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The special status of verbal knowledge in semantic memory: Evidence from performance of semantically impaired subjects on verbalizable and non-verbalizable versions of the object decision task

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ABSTRACT

According to the semantic hub hypothesis, a supramodal semantic hub is equally needed to deal with verbal *and* extraverbal "surface" representations. Damage to the supramodal hub is thought to underlie the crossmodal impairment observed in selective semantic deficits. In the present paper, we provide evidence supporting an alternative view: we hold that semantic impairment is not equal across domains but affects verbal behavior disproportionately. We investigated our hypothesis by manipulating the verbal load in an object decision task. Two pathological groups showing different levels of semantic impairment were enrolled together with their normal controls. The severe group included 10 subjects with semantic dementia and the mild group 10 subjects with Alzheimer's disease. In keeping with our hypothesis, when shifting from the low verbal load to the high verbal load condition, brain-damaged individuals, as compared to controls, showed a disproportionate impairment as a function of the severity of their semantic deficit.

1. Introduction

Neuropsychological models of semantic memory usually make two assumptions that have remained unchanged since Wernicke's (1900, as cited in Gage & Hickok, 2005) and Lissauer's (1890) original observations: the first is that semantic knowledge basically consists of memories laid down through our sensorimotor interaction with the environment; the second is that language represents one of several sources of sensorimotor experience semantic knowledge is based on. Thus, for example, when listing the "recollections" associated with a violin Lissauer (1890, translated in Shallice & Jackson, 1988, p. 182, emphasis added) mentioned "its image, *its name*, its sound, the sensation, and the tactile experiences which go along with handling it"; in the same vein, Patterson and colleagues argued that "Our knowledge of a scallop (...) includes attributes such as its visual features (...) its manner of moving on the seabed (...) its texture and taste (...) the actions its edibility affords, its *name and other descriptions that we could apply to it*" (Patterson, Nestor, & Rogers, 2007, p. 976 emphasis added).

Another widely accepted view, which also dates back to the associationism of the XIX century, is that much of the semantic knowledge we acquire through sensorimotor experience "is represented in brain regions that overlap or possibly even correspond to the regions that are responsible for perceiving and acting" (Patterson et al., 2007, p. 976). According to the associationist view and to some modern approaches (see, for example, Martin & Chao, 2001), the distributed network binding together these modality-specific processing systems is all we need to implement semantics. Alternatively, some researchers (Hillis, Rapp, & Caramazza, 1995; Patterson, Nestor, & Rogers, 2007) argue that an additive supramodal system is needed to account for our ability to appreciate semantic relationships among concepts which may exhibit very different degrees of overlap across different modality-specific representations. Thus, "Scallops and prawns have different shapes, colors, shell structures, forms of movement, tastes, names, verbal descriptions and so on, but semantically speaking, to seafood-eating humans they enter into similar scenarios and have susbstantial conceptual overlap" (Patterson et al., 2007, p. 977). In models that include a supramodal component in addition to modality-specific sensorimotor subsystems, the semantic hub account is especially interesting because it includes a hypothesis on the neural substrate underpinning the supramodal hub and makes verifiable predictions regarding the cognitive consequences of damage to this

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substrate (Lambon Ralph & Patterson, 2008; Patterson et al., 2007; Rogers, Lambon Ralph, Garrard, et al., 2004).

Adding a supramodal unit to the functional architecture of the semantic system clearly improves the model's ability to account for the complex mental operations humans perform on concepts; but, on the other hand, it accentuates a weak point common to all models sharing the two associationist assumptions we mentioned at the beginning of this paper. We believe that this weakness regards the relationship between word meanings and semantic knowledge. In the remainder of this introduction, we will discuss the problem of the status of word meanings with reference to the semantic hub model and will propose a revised model for addressing it. Then we will describe how the proposed revision affects some predictions of the model under semantic impairment. Finally, we will describe the experimental paradigm we used in the present work to test contrasting predictions of the original and the revised model.

As we have seen, in keeping with the associationist view the semantic hub hypothesis considers language one of several sources of modality-specific experience contributing to meaning acquisition. Unlike other sensorimotor surface representations, however, verbal representations are twofold because linguistic signs comprise two component parts, that is, a signifier (i.e. the word form) and a signified (i.e., the word meaning; see De Saussure, 1916). This poses some problems for considering the "verbal layer" (Rogers, Lambon Ralph, Garrard, et al., 2004) as having a similar relationship to the supramodal semantic hub as the other modality-specific components of the semantic network. In fact, although word forms can be equated without any particular problem to other surface representations, word meanings cannot considered modality-specific in the same sense as the other surface representations. As for the status of signifiers, in fact, most neuropsychological models consider so termed input and output lexicons as modality-specific (either phonologic or orthographic) word form representations, sharing many properties with modality-specific sensorimotor representations, including a similar relationship with a more "central" semantic or cognitive component (see Coltheart 2004). By contrast, as for word meanings, no one would deny that they are in some way constrained by the entire set of sensorimotor representations pertaining to the real objects the word corresponds to. Thus, for example, the fact that a sentence like "I did not saw the chair and I bumped into it" is semantically well formed clearly has something to do with the fact that we possess a visuomotor representation of real objects we can refer to with the word "chair"; on the other hand, the absence of this kind of representation for real objects we refer to with the word "voice" is clearly related to the fact that a sentence like "I did not saw the voice and I bumped into it" is semantically ill formed. If word meanings take into account the information drawn from several modality-specific processing systems, how can they have the same functional status as single, unimodal "surface" representations? On the other hand, if word meanings are multimodal how do they differ from hub representations, which are thought to "knit together the collection of attribute-specific features about a concept" (Lambon Ralph & Patterson, 2008, p. 62)?

