Neuropsychologia 45 (2007) 966–976

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Semantic relevance, domain specificity and the sensory/functional theory of category-specificity

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Received 10 February 2006; received in revised form 25 August 2006; accepted 30 August 2006
Available online 27 October 2006

Abstract

According to the sensory/functional theory of semantic memory, Living items rely more on Sensory knowledge than Non-living ones. The sensory/functional explanation of category-specificity assumes that semantic features are organised on the basis of their content. We report here a study on DAT patients with impaired performance on Living items and tests of Sensory knowledge, and show that this impairment not only disappears after parcelling out semantic relevance, but is also reversed if this parameter is appropriately manipulated. Although semantic relevance model predicts these results [Sartori, G., & Lombardi, L. (2004). Semantic relevance and semantic disorders. *Journal of Cognitive Neuroscience, 16*, 439–452], they run counter to both the sensory/functional theory and the domain-specific theory of category-specific impairment.

Keywords: Semantic memory; Category-specific impairment; Sensory knowledge; Semantic memory

1. Introduction

Concepts are assumed to be organised networks of semantic features (e.g., Collins & Quillian, 1969; Jackendoff, 1990, 2002; Minsky, 1975; Norman & Rumelhart, 1975; Saffran & Sholl, 1999; Smith & Medin, 1981). One way of analysing semantic features is to group them according to their content. In this regard, one of the most frequently examined 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 of category-specificity in semantic memory. This proposal has been enormously influential, spanning an entire area of empirical enquiry (Allport, 1985; Farah & McClelland, 1991; Martin & Chao, 2001; Saffran, 2000; Warrington & McCarthy, 1987; Warrington & Shallice, 1984).

Category-specific semantic impairment may be found in neurological patients (most frequently following HSV encephalitis and DAT), who may show specific impairments for some categories but not for others. One most frequent selective impairment

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[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; a 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 features physically defined by motor properties (e.g. ⟨used for cutting⟩, Farah & McClelland, 1991). Others have defined functional knowledge by exclusion to denote any property that is not physically defined (Thompson-Schill, Aguirre, D’Esposito, & Farah, 1999). Throughout this paper, the term “Sensory feature” is used to describe semantic features that may be perceived in any modality and “Non-sensory feature” all other types of semantic features.

0028-3932/$ – see front matter
doi:10.1016/j.neuropsychologia.2006.08.028

is for concepts belonging to the Living category, whereas performance on concepts belonging to the Non-living category is relatively spared. The opposite pattern also exists (i.e., impairment for Non-living, good performance on Living), but is rarer (see Capitani, Laiacona, Mahon, & Caramazza, 2003).

In explaining selective impairments for Living, it has been noted (Warrington & Shallice, 1984) that Living tend to be distinguished more easily on the basis of Sensory features (e.g., *Tiger*, ⟨has stripes⟩) and Non-living on the basis of functional features (e.g., *Knife*, ⟨used for cutting⟩). Consequently, if brain damage leads to a loss of Sensory knowledge then Living tends to be more affected. Instead, if Non-sensory knowledge is degraded, then the opposite dissociation results. Therefore, a patient with a specific disruption of knowledge involving Sensory semantic features is more likely to show a specific impairment for Living. Instead, a specific loss of Non-sensory features is supposed to lead to specific impairment for Non-living, a pattern that has also been reported (see Sacchett & Humphreys, 1992). In this view, category-specificity is an impairment caused by a co-existing Sensory knowledge impairment.

At least two variants of the sensory/functional theory have been proposed. Humphreys and Forde (2001) claimed that Sensory knowledge ("structural description" in their terminology) and functional-associative descriptions are found in separate but interconnected stores of knowledge. Similarly, Martin, Haxby, Lalonde, Wiggs, and Ungerleider (1995) believe that Sensory-experienced knowledge is stored in circumscribed brain regions, in a feature-based format, which is related to the encoding Sensory channels. This position is a variant of the proposal of Warrington and McCarthy (1987), who claimed that semantic processing of categories relies on differing Sensory channels. For example, *fruit* is believed to be best defined by semantic features that involve olfactory and gustatory Sensory channels, which are not involved in the semantic processing of *motor vehicles*. Other theorists also claimed that differing semantic feature-types are essential parts of semantic memory (Allport, 1985; Farah & McClelland, 1991; Martin & Chao, 2001; Saffran, 2000; Warrington & McCarthy, 1987; Warrington & Shallice, 1984). Here, the sensory/functional theory is considered as representative of a class of theories, which assumes that semantic features are encoded in the brain on the basis of their content, and that their content is important for retrieval of particular groups of concepts.

By contrast, semantic features may trigger concept retrieval, rather than on the basis of their content, on the basis of their degree of informativeness for the target concept. A concept may have uncountable semantic features, although those which are really useful in distinguishing it from other closely related concepts may not be numerous. Among dimensions proposed as descriptors of semantic features, we can list dominance (Ashcraft, 1978), distinctiveness (e.g., Garrard, Lambon Ralph, Hodges, & Patterson, 2001) and, most recently, semantic distance (Zannino, Perri, Pasqualetti, Caltagirone, & Carlesimo, 2006) and semantic relevance (Sartori & Lombardi, 2004; Sartori, Lombardi, & Mattiuzzi, 2005a). Relevance is a measure of the contribution of semantic features to the "core" meaning of a concept. Few semantic features of high relevance are sufficient for retrieval of the target concept. When semantic relevance is lower, retrieval is inaccurate. The following is a case in point: ⟨has a trunk⟩ is a semantic feature of 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. Among all the semantic features of a concept, those with high relevance are useful in distinguishing the concept from those similar to it. Instead ⟨has 4 legs⟩ is a semantic feature with lower relevance for the same concept, because few subjects use it 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 is retrieved with higher probability. For example, the three features ⟨similar to a goose⟩, ⟨lives in ponds⟩ and ⟨has a beak⟩ have top relevance for *Duck*, followed by *Swan*, and then *Ostrich* (an example taken from the normative data collected by Sartori & Lombardi, 2004). The retrieved concept, given the above 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.

