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Neuroscience Letters 390 (2005) 139–144
Neuroscience Letters
www.elsevier.com/locate/neulet

Feature type effects in semantic memory: An event related potentials study

Giuseppe Sartori [a,*], David Polezzi [a,b], Francesca Mameli [a,b], Luigi Lombardi [b]

[a] *Department of General Psychology, University of Padua, Via Venezia, 8, 35100 Padova, Italy*
[b] *Department of Cognitive Sciences and Education, University of Trento, Via Matteo del Ben, 5, 38068 Rovereto (TN), Italy*

Received 21 May 2005; received in revised form 15 July 2005; accepted 5 August 2005

Abstract

It is believed that the N400 elicited by concepts belonging to Living things is larger than the N400 to Non-living things. This is considered as evidence that concepts are organized, in the brain, on the basis of categories. Similarly, differential N400 to Sensory and Non-sensory semantic features is taken as evidence for a neural organisation of conceptual memory based on semantic features. We conducted a feature-verification experiment where Living and Non-living concepts are described by Sensory and Non-sensory features and were matched for Age-of-Acquisition, typicality and familiarity and finally for relevance of semantic features. Relevance is a measure of the contribution of semantic features to the "core" meaning of a concept. We found that when Relevance is low then the N400 is large. In addition, we found that when the two categories of Living and Non-living concepts are matched for relevance the seemingly category effect at the neural level disappeared. Also no difference between Sensory and Non-sensory descriptions was detected when relevance was matched. In sum, N400 does not differ between categories or feature types. Previously reported effects of semantic categories and feature type may have arisen as a consequence of the differing Relevance of concepts belonging to Living and Non-living categories.

Keywords: Semantic memory; Semantic relevance; N400

A highly controversial issue in cognitive neuroscience of semantic memory regards the format of concept representation. One highly credited theory states that concepts are represented in the brain on the basis of the content of their constituent semantic features. In this regard, one of the most frequently investigated distinctions is that between Sensory and Non-sensory features. Consider for example the concept *Dog*.[1,2] A Sensory feature may be ⟨has four legs⟩. Non-sensory features may include functional (e.g. ⟨is used for hunting⟩), associative (e.g. ⟨likes to chase cats⟩) and encyclopaedic features (e.g. ⟨may be one of many breeds ⟩).[3,4] The Sensory/Functional theory, one of the most influential explanations of semantic memory impairment, is based on the distinction between Sensory and Non-sensory semantic features, and has been used to explain the puzzling phenomenon

* Corresponding author.
E-mail address: giuseppe.sartori@unipd.it (G. Sartori).

[1] Concept names are printed in italics, and names of semantic features in angled brackets.

[2] Semantic features are also sometimes termed "properties" or "attributes".

[3] Throughout this paper, the term "concept" refers to a set of weighted semantic features; semantic feature is used to describe any type of statement about the concept (both Sensory and Non-sensory).

[4] Functional features are defined in different ways. Some authors use this term for features that directly refer to functions (e.g. ⟨gives milk⟩) others denote physically defined features defined by motor properties (e.g. ⟨used to cut⟩ [7]). Others have defined functional knowledge by exclusion to denote any property that is not physically defined [21]. Throughout this paper, the term "Sensory feature" is used to describe semantic features that may be perceived in any modality, whereas "Non-sensory feature" is used to describe all other types of semantic features.

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doi:10.1016/j.neulet.2005.08.015

of category-specificity in semantic memory. This proposal has been enormously influential, spanning an entire area of empirical enquiry [1,2,6,7,14,16,18,22].

At neural level, it is believed that sensory experienced knowledge is stored in circumscribed brain regions, in a feature-based format, which is related to the encoding sensory channels. Functional imaging data consistent with this claim [15] have been reported and, in addition, electrophysiological investigations have shown that the N400, a negativity induced by semantic incongruity, is larger for Sensory features as compared to Non-sensory features [3]. This latter difference has been interpreted as a neurophysiological evidence of separate encoding of Sensory and Non-sensory semantic features in the brain.