In our opinion, the most economic way of addressing this issue is to stipulate that the central component of the semantic network (i.e. the so-termed semantic hub) represents signifieds (i.e., word meanings) and that surface verbal representations are identical to signifiers (i.e. word forms).

Equating the system underpinning linguistic meanings with the semantic hub does not mean rejecting its supramodality. On the contrary, in keeping with the semantic hub hypothesis we hold that *the same* supramodal semantic knowledge is accessed through words and extraverbal stimuli in the receptive mode *and* sustains verbal (e.g. speech) and nonverbal behaviors (e.g. object use) in the expressive mode. At variance with the semantic hub hypothesis, however, we do not believe that humans invariably make recourse to this body of knowledge when interacting with the environment. By contrast, we maintain that supramodal semantic knowledge is involved every time our behaviors are based on declarative, verbalizable thought, while it is not needed when humans, like other animals, interact with their environment in an implicit way. In the latter case, modality-specific surface representations are sufficient for categorizing environmental input and acting on it. Theorists of the semantic hub maintain that object categorization based solely on modality-specific representations is impossible because item-specific *long-term stored* representations do not exist at these levels (Rogers, Lambon Ralph, Hodges, & Patterson, 2004). In this view, perceived items give rise to modality-specific activation patterns in several (visual, verbal, auditory, etc.) surface input systems; however, there are no long-term stored modality-specific representations that match such temporary input patterns, allowing for object recognition without the contribution of the supramodal hub. (Note that for the sake of brevity we have used the term 'representation' to refer to both long-term stored activation patterns and temporary activation patterns).

The distinction between a conscious, explicit, verbal-based categorization process, which relies on the supramodal component of the semantic system, and a non-conscious implicit categorization process, which is based on more peripheral modality-specific systems, is central to our account and deserve further qualification. In our account, a chief difference between modality-specific and supramodal representations is that the former are present in both humans and non-human animals and the latter evolved only in humans, as part of the language system. According to this hypothesis, animals possess a simplified semantic system that allows them to categorize patterns of sensory input in a rigid, mostly species-specific manner (according to innate categories like "predator", "prey", "food"), to select the most adaptive behavior. In addition to this rigid classification tool, humans also have the ability to consciously select relevant features in the incoming precepts according to a potentially infinite number of arbitrarily defined categories. What theorists of the semantic hub hypothesis refer to as the human ability of "knowing the range of concepts over which a component of knowledge should be generalized" thanks to "representations that abstract away from surface similarities" (Lambon Ralph & Patterson, 2008, p. 65) has much to do with this ability and, most importantly, is strictly related to the way natural languages convey meanings. In our view, the ability to think of arbitrary (i.e. not species-specific) categories likely coevolved with the ability to express them through natural languages. In fact, thanks to their productivity (Lyons, 1981), natural languages are a powerful tool for expressing a potentially infinite number of concepts spanning from biologically grounded (e.g. thirst) to culturally shared (e.g. wedding) to idiosyncratic categories (e.g. sisters who loves novels).

Summarizing, we propose two major revisions of the semantic hub hypothesis: the first regards the status of word meanings, which, according to the hub hypothesis, are represented in a surface layer and, according to our proposal, are stored in the central supramodal component of the semantic network; the second regards the status of sensorimotor representations, which in our account are long-term stored representations allowing for simple, implicit classification processes, and according to the hub hypothesis are only temporary activity patterns in modality-specific regions, which are unable to sustain categorization without the contribution of the semantic hub. For the sake of clarity, the main differences between the semantic hub approach and our proposal are summarized in Table 1.

Impaired performance of SD patients on object- and lexical-decision tasks has been considered by the sustainers of the semantic hub hypothesis as evidence supporting both features of the

Table 1
Summary of the main differences between the semantic hub hypothesis and the present account, here termed the "Language hub hypothesis". Both positions hold that semantic memory comprises a central supramodal hub and several superficial modality-specific (input and output) representations.

	Supramodal hub			Modality-specific representations		
	Function	Content	Phylogenesis	Function	Content	Connectivity
Semantic hub hypothesis	Always needed for object classification	Contains abstract meanings	Not specified	Do not allow for object categorization	Temporary activity patterns in modality- specific input and output channels	Communicate only through the central hub
Language hub hypothesis	Only needed when classification is based on explicit criteria	Contains signifieds	Is a human-specific cognitive system	Allows some simple form of implicit object categorization	Both temporary and long-term stored representations	Communicate through the central hub but are also directly interconnected

model we propose to revise, that is, the claim that supramodal hub representations have a comparable relationship with verbal representations and other surface representations, and the claim that long- term stored modality-specific representations do not exist and do not allow for object categorization without the contribution of the semantic hub.