The relevance of semantic features is different from distinctiveness. Distinctiveness is a dimension which is not concept-dependent, and scores are high when the feature is found in only a few concepts. For example, the distinctiveness value of ⟨has a beak⟩ is the same for *Duck* and *Swan*. Instead, the relevance of a given semantic feature varies across different concepts and, in a way, may be considered concept-dependent. For example, the feature ⟨has a beak⟩ has higher relevance for the concept *Duck* than for the concept *Swan*, but the same distinctiveness for both concepts.

Semantic relevance is the result of two components: (i) a local component, which measures the importance of the semantic features for the concept, which may be interpreted as dominance, and (ii) a global component, which measures the importance of the same semantic feature for all the other concepts in the lexicon, which may be interpreted as distinctiveness (see Appendix A for details). More precisely, semantic relevance may be interpreted as a non-linear combination of dominance (also called production frequency; Cree & McRae, 2003) and distinctiveness. While both dominance and distinctiveness do not predict accuracy in a "naming-to-description" task, when combined into relevance they are highly correlated with naming accuracy (Sartori et al., 2005a).

Sartori et al. (2005a) also showed that: (i) relevance is the best predictor of naming accuracy (at least in a "naming-to-description" task), when compared with a number of other parameters of semantic features (dominance, distinctiveness) and of the concept (e.g., age-of-acquisition, frequency and typicality); (ii) relevance is a robust measure, not significantly influenced by the number of concepts in the subject's lexicon or by sampling errors.

A procedure for empirically deriving these components consists in collecting feature norms for concepts in a feature-listing task (see also Cree & McRae, 2003; Garrard et al., 2001;

Vigliocco, Vinson, Lewis, & Garrett, 2004). From raw feature norms, collected from healthy subjects (Sartori & Lombardi, 2004), relevance values of semantic features for concepts are derived algorithmically, according to Eq. (1) of the Appendix A.

As regards Sensory and Non-sensory semantic features, Sartori and Lombardi (2004) analysed differences between categories in differing types of features. The Living category turned out to have more Sensory features (of low relevance) and fewer functional features per concept than Non-living (see also Farah & McClelland, 1991). In contrast, Non-living had more functional features and fewer Sensory features with respect to Living and the importance of functional features (as measured by relevance) was higher, on average, than that of Sensory features.

One consequence is that a selection of Sensory features of Living not checked for relevance tends to be of low relevance. As low relevance causes inaccuracy, the final result is lower accuracy for Sensory knowledge of Living relative to Sensory knowledge for Non-living, even in the absence of any selective deficit of Sensory knowledge.

This view seems more tenable when we consider that the neural correlates of sensory and non-sensory features, as measured by N400, do not differ when relevance is matched between the two types of features (Sartori, Polezzi, Mameli, & Lombardi, 2005b). Previously reported differences in N400 (Coltheart et al., 1998; Kiefer, 2001) between Living and Non-living and between sensory and non-sensory features disappear, as long as stimuli are matched for semantic relevance (Sartori, Mameli, Polezzi, & Lombardi, 2006).

Our model does not postulate that concept retrieval is based primarily on feature content, but rather that possible differences among feature types, as well as category effects, may emerge from differences in the semantic relevance of features. This view may provide a principled explanation for the seemingly contrasting results reported on this topic.

Here we extend such results by examining patients with two types of impairment, one for Living and one for Sensory knowledge. We show first that impairments for Living and Sensory semantic knowledge are eliminated by equating semantic relevance across categories (Living and Non-living) and feature types (Sensory and Non-sensory) and, second, that patients may turn out to be impaired for Non-living and Non-sensory knowledge by manipulating semantic relevance.

2. Methods

As some degree of semantic impairment is commonly seen in the early stages of dementia of Alzheimer's type (DAT) (Chertkow & Bub, 1990; Patterson & Hodges, 1995), this study was conducted on DAT patients with this characteristic. Category-specificity has been linked to temporal lobe dysfunction, which is typically observed in both herpes encephalitis and DAT (Gainotti, Silveri, Danieli, & Giustolisi, 1995), and DATs may have category-specific semantic deficits similar to those observed in herpes patients (see Daum, Riesch, Sartori, & Birbaumer, 1996).

2.1. *Participants: category-specific DATs, DATs, and healthy controls*

In regard to experimental design, Borgo and Shallice (2001) have noted that the use of a patient control group has the advantage of avoiding problems due to

Table 1a
Background neuropsychological tests

	Category-specific DAT patients					DAT controls									Normative sample
	M.R.	E.A.	M.S.	P.V.	Mean	T.I.	T.H.	F.F.	C.G.	O.A.	C.C.	D.M.	P.M.	Mean	Mean
Background neuropsychological tests															
Age	87	78	76	77	**79.5**	90	87	81	79	80	83	83	82	**83.1**	**80.8**
Education	1	13	4	5	**5.7**	3	3	5	3	1	17	8	5	**5.6**	**6.5**
Hachinski Ischemic Score	3	2	1	2	**1.67**	3	2	1	1	2	1	1	2	**1.6**	n.a.
[a]MMSE corrected (max. 30, cut off 24)	13.2	20	20	19.7	**18.2**	14.2	21.2	16.4	16	19.5	14.1	14.7	17.4	**16.7**	**26**
[b]TIB Premorbid IQ ($N=40$)	77.9	96.3	78.9	84.3	**84.4**	87.8	86.8	90.0	85.9	84.6	94.2	90.1	85.3	**88.1**	**100**
[c]Prose Memory %accuracy ($N=28$)	5.4%	5.4%	7.1%	7.1%	**6.3%**	0%	44.6%	7.1%	23.2%	0%	1.8%	3.6%	10.7%	**11.4%**	**32.1%**
[d]Phonemic Incidental Memory %accuracy ($N=20$)	5%	0%	10%	5%	**5%**	0%	20%	10%	0%	10%	0%	0%	10%	**6.3%**	**25%**

n.a.: not administered.
[a] Folstein, Folstein, and McHugh (1975).
[b] Sartori et al. (1997).
[c] Spinnler and Tognoni (1987).
[d] Sartori, Job, Miozzo, Zago, and Marchiori (1993).

ceiling performance, which are frequently observed when only healthy controls are used.