Here we report an ERP study, in accordance with an opposing theory about semantic features. According to this contrasting view, semantic features are encoded in the brain on the basis of their contribution to the meaning of a concept. A concept may have many semantic features, although those really useful in distinguishing it from closely related concepts are only a few. The information content of semantic features may be measured by semantic relevance [19,20]. Relevance is a measure of the contribution of semantic features to the "core" meaning of a concept. Elite few semantic features of high relevance are sufficient for an accurate retrieval of the target concept. In contrast, when semantic relevance is low, retrieval is inaccurate. Among all the semantic features of a concept those with high relevance are also critical in distinguishing it from other similar concepts. The following is a case in point: ⟨has a trunk⟩ is a semantic feature of very high relevance for the concept *Elephant*, because most subjects use it to define *Elephant,* whereas very few use the same feature to define other concepts. Instead ⟨Has 4 legs⟩ is a semantic feature with low relevance for the same concept, because few subjects use to define *Elephant* but do use it to define many other concepts. When a set of semantic features is presented, their overall relevance results from the sum of the individual relevance values associated with each of the semantic features. The concept with the highest summed relevance is the one that will be retrieved. For example, the three features ⟨similar to a goose⟩, ⟨lives in ponds⟩ and ⟨has a beak⟩ have topmost relevance for *Duck*, followed by *Swan*, and then by *Ostrich* (example taken from the normative data collected by Sartori and Lombardi [19][5]). The retrieved concept, given the three features, will be *Duck*, because it has the highest relevance. Hence, overall accuracy in name retrieval is poor when concepts have low relevance, and when they have many other semantically related concepts with which they may be confused. It has been shown that [20]: (i) relevance is the best predictor of naming accuracy (at least in a "naming-to-description" task) when contrasted to a number of other parameters of semantic features (dominance, distinctiveness) and of the concept (e.g. Age-of-Acquisition, familiarity and typicality), (ii) relevance is a robust measure, not significantly influenced by the number of concepts in the database or by sampling errors.

Here we will report an ERP study designed to address the issue of how semantic features are coded in the brain. In this paper we will show that: (i) low relevance descriptions have larger N400 with respect to high relevance descriptions; (ii) no effects of feature type arise when relevance is matched; (iii) no differences in N400 to differing categories of Living and Non-living concepts can be detected when relevance is matched.

Twenty-four Italian undergraduate students (age range 19–29 years; mean = 22.6, S.D. = 2.55) participated in the experiment. Nine were male and 15 female. Average education was 16.7 years. All the subjects were healthy and had normal or corrected-to-normal vision.

Every trial consisted in the sequential presentation of a verbal description of three semantic features on a computer screen (e.g. ⟨has a carriage⟩, ⟨found in the airport⟩ and ⟨found in the sky⟩) followed by the presentation of a target word (e.g. *Airplane*) after which a Yes/No response was required. The task was to indicate whether the three features correctly indexed the concept or not. Half subjects responded with their right hand using the index finger for Yes responses and the middle finger for No responses; the remaining half used the fingers in opposite order.

In regard to the experimental stimuli, they varied according to the following dimensions: (i) Category (Living versus Non-living); (ii) Relevance (High versus Low); (iii) Feature type (Sensory versus Non-sensory); (iv) Congruency (Yes versus No). A total of 80 concepts were used. For each concept four descriptions were presented (two of high relevance, one Sensory and one Non-sensory and two low relevance, again one Sensory and one Non-sensory). These 320 stimuli were followed by the target concept and required a Yes response. Target words were matched across categories (Living $n = 40$ and Non-living $n = 40$) for Age of Acquisition ($p = 0.58$), Typicality ($p = 0.90$) and Familiarity ($p = 0.60$) (norms collected by Dell'Aqua et al. [5]). Average semantic relevance for Living (2.73) did not differ from that of Non-living (2.83) ($p = 0.51$). Average semantic relevance for Sensory features (2.80) did not differ from that of Non-sensory features (2.75) ($p = 0.74$). Relevance values of the three semantic features presented sequentially to the subjects were taken from the norms collected by Sartori and Lombardi [19]. All the 320 stimuli requiring a No response had the same level of dissimilarity with the correct target as measured by standardized cosine.[6] The following is a telling example: if the correct description for the concept *Peach* is, instead, followed by *Violet* a No response is required. The cosine similarity of *Violet* with respect to *Peach* is 0.073

[5] Relevance values are derived algorithmically from a feature-listing task and are not based on subjective ratings. The computation is based on the number of times people report a given feature in defining a concept [20].

[6] Standardized cosine is a popular measure of similarity between vectors of semantic features. Matching cosine similarity guarantees that the foils are equally dissimilar to the target.