Object decision (OD; Riddoch & Humphreys, 1987a, 1987b) and lexical decision (LD; Coltheart, 2004) are two tasks originally devised to test modality-specific categorization abilities in the visual and verbal domains respectively. In these tasks, subjects are required to endorse real items (either pictures or words) and to reject non-existent ones. Items to be rejected in OD and LD, respectively, are chimerical figures obtained by rearranging parts of realistic ones (e.g. a dog with the head of a cow) or legal strings of phonemes that do not correspond with any lexical entry in a given natural language. At variance with the semantic hub theorists, the authors who devised these tasks assumed that long-term stored modality-specific representations exist and that they can match (or mismatch) temporary input representations. In a series of well-conducted studies (Patterson, Lambon Ralph, Jefferies, Jones, et al., 2006; Rogers, Hodges, Lambon Ralph, & Patterson, 2003; Rogers, Lambon Ralph, Hodges, & Patterson, 2004), sustainers of the semantic hub hypothesis demonstrated that patients suffering from semantic dementia (SD), a pathology that selectively affects semantic knowledge, performed poorly on both tasks. This failure was interpreted as proof that patterns of activation in visual and verbal surface input systems cannot be recognized as existing or non-existing without the contribution of the central hub.

In our view, SD patients do not fail on OD and LD tasks because modality-specific, long-term stored input representations do not exist, but because they rely on their faulty, supramodal, verbally-based semantic representations to solve the task. We believe that supramodal knowledge is required every time we apply an explicit, verbalizable classification criterion to a percept. In our opinion, this is the default mode used by humans to approach both verbal and non-verbal input when they are requested to provide an explicit judgement; thus, although it would be better for SD patients to rely on spared modality-specific, long-term stored input representations instead of defective supramodal representations, they cannot refrain from adopting the more usual verbal strategy to solve the task. At variance with people suffering from SD, aphasic and agnosic patients are sometimes able to perform LD and OD, respectively, even though they are unable to verbalize any piece of knowledge about the items they correctly endorse as real (see Coltheart, 2004 for a brief review of these cases; see also Zannino, Perri, Caltagirone, & Carlesimo, 2011, for a more in depth review of the literature on OD in SD). We believe that in these cases a disconnection from the (disrupted or spared) supramodal knowledge system allows them to rely on modality-specific representations, such as structural descriptions (in the case of OD) and input lexicons (in the case of LD), when performing the tasks. According to this view, in a single case study of a patient with SD we demonstrated (Zannino, Perri, et al., 2011) that our patient's performance returned to normal on an OD task when recourse to a verbal strategy was discouraged by means of an experimental manipulation. We reasoned that in the usually administered version of OD, chimerical items can be rejected by applying a verbalizable rule, such as: "pictures that simultaneously show parts taken from different real items (e.g. a dog and a cow) should be rejected". On the other hand, subjects might use language as a guide also for endorsing real items simply by applying the following rule: items you can name need to be endorsed. To contrast this verbal strategy, we devised a task in which items to be rejected were obtained by slightly deforming pictures of individual real animals. In this condition, subjects have to perform the task without being able to verbalize their inclusion/exclusion criterion; indeed, normal controls stated that they endorsed/rejected items because they were normal/strange without being able to say why they were so.

In the present study, we attempted to provide a stronger case for our hypothesis by manipulating reliance on a verbal vs. visual strategy to solve a new OD task with living and nonliving items and administering them to two groups of brain-damaged people and their normal controls. Patients with SD and Alzheimer's disease (AD) were enrolled. Although both of these neurodegenerative diseases are associated with impaired conceptual knowledge, the latter is characterized by a less isolated and also less severe semantic deficit as compared to the first one (Patterson et al., 2007). Thus, by enrolling both SD and AD patients we were able to investigate the effects of the experimental manipulation (verbal vs. visual strategy) at two different levels of semantic impairment. This was critical for our purpose because the semantic hub hypothesis and our revised model make contrasting predictions about the possible interaction between the variables Degree of semantic impairment and Type of prevailing cognitive strategy (verbal vs. visual strategy). According to the semantic hub hypothesis, the degree of semantic impairment should not interact with the different experimental conditions: in fact, in this view damage to the supramodal hub should exert a comparable effect regardless of whether the experimental manipulations tax more heavily recourse to the visual or the verbal modality-specific input layer. In fact, both of these systems are supposed to be spared in patients suffering from degenerative semantic impairment; however, according to the semantic hub hypothesis they are not able to sustain categorization without the contribution of the semantic hub. By contrast, according to our proposal, the effects of supramodal semantic damage should have a much greater impact on the experimental condition in which a verbal strategy prevails. This should occur for two reasons: first, as in our view (at variance with the semantic hub hypothesis) only signifiers (i.e. word forms) are represented in a modality-specific verbal input layer and signifieds (i.e. word meanings) are at the core of the supramodal semantic system, damage to the supramodal semantic system should have a direct impact on the possibility of implementing a verbal strategy; the same does not, however, apply to a visual strategy. The second reason why we expect an interaction between level of semantic impairment and experimental condition (i.e. verbal vs. visual strategy) is because, at variance with the semantic hub approach, we believe that long-term stored input representations, such as lexicons (i.e. signifiers) and visual structural descriptions, exist and allow some degree of perceptual categorization without the contribution of supramodal semantic knowledge.

In summary, our predictions are as follows: compared to normal controls, pathological subjects are expected to show a disproportionate impairment in the verbal strategy condition; this should be more evident in the SD than the AD group because of the more profound semantic deficit that characterizes the former neurodegenerative disease.

2. Methods

2.1. Subjects

Ten subjects with semantic dementia (SD; according to the criteria proposed by Hodges, Patterson, Oxbury, & Funnell, 1992), ten subjects with Alzheimer's disease (AD; according to the criteria proposed by McKhann et al., 1984) and twenty normal controls (NC) were enrolled in this study.