For this reason three groups participated in the experiment: (i) a group of four category-specific DATs; (ii) a group of eight control DATs matched for age, sex and education to the previous group, but without category-specific impairments and with an overall semantic impairment comparable to that of category-specific DATs; and (iii) a group of eight healthy controls matched for age and education to the other two groups. The two groups of DAT patients were selected, in the Veneto region (North-East Italy) from a cohort of 208 patients enrolled in the Cronos project. Diagnosis of probable DAT was made according to NINCDS and ADRDA criteria (McKhann et al., 1984).

Four basic neuropsychological tests and four category-specificity tests were administered. The four basic neuropsychological tests were MMSE, TIB premorbid IQ, prose memory, and phonemic incidental memory. The four category-specificity tests were property verification (Sartori, Job, & Zago, 2002), picture-naming (Sartori et al., 2002), and two "naming-to-description" tests (Lambon-Ralph, Howard, Nightingale, & Ellis, 1998; Silveri & Gainotti, 1988, see also Tables 1a and 1b). The two "naming-to-description" tests were slightly different from each other. The Lambon-Ralph et al. (1998) test indexed both category differences and feature type differences, whereas the Silveri and Gainotti (1988) test used only animals, which were described using Sensory and Non-sensory features. The four category-specific tests had been used previously to establish category-specificity. These tests did not control for semantic relevance, and most of their concepts and semantic features were not included in our normative study (Sartori & Lombardi, 2004). On the basis of these tests, four patients were selected who showed significant, consistent impairments for Living and Sensory knowledge. This pattern is that required by the sensory/functional theory of semantic memory for a direct test of the theory itself. These four category-specific patients were contrasted with a group of eight DAT controls matched for age and level of education. No control DAT showed any difference between categories or feature types in any of the four background category-specific tests.

All 12 patients (four category-specific, eight controls) had a Hachinski score of less than 4 and a MMSE below 24/30, and underwent CT or MRI scanning together with the usual battery of screening blood tests to exclude treatable causes of dementia. Patients with major depression, past history of known stroke or TIA, alcoholism, head injury, or major medical illnesses were excluded. All patients were recruited in three hospitals and four nursing homes located in the Veneto region (Italy).

2.2. Basic neuropsychological information and background semantic memory tests

Basic neuropsychological tests showed that the two pathological groups did not differ as regards premorbid IQ, as measured by TIB (Sartori, Colombo, Vallar, Rusconi, & Pinarello, 1997; $p = 0.36$). Measures of anterograde memory also yielded comparable results between these two groups (prose memory $p = 0.53$; phonemic incidental memory $p = 0.76$).

The tests used as screening for category-specificity did not check relevance of semantic features, and were originally developed and used for assessing category-specificity and other knowledge disorders. Semantic features, where appropriate, were classified as Sensory and Non-sensory, following Caramazza and Shelton (1998). Each of the four category-specific DATs was significantly

Table 1b
Background category-specific tests showing performance of category-specific DAT group on four tests aimed at evaluating category-specificity and feature knowledge

	Category-specific DAT patients (performance is reported in %accuracy)				Mean
	M.R.	E.A.	M.S.	P.V.	
Living–Non-living					
[a]Feature verification ($N = 144$)					
Living	57.5%	47.5%	53.8%	21.3%	45%
Non-living	76.6% $\chi^2_{(1)} = 5.75$	65.6% $\chi^2_{(1)} = 4.66$	71.9% $\chi^2_{(1)} = 4.95$	37.5% $\chi^2_{(1)} = 4.62$	62.9% $F_{(1,3)} = 929.01$; $p < 0.001$
[b]Picture naming ($N = 64$)					
Living	21.9%	37.5%	15.6%	46.9%	30.5%
Non-living	46.9% $\chi^2_{(1)} = 4.42$	62.5% $\chi^2_{(1)} = 4$	46.9% $\chi^2_{(1)} = 7.28$	71.9% $\chi^2_{(1)} = 4.14$	57% $F_{(1,3)} = 289.01$; $p < 0.001$
[c]Naming-to-description ($N = 56$)					
Living	18.8%	25%	28.1%	6.3%	19.5%
Non-living	45.8% $\chi^2_{(1)} = 4.76$	58.3% $\chi^2_{(1)} = 6.47$	62.5% $\chi^2_{(1)} = 6.61$	33.3% $\chi^2_{(1)} = 6.79$	50% $F_{(1,3)} = 240.2$; $p < 0.001$
Sensory–Non-sensory					
[c]Naming-to-description ($N = 56$)					
Sensory	17.9%	25%	28.6%	3.6%	18.8%
Non-sensory	42.9% $\chi^2_{(1)} = 4.14$	53.6% $\chi^2_{(1)} = 4.79$	57.1% $\chi^2_{(1)} = 4.66$	32.1% $\chi^2_{(1)} = 7.79$	46.4% $F_{(1,3)} = 961.00$; $p < 0.001$
[d]Naming-to-description ($N = 25$)					
Sensory	0%	18.2%	18.2%	0%	9.1%
Non-sensory	64.3% $\chi^2_{(1)} = 11.04$	71.4% $\chi^2_{(1)} = 6.98$	57.1% $\chi^2_{(1)} = 3.89$	42.9% $\chi^2_{(1)} = 6.19$	58.9% $F_{(1,3)} = 76.9$; $p < 0.003$

All four category-specific DAT were seriously impaired on Living and Sensory knowledge on all tests.

[a] Sartori et al. (2002): 8 Non-living and 10 Living. For each concept eight features are randomly listed: 4 true and 4 false features.

[b] Sartori et al. (2002): 64 black and white pictures representing 32 Living and 32 Non-living, matched for frequency, familiarity and visual complexity.

[c] Lambon-Ralph et al. (1998): naming-to-description task, adapted by the authors and translated into Italian. Twenty-eight concepts: 12 of Non-living and 16 of Living. Every concept is described by a Sensory description or by a Non-sensory description. Items matched for familiarity, frequency, visual complexity and age-of-acquisition across categories.

[d] Silveri and Gainotti (1988): 25 descriptions of Living concepts constituted the test: 14 were Non-sensory and 11 Sensory.

