations at the same hierarchical level (e.g., both robin and sparrow are subordinate concepts), but various types of thematic relations. Thematic relations could be productive (e.g., bees produce honey), spatial (e.g., a window is in the wall), causal (e.g., the wind makes stone weather), temporal (e.g., bills typically come after shopping in a supermarket), and script or text relations (e.g., a stamp-collecting script included stamp and the collecting actions) (Lin & Murphy, 2001; Estes et al., 2011). As a result, the way in which they are labeled is quite different (Sachs et al., 2008).

In our study, we use hierarchical related concepts (e.g., bird-robin) to replace the taxonomically related concepts with the same hierarchical level (e.g., robin and sparrow). Furthermore, we use external semantic relations (as in bee– honey) or complementary relations (as in guest room–tenant) to refer to thematically related concepts, although they are not necessarily related on the lexical level (as in gold–golden). Using taxonomic relations with a different hierarchical level (e.g., bird- robin), as well as different types of thematic relations, may extend our understanding of semantic relations.

Another limitation of previous research is that most ERP studies used slow, controlled and conscious tasks with a long SOA (>600 ms), such as making related/unrelated judgments (e.g., 650 ms for Khateb et al., 2003), passive listening tasks (e.g., 1183 ms for Hagoort et al., 1996; Maguire et al., 2010), or performing similarity judgment tasks (e.g., 1600–1800 ms for Chen et al., 2013). As a result, strategic, task-specific effects would have a large effect on category-specific activation patterns (Grossman et al., 2006). These effects can be reduced by using faster, automatic tasks with a short SOA (300 ms) to investigate implicit processing of semantic relations (Sachs et al., 2008).

One way of investigating the neural correlates of semantic relations is semantic priming with a short SOA (<400 ms) in combination with ERP. Specifically, a prime word (e.g., bee) was presented on a computer screen, followed by a target that was a real word (e.g., honey) or a non-word (e.g., fuber), and participants were required to decide whether the target was a real word, as quickly as possible. The main outcome was that the response for related prime-target words (e.g. bee–honey) was faster than unrelated prime-target words (snow–table). The basic assumption of this paradigm is that the priming effect is an automatic spreading activation between related words within the semantic network at a short SOA (<400 ms; Neely, 1991). Moreover, the related prime-target words with shorter SOA (<400 ms) were usually recognized as automatic processing, whereas the semantic priming with longer SOA (600–1000 ms) were recognized as controlled or strategic processing because participants had enough time to consciously process the relationship between the prime and the target (Sachs et al., 2008; Sass, et al., 2009).

In fact, several studies have investigated the role of SOA length by comparing the processing of related and unrelated prime–target words using a short SOA and a long SOA (Hill, Strube, Roesch-Ely, & Weisbrod, 2002; Hill, Ott, Weisbrod, 2005; Franklin, Dien, Neely, Huber, & Waterson, 2007). For example, Hill et al. (2002) found the P250 and LPC effects were sensitive to semantic relatedness only in the short SOA condition, and that N310 was sensitive to semantic relatedness more prominently in the short SOA condition, by using ERP priming with SOAs of 150 or 700 ms. Another study used a delayed lexical decision to separate priming and lexical decisions (Hill et al., 2005). The study found that an early P300-like component was evoked by primed targets only under the short SOA condition, and noticeably larger N400 effects were elicited in the long SOA condition. They concluded that the early P300 reflected the implicit detection of semantic relationships, whereas the N400 was related to deeper semantic processing under the long SOA condition. These results indicate there were two separate processes of semantic processing: an access to semantic memory facilitated by spreading activation, and the integration of prime and target into a semantic context requiring word meaning.

However, most previous ERP studies that have investigated the processing of taxonomic and thematic relation have used a relatively long SOA. Moreover, these ERP studies did not differentiate between different types of semantic relations, or used different types of thematic relations together. As mentioned earlier, the thematic relations included various types of semantic relations, such as productive, spatial, causal and script relations (Lin & Murphy, 2001; Estes et al., 2011). Specifically, script relations are thematically related because they refer to complementary relationships of actions and instruments associated with the execution of some event. For example, stamps and collecting activities are related by the event itself and perform complementary roles in the stamp-collecting script. However, gold–golden and snow–white are semantically related at the lexical level rather than having an external relationship, because they occur within a single entity and entail no other concepts, except for "gold" or "snow" itself (recognized as internal features).

The goal of this study was to explore the processing of hierarchical categories and thematic categories via ERP priming using a short SOA (300 ms), in which fast and implicit processing will minimize the strategic decisions or expectancy, complementary to fMRI studies (Sachs et al., 2008; Sass et al., 2009). Furthermore, one issue encountered in previous studies of