Demographic characteristics of the experimental sample and age and education adjusted scores on the Mini-Mental State Examination (Measso et al., 1993) are reported in Table 2. The three experimental groups did not differ significantly for age and educational level. Both sexes were represented equally in the SD and CT groups, but there were more males in the AD group. Mean Mini-Mental State Examination scores did not differ significantly across the pathological groups, but the NC group scored significantly better than both the SD ($t = 3.6$; $p = 0.001$) and the AD ($t = 12.3$; $p < 0.001$) group.

As our experimental tasks included pictorial stimuli, a deficit in visual processing could, in principle, have affected performance over and above the semantic impairment, which was our variable of interest. To take this nuisance variable into account, we administered the Visual Object and Space Perception Battery (VOSP, Warrington & James, 1991) to the cognitively impaired subjects. We did not, however, administer the two subtests of the VOSP that require naming abilities (i.e. Silhouettes and Progressive Silhouettes) because of the confound due to the semantic-based naming impairment, which is known to affect all SD and AD patients in variable degrees. Another subtest (Object Decision) was excluded because of the overlap between the cognitive processes tapped by this test and those required by our experimental task.

Table 3 shows mean group accuracy (expressed in percentage of correct responses) on the other six subtests of the VOSP battery. The last column shows a composite score (expressed as mean group accuracy) across the different subtests. As can be seen, mean group performance was below the cut-off score for a given subtest in only one case; this occurred in the AD group on the Incomplete Letters subtest. In both groups, the composite VOSP score was clearly above that obtained by averaging the cut-off scores of the subtests considered; nevertheless, the SD group scored reliably higher than the AD group ($t = 4.3$; $p = 0.001$). When comparing the two groups across the different subtests (see Table 3), the AD group scored consistently worse than the SD group. Between group differences reached statistical significance only in the following three subtests: Screening test ($t = 2.7$; $p = 0.020$), Number location ($t = 2.4$; $p = 0.029$), and Cube analysis ($t = 3.0$; $p = 0.009$). At the individual level, seven AD patients vs. one SD performed pathologically on at least one out of six subtests. In summary, the SD population was clearly unimpaired at both the group and the individual level, whereas most patients in the AD group showed some degree of visuospatial impairment.

Table 2
Demographic characteristics and MMSE scores of the experimental sample. Sex frequencies, mean (standard deviation) for age and education level (expressed in years) and mean adjusted MMSE score are reported for the different experimental groups.

	Sex (male/female)	Age	Education	MMSE
SD	5/5	69.3 (8.1)	10.5 (4.3)	24.1 (6.4)
AD	2/8	74.7 (6.8)	9.9 (5.0)	23.1 (1.6)
NC	11/9	69.9 (8.6)	10.9 (4.3)	29.3 (1.1)

2.2. Materials and procedures

To construct the experimental tasks, we selected 34 line drawings of animals and 34 line drawings of artefacts from existing databases and the web. Specifically, we constructed a naming task and an OD task comprising four experimental conditions.

In the naming task, participants had to name aloud 68 pictures (34 living and 34 nonliving). Figures were presented one at a time in random order at the center of a computer screen.

The same pictures were used to construct the four OD conditions by manipulating the factor Processing Strategy and Domain. The four conditions were as follows: verbal strategy on living items, verbal strategy on nonliving items, visual strategy on living items, and visual strategy on nonliving items. Items belonging to the same condition were presented together, that is, items were grouped in four blocks according to the four experimental conditions. In the verbal strategy blocks, items to be rejected (either living or nonliving) were created by recombining parts of the original drawings, as is usually done in OD tasks. In the visual strategy blocks, items to be rejected (either living or nonliving) were created by deforming the original figures. Deformed items appeared in the half of the cases swollen and in the other half shrunken as compared to the original items. For both the deformed and the recombined foils, particular care was taken to avoid low-level visual cues being used to reject a picture. Fig. 1 shows examples of swollen, shrunken and recombined items in the living and nonliving domains. Each of the four experimental blocks comprised 34 original figures and 34 altered figures. Each original figure was used in two different blocks: once with recombined foils and once with deformed foils. Two blocks comprising the same original figures were administered in two different testing sessions (see below). In all experimental conditions, participants were shown one figure at a time at the center of a computer screen and were requested to say whether it looked normal or strange; if subjects asked for further qualifications (which occurred very infrequently), the term normal was explained as "depicting things in a realistic way, as they really look" and the term "strange" was explained as "as unrealistic and odd"; no mention was made of the two kinds of alterations (i.e. deformed or recombined). Each experimental block began with a practice set of 12 items (half original and half altered) to aquaint subjects with the material; none of the target pictures were used to create the practice items.

The naming task and the four OD conditions were administered to the patients and NCs in two different sessions on separate days at least one week apart. To avoid showing the same original figures twice in the same session, each session comprised an OD block with living items and an OD block with nonliving items. The OD blocks administered in the same session were either both in the "verbal strategy" condition or the "visual strategy" condition to avoid problems related to the need to shift between strategies in the same session. Within these constraints, block presentation order in terms of domain (living vs. nonliving) and strategy (verbal strategy vs. visual strategy) was counterbalanced across the subjects in each group. The naming task was administered at the end of the second session.

Table 3
Performances on the VOSP battery. Mean percentage (and standard deviations) correct responses on individual subtests of the VOSP according to the different experimental groups. The last column reports raw means.

5% Cut-off	Screening test 75%	Incomplete letters 80%	Dot counting 80%	Position discrimination 90%	Number location 70%	Cube analysis 60%	Overall 75.8
SD	98.5 (2.4)	84.4 (10.7)	97.0 (6.7)	97.2 (6.7)	90.0 (7.6)	90.0 (16.6)	93.5 (4.3)
AD	92.0* (7.1)	67.5 (27.9)	88.0 (14.8)	95.0 (7.8)	76.0* (15.1)	63.0* (22.6)	80.3* (8.9)

* Statistically significant differences across groups.