Table 1c
Background category-specific tests showing performance of DAT controls on four tests aimed at evaluating category-specificity and feature knowledge

	DAT controls (performance is reported in %accuracy)								Mean
	T.I.	T.H.	F.F.	C.G.	O.A.	C.C.	D.M.	P.M.	
Living–Non-Living									
[a]Feature verification ($N = 144$)									
Living	61.25%	82.5%	53.75%	77.5%	43.75%	46.25%	40%	57.5%	57.8%
Non-Living	51.56%	87.5%	54.69%	82.81%	46.88%	50.0%	51.56%	57.81%	60.3%
	$\chi^2_{(1)} = 1.36$ $p = 0.24$	$\chi^2_{(1)} = 0.68$ $p = 0.40$	$\chi^2_{(1)} = 0.02$ $p = 0.89$	$\chi^2_{(1)} = 0.62$ $p = 0.43$	$\chi^2_{(1)} = 0.14$ $p = 0.71$	$\chi^2_{(1)} = 0.2$ $p = 0.65$	$\chi^2_{(1)} = 1.91$ $p = 0.17$	$\chi^2_{(1)} = 0.001$ $p = 0.97$	$F_{(1,7)} = 1.42$; $p = 0.27$
[b]Picture Naming ($N = 64$)									
Living	59.4%	71.88%	25.0%	62.5%	59.38%	9.38%	46.88%	59.38%	49.2%
Non-Living	56.25%	75%	40.63%	62.5%	68.75%	21.88%	46.88%	40.63%	51.6%
	$\chi^2_{(1)} = 0.06$ $p = 0.81$	$\chi^2_{(1)} = 0.08$ $p = 0.78$	$\chi^2_{(1)} = 1.78$ $p = 0.18$	$\chi^2_{(1)} = 0$ $p = 1$	$\chi^2_{(1)} = 0.61$ $p = 0.43$	$\chi^2_{(1)} = 2.54$ $p = 0.11$	$\chi^2_{(1)} = 0$ $p = 1$	$\chi^2_{(1)} = 1.004$ $p = 0.32$	$F_{(1,7)} = 0.37$; $p = 0.56$
[c]Naming-to description ($N = 56$)									
Living	56.25%	78.13%	28.13%	37.50%	46.88%	6.25%	18.75%	34.38%	38.28%
Non-Living	58.33%	62.5%	33.33%	45.83%	66.67%	16.67%	33.33%	50.0%	45.83%
	$\chi^2_{(1)} = 0.02$ $p = 0.89$	$\chi^2_{(1)} = 1.64$ $p = .20$	$\chi^2_{(1)} = 0.18$ $p = 0.67$	$\chi^2_{(1)} = 0.39$ $p = 0.53$	$\chi^2_{(1)} = 2.17$ $p = 0.14$	$\chi^2_{(1)} = 1.55$ $p = 0.21$	$\chi^2_{(1)} = 1.55$ $p = 0.21$	$\chi^2_{(1)} = 1.38$ $p = 0.24$	$F_{(1,7)} = 3.7$; $p = 0.093$
Sensory–Non-sensory									
[c]Naming-to description ($N = 56$)									
Sensory	57.14%	78.57%	35.71%	46.43%	50.0%	14.29%	32.14%	50.0%	45.54%
Non-sensory	57.14%	64.29%	25.0%	35.71%	60.71%	7.14%	17.86%	32.14%	37.50%
	$\chi^2_{(1)} = 0$ $p = 1$	$\chi^2_{(1)} = 1.40$ $p = 0.24$	$\chi^2_{(1)} = 0.76$ $p = 0.38$	$\chi^2_{(1)} = 0.66$ $p = 0.42$	$\chi^2_{(1)} = 0.65$ $p = 0.42$	$\chi^2_{(1)} = 0.74$ $p = 0.39$	$\chi^2_{(1)} = 1.52$ $p = 0.22$	$\chi^2_{(1)} = 1.84$ $p = 0.18$	$F_{(1,7)} = 1.61$; $p = 0.24$
[d]Naming-to-description ($N = 25$)									
Sensory	45.45%	90.91%	9.1%	63.63%	54.54%	18.18%	18.18%	81.81%	47.73%
Non-sensory	64.29%	92.86%	28.57%	78.57%	50.0%	7.14%	28.57%	35.71%	48.21%
	$\chi^2_{(1)} = 0.94$ $p = 0.33$	$\chi^2_{(1)} = 0.03$ $p = 0.86$	$\chi^2_{(1)} = 1.46$ $p = 0.23$	$\chi^2_{(1)} = 0.68$ $p = 0.41$	$\chi^2_{(1)} = 0.05$ $p = 0.82$	$\chi^2_{(1)} = 0.2$ $p = 0.65$	$\chi^2_{(1)} = 0.36$ $p = 0.65$	$\chi^2_{(1)} = 0.88$ $p = 0.35$	$F_{(1,7)} = 0.004$, $p = 0.952$

DAT controls did not show any effect, neither individually nor as a group.

[a] Sartori et al. (2002): 8 Non-living and 10 Living. For each concept eight features are randomly listed: 4 true and 4 false features.

[b] Sartori et al. (2002): 64 black-and-white pictures representing 32 Living and 32 Non-living, matched for frequency, familiarity and visual complexity.

[c] Lambon-Ralph et al. (1998). Naming to description task adapted from the authors and translated into Italian. Twenty eight concepts: 12 of Non-living and 16 of Living. Every concept is described by a Sensory or Non-sensory description. Items matched for familiarity, frequency, visual complexity and age-of-acquisition across categories.

[d] Silveri and Gainotti (1988): 25 descriptions of Living concepts constituted the test, 14 Non-sensory and 11 Sensory.

Table 2
Sample descriptions for the Non-Living item *bicycle* and the Living item *camel* (Semantic features are represented in boldface)

Type of description	Description	Target response
Non-living Sensory, high relevance	Has a **saddle**, **pedals** and **spokes**;	BICYCLE
Non-living Sensory, low relevance	Looks like a **motorbike**, made of **metal** and **light-weight**	BICYCLE
Non-living Non-Sensory, high relevance	You can **brake** it, **pedal** it, and find it on **cycling tracks**	BICYCLE
Non-living Non-Sensory, low relevance	A **vehicle**, moved with the **feet**, can be seen in a **park**	BICYCLE
Living Sensory, high relevance	Has **two humps**, **four legs**, and is **large**	CAMEL
Living Sensory, low relevance	Has a **long neck**, **smells**, and is **brown**	CAMEL
Living Non-Sensory, High relevance	Found in the **desert**, is a **ruminant**, used for **carrying people**	CAMEL
Living Non-Sensory low relevance	May be found in **Egypt**, is an **animal**, is **tough**	CAMEL

Table 3
Relevance values for descriptions used in the experimental design

	Mean (S.D.)				Significance (*p*)
	Living		Non-living		
Sensory	High Relevance	4.66 (0.46)	High Relevance	4.77 (0.38)	0.61
	Low Relevance	1.74 (0.25)	Low Relevance	1.86 (0.14)	0.24
Non-sensory	High Relevance	4.6 (0.44)	High Relevance	4.72 (0.42)	0.59
	Low Relevance	1.81 (0.26)	Low Relevance	1.77 (0.14)	0.71

Average relevance of Living did not differ from that of Non-living ($p = 0.84$).

Table 4
Results for three groups (Category-specific DATs, Control DATs, Healthy controls) on the “naming-to-description” test with controlled relevance

Concept description, three semantic features	Mean (S.D.)		
	Category-specific DATs	Control DATs	Healthy controls
Living Sensory, high relevance ($N = 8$)	5.25 (1.71)	4.375 (2.33)	7.375 (0.52)
Living Non-sensory, high relevance ($N = 8$)	3.25 (0.96)	3.75 (1.488)	7.625 (0.52)
Living Sensory, low relevance ($N = 8$)	0.75 (0.5)	1.5 (0.93)	4.5 (1.19)
Living Non-sensory, low relevance ($N = 8$)	2 (1.41)	1.62 (1.30)	4.625 (0.92)
Non-Living Sensory, high relevance ($N = 8$)	3.25 (0.5)	3.375 (2.134)	7.125 (1.13)
Non-Living Non-sensory, high relevance ($N = 8$)	5 (1.155)	4.375 (1.41)	7 (0.76)
Non-Living Sensory, low relevance ($N = 8$)	1.75 (1.71)	1.5 (0.76)	5.25 (1.39)
Non-Living Non-sensory, low relevance ($N = 8$)	0.5 (0.58)	1.625 (1.30)	4.875 (0.64)

impaired for Living and Sensory knowledge (see Table 1b). None of the control DATs showed any specific impairment for Living or Sensory knowledge (see Table 1c).[5]

2.3. Relevance-controlled “naming-to-description” task

One possible explanation of combined category and Sensory knowledge impairment calls semantic relevance into account. To verify whether both impairments disappeared in category-specific DATs after matching semantic relevance across categories and feature types, we developed a new “naming-to-description” test.

Concepts were selected from a database of 254 concepts (Dell’Acqua, Lotto, & Job, 2000) on which semantic relevance was mapped (Sartori & Lombardi, 2004). For each concept one description consisting of three Sensory features and another description consisting of three Non-sensory features with matched relevance were derived. The criteria for defining what is a sensory and a non-sensory feature are debatable. We have applied those used by Cree and McRae (2003). Sensory features included visuo-motor, form and surface, colour, sound, taste, smell and tactile features. Non-sensory features included functional, encyclopedic and taxonomic features.

Table 2 gives examples of descriptions including three semantic features for the differing conditions.

Concept descriptions included three semantic features with known relevance values taken from the Sartori and Lombardi (2004) database. A total of 64 descriptions of 16 concepts were selected, according to a 2 (categories: Living versus Non-living) × 2 (semantic feature type: Sensory versus Non-sensory) × 2 (semantic relevance: high versus low) design (see Table 3).

The experimental test, a “naming-to-description” test with controlled semantic relevance, was also given to a group of eight healthy controls (mean age = 81.2; mean education = 6.3; mean MMSE = 28.7). Healthy controls were included in order to ensure that low relevance descriptions contained enough information to retrieve the target concept with satisfactory accuracy. Average accuracy for low relevance items in the experimental “naming-to-description” task was 4.8/8 (see Table 4).

The average accuracy on low relevance descriptions was 60% for healthy controls, thus excluding a floor effect. Target Living and Non-living concepts were matched for potentially confounding variables such as frequency ($p = 0.10$), familiarity ($p = 0.22$) and age-of-acquisition ($p = 0.52$); feature types were matched for relevance (Sensory = 3.26, Non-sensory = 3.23; $p = 0.98$). Relevance was also matched across categories (Living = 0.81; Non-living = 0.84; $p = 0.84$). As naming accuracy is assumed to depend on semantic relevance,

[5] Category-DATs have slightly lower performance in overall accuracy in all tests reported in Tables 1b and 1c with respect to Control DATs.

performance to descriptions with the same relevance values should be equal. Instead, the sensory/functional theory predicts that a patient, impaired in Living and Sensory knowledge will still be impaired on this new test because the cause of inaccuracy is considered feature type.

3. Results

Results on the experimental test are listed in Table 4.

Three separate ANOVAs were carried out in the three groups. Each within subject ANOVA had three factors: relevance (high versus low), category (Living versus Non-living), and feature type (Sensory versus Non-sensory). Each analysis by subjects was paralleled by a corresponding analysis by stimuli.

3.1. Healthy controls

Relevance was significant for both subjects ($F_{(1,7)} = 176.88$; $p < 0.001$) and for stimuli ($F_{(1,14)} = 27.46$; $p < 0.001$), and high relevance descriptions were more accurate than low relevance ones. No other source reached significance by subjects or by stimuli.

3.2. Control DATs

As in Healthy controls, relevance was significant both in an ANOVA by subjects ($F_{(1,7)} = 17.77$; $p < 0.005$) and by stimuli ($F_{(1,14)} = 29.83$; $p < 0.001$). No other source reached significance by subjects or by stimuli.

3.3. Category-specific DATs

Overall, the performance of category-specific DATs did not differ from that of Control DATs (2.71/8 versus 2.76/8; $p = 0.91$), confirming that the two groups had a similarly severe naming impairment. Relevance, as in the other two groups, was significant both in an ANOVA by subjects ($F_{(1,3)} = 348.79$; $p < 0.001$) and by stimuli ($F_{(1,14)} = 16.42$; $p < 0.001$). A critical interaction was Category × Feature type, which was not significant neither by subjects ($F_{(1,3)} = 2.27$; $p = 0.15$) nor by stimuli ($F_{(1,14)} = 0.41$; $p = 0.53$). The triple interaction Category × Relevance × Feature type was close significance by subjects ($F_{(1,3)} = 9.6$; $p = 0.053$) but was significant by stimuli ($F_{(1,14)} = 15.8$; $p < 0.001$).