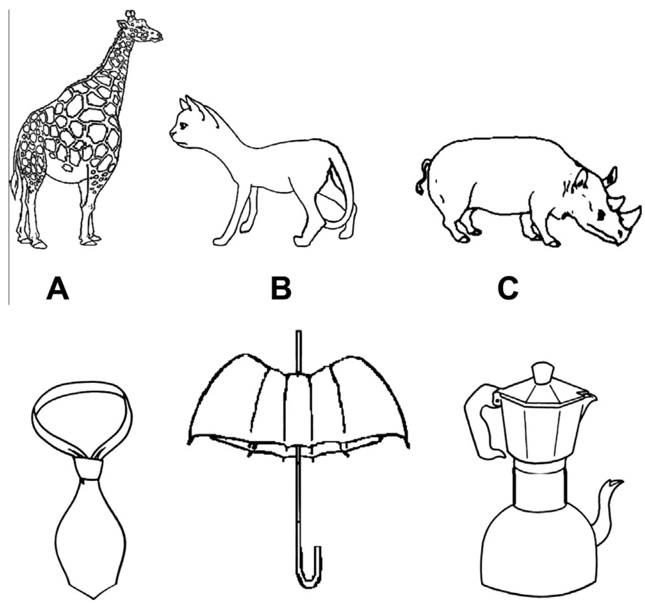

Fig. 1. From left to right, examples of swollen (A), shrunken (B) and recombined (C) items in the living (above) and non-living (below) domains.

3. Results

3.1. Picture naming

It is now widely accepted that in brain-damaged people semantic impairment affects naming accuracy as a function of its severity. Of course, other kinds of cognitive impairments, such as deficits of the visual processing stream, can also affect naming performance. To investigate semantic impairment on the same concepts involved in the OD tasks, patients and their controls were asked to name the original 68 line drawings (34 living and 34 non-living items) used to construct the OD tasks. In the first step, naming accuracy in the three subject groups was analyzed to obtain a raw estimate of the relative semantic impairment of SD and AD participants compared with controls. In the second step, performance of the brain-damaged population was analyzed by taking VOSP scores into account to partial out the contribution of vision to the naming impairment.

First, we carried out a one-way between-subjects ANOVA to investigate the effect of Group (NC, AD, SD) on naming accuracy. The effect of the independent variable was highly significant ($F(2,39) = 57.6$; $p < .001$). Mean number of correct responses (and standard deviations) on the 68- item naming test in the NC, AD and SD groups were as follows: 66.7 (1.7), 45.9 (17.6), 20.4 (14.2). Employing the Bonferroni post hoc test, all comparisons were found to be significant (p consistently < .001). This means that both pathological groups scored worse than the NC group *and* that the more severely impaired SD group scored reliably below the less severely impaired AD group.

Naming accuracy is believed to directly reflect level of semantic impairment in patients with SD, whereas a visual processing deficit may contribute to the naming impairment in patients with AD (Hodges, Salmon, & Butters, 1991; Patterson et al., 2006). This is particularly true in the present case if one considers that overall the participants with AD, unlike those with SD, performed poorly on the VOSP battery. The possible confound arising from the contribution of a visuospatial deficit (in addition to a semantic deficit) to the naming impairment in AD does not, however, undermine the conclusion that the semantic deficit in the SD population was more severe than the semantic deficit in the AD population. In fact, misrecognizing a possible contribution of vision in the AD naming impairment would lead to overestimating rather than underestimating the semantic impairment. Nevertheless, to partial out the possible role of visual abilities in naming accuracy, we performed an ANCOVA on AD and SD naming scores, adjusting for our composite VOSP scores. Results showed that the covariate was not significantly related to the dependent variable ($F(1,17) = 0.3$; p = n.s.), suggesting that in our sample visual deficits were not severe enough to affect picture recognition. By contrast, adjusted mean naming scores across groups were still reliably different ($F(1,17) = 8.1$; $p = .011$), confirming a higher degree of semantic driven naming deficit in the SD group than the AD group.

3.2. Object decision

Each participant had to judge 272 pictures, which were grouped in four conditions according to semantic domain (living vs. non-living) and kind of manipulation applied to the original line drawings to construct unreal items (recombination vs. deformation). Note that recombined foils were used to shift the cognitive load toward a verbal strategy and deformed foils were used to elicit a mostly visual based strategy. Each condition (living items-verbal strategy, living items-visual strategy, nonliving items-verbal strategy, nonliving items-visual strategy) included 68 items (34 original line drawings and 34 altered pictures). Individual accuracy scores (i.e. number of correct responses, range: 0–68) on the OD task were analyzed with a three-way mixed ANOVA with Strategy (verbal vs. visual) and Domain (living vs. non-living) as within-subjects factors and Group (NC, SD, AD) as between-subjects factor.

The ANOVA yielded a significant main effect of Group ($F(2,37) = 58.5$; $p < .001$). Marginal means for SD, AD and NC were 46.1, 49.4, 62.3 respectively. Using the Bonferroni post hoc test, the difference between SD and AD did not reach statistical significance, but both pathological groups scored significantly worse than the control group (p consistently < .001). A main effect also emerged for Domain, because overall the living items proved to be harder than the non-living ones: marginal means, 50.5 and 54.8, respectively ($F(1,37) = 52.0$; $p < .001$). By contrast, the factor Strategy did not lead to a significant main effect; in fact, accuracy was comparable in the Visual Strategy and the Verbal Strategy conditions: marginal means, 52.9 and 52.4, respectively ($F(1,37)$=0.3; p = n.s.).

More interestingly for our hypothesis, the Group by Strategy interaction was highly significant ($F(2,37) = 19.8$; $p < .001$). As can be seen in Fig. 2, this was due to a dramatic difference across groups as for the impact on accuracy of the shift from the visual to the verbal strategy. In passing from the OD task with deformed foils (eliciting a visual strategy) to that with recombined chimeras

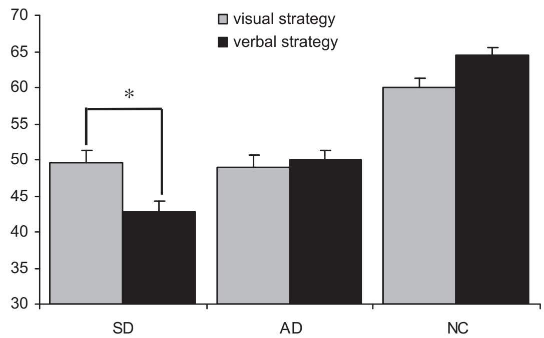

Fig. 2. Marginal means (and Error SD) of correct responses on the OD tasks according to Group and Strategy. * = reliable difference ($p < .05$) using the Bonferroni post hoc test.

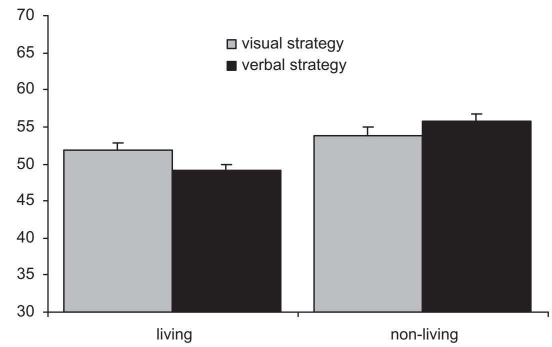

Fig. 3. Marginal means (and Error SD) of correct responses on the OD tasks according to Domain and Strategy.

(eliciting a verbal strategy) NCs improved their performance, AD showed no difference in accuracy, and SD showed a disproportionate impairment. A Bonferroni post hoc test showed that the Strategy effect was reliable in the SD group ($p = .033$), marginally reliable in the NC group ($p = .064$), and far from significant in the AD group.

Inspecting Fig. 2, it becomes apparent that the disproportionate impairment of the SD and (to a lower extent) of the AD group in the verbal condition as compared to the visual condition does not lead to a "classical dissociation" (Shallice, 1988) since performance of both pathological groups is below normal level also in the less impaired visual condition (Bonferroni post hoc test yielded significant results both when comparing NC and SD ($p = .047$) and NC and AD ($p = .027$) in the visual condition). As we will discuss later, the finding of a non classical dissociation does not undermine the conclusion we can draw from the presence of a significant Group by Condition interaction.

The Group by Domain interaction was only marginally significant ($F(2,37) = 2.8$; $p = .075$). In keeping with the Domain main effect (see above), marginal means showed a more or less pronounced living disadvantage across all subject groups; living/non-living scores were 42.9/49.3, 47.8/51.1, 60.7/64.0 in the SD, AD and NC group, respectively.

The Domain by Strategy interaction was also statistically significant ($F(1,37) = 10.2$; $p = .003$). As can be seen in Fig. 3, this occurred because accuracy on living items was higher in the Visual Strategy than the Verbal Strategy condition, and the opposite was true for non-living items. Results of a Bonferroni post hoc test showed that the strategy effect was marginally significant only in the non-living domain ($p = .053$).

Finally, the three-way Strategy by Domain by Group interaction was far from significant ($F(2,37) = 1.7$; $p = .203$). Looking at the marginal means when all three experimental factors are taken into account (see Table 4) can be useful to reconcile apparently contrasting results from the two significant two-way interactions (i.e., Group by Strategy and Domain by Strategy). Indeed, the pattern of Domain by Strategy interaction shown in Fig. 3, that is, the visual strategy advantage for living items and the verbal strategy advantage for non-living things, is only true for the AD group; NCs exhibited an overall verbal strategy advantage, which was more marked for non-living items, and SD patients showed an overall verbal strategy disadvantage, which was more pronounced in the living domain. These more fine-grained group pictures, which are all characterized by a disproportionate disadvantage for living items in the verbal condition, are more in keeping with the picture of the Group by Strategy interaction described above (see Fig. 2), that is, a verbal strategy advantage in the NC group, a visual strategy advantage in the SD group, and no difference in the AD group.

Table 4
Marginal means in the OD task according to Strategy, Domain and Group.

	Living		Non-living	
	Visual strategy	Verbal strategy	Visual strategy	Verbal strategy
NC	58.9	62.5	61.4	66.5
AD	48.5	47.0	49.3	52.8
SD	48.2	37.7	50.9	47.8

As predicted by our hypothesis, in the two pathological groups the degree of the relative visual-strategy vs. verbal-strategy disproportionate impairment was predicted by the extent of the semantic deficit exhibited in the naming task. In fact, both AD and SD showed a disproportionate verbal-strategy impairment compared with NCs, but this effect was much more evident in the SD group, which in turn scored worse than the AD group on the naming task.