This triple interaction contains important information, which was analysed using *a posteriori* statistics called the Fisher–Hayter (F–H) test (Hayter, 1986; Kirk, 1995) which may be used within the context of randomised block design. Fig. 1 clearly shows that category-specific DATs perform low on Living with Sensory descriptions of low relevance (9.38%) and high on Non-living with Non-sensory descriptions high relevance (62.5%) ($q\text{FH}_{(1,3)} = 5.17$; $p < 0.05$). This pattern corresponds to the prediction of the sensory/functional theory of category-specificity, and also to the results expected from developing a "naming-to-description" task without controlling for semantic relevance, for the reasons reported above. Instead, the pattern was completely reversed when Living have Sensory descriptions of high relevance (65.6%) and Non-living Non-sensory descriptions of low relevance (6.25%) ($q\text{FT}_{(1,3)} = 5.78$; $p < 0.05$). This reversal is the critical result, and will be commented on extensively later (see. Fig. 1).

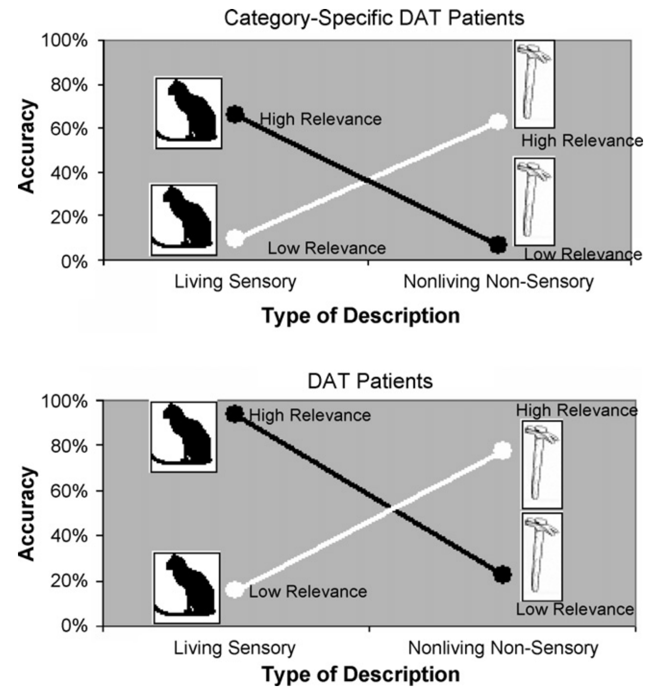

Fig. 1. Critical comparisons for two groups. White line: predictions of sensory/functional theory. Black line: reversal of feature-type effect, believed to be impossible according to sensory/functional theory. Neither of these is accommodated by Domain-specific theory.

Also notable is the fact that low-relevance Sensory descriptions were equally accurate (15.6%) with respect to Non-sensory descriptions (15.6%). Furthermore high-relevance Sensory (26.5%) were as accurate as high relevance Non-sensory (25.8%). Among high relevance items there was no difference between Living sensory and Living Non-sensory ($q\text{FT}_{(1,3)} = 1.49$, n.s.) and between Non-living sensory and Non-living non-sensory ($q\text{FT}_{(1,3)} = 1.30$, n.s.).

Therefore, the selective impairment of Sensory knowledge expected by the sensory/functional theory is not confirmed.

We conducted an ANOVA with group × (low SR living/sensory versus high SR non-living/non-sensory) and the non-significant interaction indicated that the difference between low SR living/sensory and high SR non-living/non-sensory is similar in all three groups $F_{(2,17)} = 1{,}632$, $p = 0.225$. We also conducted another ANOVA with group × (high SR living/sensory versus low SR non-living/non-sensory). The non-significant interaction indicated that this difference too was similar in all three groups $F_{(2,17)} = 2{,}487$, $p = 0.113$.

4. Discussion

The origin of category and feature type effects in semantic memory patients has been hotly debated. The sensory/functional theory posits that semantic features are subdivided into two basically distinct types; Sensory and Non-sensory. This distinction apparently makes sense in a broad variety of phenomena in semantic memory disorders. In this view, Sensory information is thought to contribute disproportionately to the features of Living concepts, and selective impairment on Sensory features is thought to lie at the basis of category-specificity for Living. Instead, Non-sensory and in particular functional semantic features in particular are considered to be important in accomplishing semantic tasks on Non-living concepts; similarly, selective impairment on Non-living is believed to depend on selective impairment of this Non-sensory knowledge.

This study was intended to contrast the sensory/functional theory of category-specificity with the semantic relevance theory which distinguishing semantic features on the basis of their content (Sensory versus Non-sensory), rather than on their diagnostic value for the concept.

We found that an initial seeming impairment for Living combined with a Sensory knowledge impairment disappeared after equating the relevance level of the semantic features. Four background semantic memory tests were used to identify a group of four category-specific DAT patients. These tests did not control for semantic relevance, and were selected among those used in the literature to establish category-specificity and Sensory knowledge impairments. We then developed a “naming-to-description” test in which the relevance of semantic features (high versus low), category (Living versus Non-living) and feature type (Sensory versus Non-sensory) was varied orthogonally.

The predictions of the sensory/functional theory diverge from those of the semantic relevance theory in this experimental test. According to the former, patients should replicate their performance and behave as in preliminary tests, i.e., those used to establish their impairment. According to this theory, what actually counts is the feature type (Sensory versus Non-sensory) which characterises the differing categories. As Living concepts are better retrieved from Sensory features, then patients should continue to show a major impairment in retrieving Living concepts with respect to Non-living, and a parallel major impairment in retrieving concepts from Sensory features with respect to Non-sensory ones. In other words, if the importance of a semantic feature relies on its content then the pattern should remain unchanged at differing levels of relevance.