In a latter analysis, we wanted to exclude that the uneven level of visuospatial resources across the two pathological groups could have contributed to the above described significant Strategy by Group interaction. To this aim, we covaried for the VOSP composite score, as in the naming task. Specifically, we carried out a three-way mixed ANCOVA with Group (AD, SD) as between-subjects factor, Strategy (Visual-, Verbal-Strategy) and Domain (living, non-living) as within-subjects factors, and VOSP composite score as covariate. For the sake of brevity, we will limit our report to the main results. First, a reliant Group by Strategy interaction was found ($F(1,17) = 8.8$; $p = .009$), confirming a disproportionate verbal strategy disadvantage in the SD group. Second, the covariate was not significantly related to the dependent variable ($F(1,17) = 1.5$; $p =$ n.s.). Finally, the covariate by Strategy interaction was far from significant ($F(1,17) = 0.4$; $p =$ n.s.). These results clearly suggest that the disproportionate verbal strategy impairment exhibited by SD patients compared with AD patients was due to uneven semantic resources rather than uneven visuospatial resources across brain-damaged groups.

4. Discussion

The main aim of our study was to demonstrate that semantic impairment in brain-damaged individuals disproportionately affects behavior in the verbal domain. In our view, the special status of language compared with other modality-specific processing systems is based on the assumption that supramodal semantic knowledge is identical to word meanings (signifieds). Thus, we assume that only signifiers are processed by modality-specific systems (notably the input and output lexicons), like other "surface" representations in the visual, auditory or motor domain. By contrast, the semantic hub hypothesis and other models of semantic memory that include a supramodal component stipulate that the entire verbal domain (i.e. signifiers and signifieds) are processed in a "surface layer" like other modality-specific representations (Rogers, Lambon Ralph, Garrard, et al., 2004). Consequently, damage to the semantic hub, which is supposed to occur in SD and AD patients, should affect behavior equally in the verbal and non-verbal domains (Patterson et al., 2007).

In our account, supramodal semantic deficits affect word meanings and thus disrupt behavior based on them. This is not the same as saying that processing verbal stimuli will be impaired and processing, say, visual stimuli will be spared. Judging whether two words rhyme involves verbal items, but only signifiers are needed to solve this task. By contrast, sorting animal pictures according to their edibility involves visual stimuli, but subjects have to resort to word meanings to explicitly conceptualize inclusion and exclusion criteria. Obviously, when natural languages are used in a communicative context (the rhyming task is not such a case) signifieds are always needed; by contrast, when extraverbal stimuli are processed recourse to them can vary greatly in extent depending on the particular task at hand. This is why, in our view, semantic impairment has a greater impact in verbal than extraverbal domains.

In the present work, we attempted to experimentally manipulate recourse to verbalizable rules in an OD task. We reasoned that if we kept constant the visual modality of stimulus presentation, recourse to word meanings could be manipulated by presenting a condition in which the inclusion/exclusion criteria were easy to verbalize (our Verbal Strategy condition) and a condition in which the inclusion/exclusion criteria were difficult to verbalize (our Visual Strategy condition). In the Verbal Strategy condition, which involved recombined foils, items could be endorsed/rejected based on the ability to name them or name their component parts, respectively. In the Visual Strategy condition, which involved deformed foils, items could not be endorsed/rejected based on such a verbal rule, because both real items and foils were nameable and no incongruent nameable parts were presented.

Three subject groups were enrolled: patients with SD who exhibited a severe level of semantic impairment, patients with AD who exhibited a less severe semantic impairment, and neurologically healthy NCs. The relative level of semantic impairment across patient groups was measured using a naming task, after the possible role of visuospatial deficits was partialled out. In keeping with our hypothesis, brain-damaged people exhibited a disproportionate impairment in the verbal strategy condition as a function of the degree of their semantic impairment. In particular, a significant group by strategy interaction was found because NCs fared better when the experimental manipulation elicited a verbal strategy, AD patients (in keeping with their moderate semantic deficit) did not show this verbal strategy advantage, and SD patients (in keeping with their severe semantic impairment) showed a clear-cut verbal strategy disadvantage. This pattern of group by strategy interaction persisted in the pathological population after the possible role of unequal visuospatial resources across groups was partialled out.

As already noted (see Section 3) the disproportionate impairment of brain damaged people in the Verbal Strategy condition did not lead to a "classical dissociation" (Shallice, 1988), since both SDs and ADs were also impaired in the Visual Condition, as compared to NCs. It should be noted however that the lack of a classical dissociation does not undermine the conclusion we draw from the observed pattern of group by condition interaction. The most economic way for interpreting impaired performance of AD and SD *also* in the Visual Condition is that our experimental manipulation (i.e. shifting from recombined to deformed chimerical foils) was effective in reducing the contribution of verbal knowledge in solving the OD task, not however in completely abolishing it. It should be noted at this regard that although the simple verbal rule, based on naming, we mentioned above can not be applied to deformed chimeras, this does not rule out a possible contribution of verbal reasoning in solving the OD task also in the Visual Condition. Thus, for example, verbally unimpaired subjects could reject the figure of a shrunken hippopotamus relying on a verbal reasoning like "I know that hippopotamuses are quite fat animals".