Instead, in the model we propose, the predictions are those of similar performance to Living and Non-living and to Sensory and Non-sensory semantic features in the experimental task. If relevance is equated, then no difference in naming accuracy is expected. In other words, when semantic relevance is similar across categories, retrieving names of Living concepts is expected to be equally accurate with respect to retrieving Non-living ones. More importantly, retrieving concepts on the basis of Sensory features is expected to be as accurate as retrieving them on the basis of Non-sensory features. Lastly, for category-specific patients, retrieving Living concepts on the basis of Sensory features is expected to be equally accurate with respect to retrieving Non-living concepts on the basis of Non-sensory features. This result would be difficult to accommodate within the sensory/functional theory without further assumptions, which would include some measure of the importance of semantic features not related to feature content (Sensory versus Non-sensory).

The four category-specific patients, originally classified as having a category-specific semantic disorder also involving Sensory knowledge, did not show the selective impairments when semantic relevance was matched across categories and feature types. These findings lend support to the idea that Sensory knowledge impairment in category-specific patients may be the result of uncontrolled effects of semantic relevance in the tests used to establish category-specific deficits. If this is true a sensory knowledge impairment may not be considered at the origin of category specificity contrary to what hypothesised by the sensory/functional theory.

The patients were selected, in the first place, because they were unambiguously impaired on Living items with descriptions based on Sensory knowledge, as compared with Non-living with Non-sensory descriptions. This study also showed that the previous pattern is replicated only when Sensory descriptions of Living tend to be of low relevance, and Non-sensory descriptions of Non-living of high relevance. This specific combination corresponds to that probably observed from a sampling of concepts and semantic features, which does not take relevance into account (Sartori & Lombardi, 2004).

Most importantly, in our study, we were able to reverse the original pattern of category and feature-type impairment simply by manipulating the level of relevance of the semantic features. Patients who on preliminary testing were selectively impaired for Living probed by Sensory features, as compared with Non-living probed by Non-sensory features were shown to be impaired in the opposite direction. These results indicate that what counts in predicting impairment in “naming-to-description” tasks are not category or feature-type, but relevance of semantic features which, if not controlled, may cause spurious category and feature-type deficits.[6] A re-analysing of previous studies which have shown category-specific effects could further strengthen our argument, but this avenue of research would require collecting new normative data on the stimuli originally used by the authors. At this stage, the following conclusions may be drawn: the Sensory knowledge impairment observed in patients with a category impairment for Living (however, see Capitani et al., 2003) disappears when relevance of semantic features is controlled in a “naming-to-description” task. Borgo and Shallice (2001, 2003) enhanced the credibility of

[6] One may ask why the same patients show a different pattern of results on preliminary category-specific tests but similar performances on the experimental test. Laws and Sartori (2005) showed that a category-specific impairment on one test is frequently observed just by chance. Patients with an impairment which is consistently observed in more than one test are rarer but can still be found by chance. There is also another reason, partly related to the previous one, why patients with qualitatively different performances on preliminary category-specific tests (Category-specific DATs and Control DATs) may produce similar results on relevance-controlled experimental tests. Assume that a participant correctly retrieves a given target concept if and only if the amount of relevance of the presented features is greater than a given threshold. In this case, a dissociation may be observed by chance whenever stimuli which are not too easy or too difficult are presented, and this is the situation expected in the preliminary category-specific tests. This happens when a concept description has a relevance value which is very close to the threshold. By contrast, if a relevance value is either well above (high relevance) or below (low relevance) this threshold, as in our experimental test, then previously detected differences should disappear.

the sensory/functional theory by reporting that category-specific patients, impaired for Living, are equally impaired for those Non-living concepts which are of the so-called mass-kind (e.g., fluids, edible substances, etc.). While Non-living usually rely heavily on Non-sensory features, these particular Non-living, like Living, rely on Sensory features. These findings were used as supporting evidence that category-specificity is due to a Sensory knowledge impairment. Sartori and Lombardi (2004) did not analyse semantic relevance for these mass-kind concepts, but we believe they are characterised by low relevance. Therefore, a similar result as for Living would be predicted for them. In fact, features that are used in defining these concepts are also used in many other mass-kind concepts. Indirect evidence in line with this hypothesis was shown by Borgo and Shallice (2003), who demonstrate that mass-kind concepts have roughly the same number of shared features as those of Living concepts.

An interesting issue is related to the frequency of occurrence of Sensory knowledge impairments, which are observed more frequently than Non-sensory knowledge ones (Lambon-Ralph, Graham, Patterson, & Hodges, 1999) and the reasons for this pattern are not clear. Using the database of Sartori and Lombardi (2004), we can predict that observations of impaired Sensory knowledge for Living are more frequent than those of Non-sensory knowledge for Non-living on the grounds that 69% of Non-sensory features of Non-living have higher total relevance than the median of Sensory features of Living (data from Sartori and Lombardi database, Sartori & Lombardi, 2004). In addition, Non-sensory features, irrespective of category, are expected to be easier than Sensory features, as 71% have total relevance values above the median of Sensory features (again from Sartori & Lombardi, 2004).[7] One consequence is that, if tests not controlled for relevance are developed, Living Sensory descriptions will probably be of lower relevance and therefore more inaccurate. Consequently, Sensory knowledge impairment is more frequently observed, as in fact it is.

The appeal of the sensory/functional theory partly resides in the fact that some evidence of neuroanatomical localisation of feature knowledge has been found. It has been hypothesised that semantic features of similar types are represented in the brain in adjacent regions, which are in turn adjacent to the corresponding Sensory or motor area. In this extension of the sensory/functional theory, knowledge representation of visual features is expected to be found close to the visual system, whereas knowledge representation of functional features is closer to motor areas, regardless of their category (Martin & Chao, 2001).

However, as regards the issue of whether semantic features are organised in the brain according to their content or not, data from imaging studies are conflicting. On one hand, data supporting the notion that Sensory and Non-sensory semantic features are processed separately in the brain have been reported (Thompson-Schill, 2003). For example, naming actions typically associated with an object activates sites close to those active during motion perception, whereas generating a colour activates sites close to those active during colour perception (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995). Conversely, data interpreted as evidence for a single network, encompassing the left inferior frontal, lateral inferior temporal and anterior medial fusiform gyri, have also been reported (Noppeney & Price, 2003).

On the theoretical side, issues about the way in which semantic features contribute to conceptual knowledge are independent of issues regarding how these semantic features are organised in the brain. The semantic relevance model is agnostic about whether concepts are represented in the brain in a modal or amodal fashion (Barsalou, Simmons, Barbey, & Wilson, 2003; Damasio, 1990; Martin & Chao, 2001). Therefore, from this behavioural study, we have no reason to believe that conceptual representation in the brain is amodal. On one hand, if relevance is coded neurally across modalities, then we can still have similar accuracy on different modalities without assuming an amodal semantic. On the other hand, as relevance covaries with feature type, brain-imaging evidence pointing to modal representation may indicate differences in relevance.

The neural correlates of semantic relevance have recently been studied. Mechelli, Sartori, Orlandi, and Price (2006), in an fMRI study using a picture-naming task, have shown that relevance of higher order visual features activates the medial fusiform gyrus bilaterally, thus demonstrating that neuronal responses during concept retrieval are modulated by the semantic relevance of the features. Sartori et al. (2005b) and Sartori et al. (2006) examined whether the larger N400, usually found for Living items with respect to Non-living ones, depends on uncontrolled relevance, and reported that when semantic relevance is low, the N400 is large. In addition, they found that, when the two categories of Living and Non-living are equated for relevance, the seeming category effect at behavioral and neural level disappeared; the same result was observed for Sensory and Non-sensory features. In sum, N400 does not differ between categories or feature types when relevance is matched, and this lends support to the idea that effects of semantic categories and feature types, arise as a consequence of the differing relevance of concepts belonging to Living and Non-living categories.

A related theoretical issue may also be addressed here, and regards the alternative theory of category-specificity known as the Domain-specific hypothesis (Caramazza & Shelton, 1998), according to which domain-specific neural systems evolved (for animals, plants and tools) under pressure of selection. One prediction of this theory is that selective damage to one category will equally affect all feature types in that category (Capitani et al., 2003). As it now stands, the category-specific hypothesis cannot explain the reversal of category and feature-type effects which, instead, may be predicted from the semantic relevance model and which are shown in the present study, unless it also assumes that relevance with category is an important factor in semantic processing.

Appendix A

In our model, concepts are represented by a vector of semantic features and relevance is a measure of the contribution of

[7] Similar results were observed when analysing the database of Cree and McRae (2003) on which relevance was computed.

semantic features to the "core" meaning of a concept. The "core" meaning of a concept is thought to include those semantic features that enable us to identify the concept and to discriminate it from other similar concepts. We assume that subjects' verbal descriptions, as collected in a feature-listing task, can be used to derive these important features.

Several weighting schemes can be derived from information retrieval models (e.g., Dumais, 1991) and adopted, after appropriate modifications, within a relevance analysis approach. In this paper, we refer to a simple weighting scheme called FF × ICF (Feature Frequency × Inverse Concept Frequency), adapted from Salton's well-known TF × IDF (Term Frequency × Inverse Document Frequency) measure (Salton, 1989).

The whole procedure may be split into three consecutive steps:

(i) Cued verbal descriptions of *I* concepts are collected.
(ii) *J* semantic features are identified from verbal descriptions of subjects.
(iii) *I* (concepts) × *J* (semantic features) co-occurrence data matrix **X** is computed by setting entry x_{ij} of **X** as equal to the frequency of occurrence of Feature *j* in Concept *i* over all subjects' descriptions (for details, see Sartori & Lombardi, 2004).
(iv) Under the FF × ICF (Feature Frequency × Inverse Concept Frequency) assumption, semantic relevance values k_{ij} may be computed from **X** as follows:

$$k_{ij} = l_{ij} \times g_j = x_{ij} \times \log\left(\frac{I}{I_j}\right)$$
$$(\forall_i = 1, \cdots, I; \forall j = 1, \cdots, J) \quad (1)$$

where k_{ij} and I_j denote the relevance of Feature *j* for Concept *I* and the number of concepts in which Feature *j* occurs (that is $I_j = |\{i: x_{ij} > 0\}|$). Note that $l_{ij} = x_{ij}$ defines the local component of k_{ij}, whereas $g_j = \log(I/I_j)$ indicates the global component of k_{ij}. In words, (1) states that a feature diagnostic of a concept will have both high local value and high global value (see also Marques, 2005).

In contrast to other parameters used to index semantics such as familiarity, typicality and age-of-acquisition, relevance does not come from subjective ratings but from verbal descriptions of the concepts. It indexes the amount of information that a semantic feature carries for a given concept.

A semantic feature may be any statement about the concept and relevance removes from possible semantic features other perhaps highly idiosyncratic features on the basis of the following mechanism. Consider this hypothetical example based on 100 subjects defining 100 concepts, one of which is *Tiger*. Now consider the following two features: (i) ⟨has black stripes on yellow background⟩ and (ii) ⟨was seen yesterday at the zoo with my aunt Mary⟩. Assume that both are only reported in 1 of the 100 concepts, exactly in *Tiger*. Accordingly, the two features have the same distinctiveness, which is $\log(I/I_j) = \log(100/1) = 4.605$. Assume that all 100 subjects list the feature ⟨has black stripes on yellow background⟩ (dominance = 100) but only one subject reports ⟨was seen yesterday at the zoo with my aunt Mary⟩ (dominance = 1). Then the relevance of ⟨has black stripes on yellow background⟩ is much higher than ⟨was seen yesterday at the zoo with my aunt Mary⟩ for the concept *Tiger*, but these two features have the same distinctiveness. Intuitively, the importance of ⟨has black stripes on yellow background⟩ in indexing Tiger is much higher then ⟨was seen yesterday at the zoo with my aunt Mary⟩, and this importance is captured by relevance but not by distinctiveness. The final result is that relevance of the former is much higher than that of the latter for the concept *Tiger*. This shows how any description may potentially be a semantic feature, but only those that are consistently used by subjects have a high relevance value. Defining semantic features in other ways creates a number of problems: (i) which statement is a semantic feature? (ii) what distinguishes a description which is also a semantic feature from ones which are not semantic features? (iii) what are the constituents of semantic features (regressum ad infinitum). This approach has also the advantage of permitting some episodic statements to enter the semantic such as ⟨Won in Berlin in 2006 by Italy⟩ for the *Football World Cup*.

Further formal and substantive interrelationships among dominance, distinctiveness and semantic relevance are discussed in Sartori et al. (2005a).

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