A second point of interest in our results is that they provide evidence of long-term stored visual representations (as opposed to temporary activity patterns). In fact, to account for the better SD performance in the visual strategy condition, we have to assume that to circumvent their supramodal semantic impairment they rely on some form of modality-specific long-term memories when endorsing/rejecting pictures in this condition. Such extra-semantic representations are likely identical to structural descriptions (Riddoch & Humphreys, 1987a, 1987b), that is, purely visual long-term stored representations (Zannino, Perri, et al., 2011) that match or mismatch incoming real or unreal percepts (i.e. temporary activity patterns), respectively.

Finally, the significant Domain by Strategy interaction deserves some comment. It was due to the fact that although living things were overall harder than nonliving things (the Domain main effect was significant), a disproportionate disadvantage for living things in the verbal condition was observed across all subject groups. This result was not directly predicted by our hypothesis, but based on the assumption that the Visual strategy condition stresses recourse to structural descriptions to solve the OD task, it can be interpreted as suggesting a larger role of structural description in processing living than nonliving things. That is, if structural descriptions are more important in recognizing living vs. nonliving things, it is not surprising that shifting to a strategy that minimizes recourse to structural descriptions penalizes living things. In fact, in an earlier study we provided empirical evidence supporting the hypothesis of a major reliance of living things from the structural description system "due to the fact that as a rule (...) exemplars of living categories (e.g., two individual ducks) look much more alike than exemplars of manmade categories (e.g., two individual houses)." (Zannino, Barban, Macaluso, Caltagirone, & Carlesimo, 2011, p. 2879, see also Price & Humphreys, 1989).

In the present paper, we suggest that visual material can be processed either with an implicit visual or an explicit verbal strategy based on word meanings. In our account, the fact that patients suffering from a deficit in the supramodal component of their semantic system (as is the case in SD and AD) show a disproportionate impairment when a verbal strategy is induced (e.g. in our Verbal condition) suggests that word meanings are at the core of this "central" body of semantic knowledge. The claim that word meanings have a hub-like role in the semantic system has important consequences for a longstanding issue in the literature on semantic memory, specifically, the relationships between perceptual and nonperceptual knowledge. Subsequently, we will address this point with reference to the hub hypothesis and other influential current views. According to the hub hypothesis, nonperceptual knowledge (often termed encyclopaedic knowledge) is represented in terms of verbal descriptors within the verbal layer, that is, within a modality-specific surface system; other models, however, still arguing for the verbal nature of encyclopaedic information, acknowledge a more central role of this kind of knowledge within the semantic system. Here, we will focus on the model of Coltheart and colleagues (Coltheart et al., 1998), but most of our observations also extend to other models, such as that of Humphreys and colleagues (e.g. see Humphreys, Riddoch, & Quinlan, 1988). In Coltheart's model, verbal signifiers (stored in lexicons) activate nonperceptual verbal knowledge, which in turn gains access to modality-specific perceptual (and motor) representations that are stored separately in a modality-specific way. In keeping with our proposal, this hypothesis considers that encyclopaedic, verbal-based knowledge is at the core of the semantic system, insofar as the different modality-specific representations of a given object connect to that shared body of knowledge. On the other hand, as for perceptual features, at variance with our hypothesis these authors do not distinguish between implicit (purely sensorial) and explicit (verbal-based) sensorimotor knowledge. In particular, they claim that "each perceptual domain has its own distinct knowledge base, which not only functions as a recognition system for objects presented in that perceptual modality but also is the locus from which information is retrieved when questions about perceptual properties in that domain are posed" (Coltheart et al. 1998, p. 365). Although we agree (in contrast to the semantic hub view) that modality-specific sensory representations allow for object recognition, we do not believe that *the same* sensory information is invariably used regardless of the task; in our opinion, when subjects rely on a verbal strategy to deal with perceptual information (irrespective of the verbal or visual nature of the proposed stimuli) they do not rely on the information stored in modality-specific input systems but on its explicit verbal translation. We believe that this kind of verbalized perceptual information is stored together with encyclopaedic information in the supramodal component of the semantic system, where it undergoes pathological disruption independently from the "corresponding" sensory knowledge stored in modality-specific input systems. This pattern of selective impairment of the explicit verbal format of perceptual (as well as nonperceptual) knowledge is precisely what we attempted to demonstrate in our SD and AD patients by manipulating the choice of a verbal vs. visual strategy to judge the pictorial stimuli of our OD tasks. In our Verbal strategy condition, patients were supposed to match incoming stimuli with the visual features stored in a verbal format in their (disrupted) supramodal semantic representations. By contrast, in our Visual condition patients were supposed to rely on visual features stored in their (spared) modality-specific visual representations. Indeed, the proposal of reliance on different kinds of sensory knowledge depending on the cognitive strategy one chooses to deal with the task at hand is not completely new. Thirty years ago, to account for the behavior pattern of a patient suffering from optic aphasia for colors, Beauvois (1982) suggested that visual material might sometimes be processed with a verbal strategy and that verbal material might sometimes be processed with a visual strategy, arguing for a double format storing the "same" information in the brain ("our findings support the view that color semantics have two distinct components, one visual and one verbal" p. 45). The same author also suggested that patients might perseverate in using the same strategy they used premorbidly and that "this would (...) sometimes result in failure on a task that would have been performed normally if the appropriate strategy (i.e. the strategy appropriate to a particular disturbance) had been used" (Beauvois, 1982, p. 40). These observations are indeed totally in keeping with our account of the frequently observed failure of SD patients on OD tasks (see introduction).

The hypothesis of a "duplication" of sensory (and motor) information may seems *prima facie* not economical. But the usefulness of having modality-specific information repeated in a supramodal format can be better appreciated if one considers that there is no reason to think that mental representations are isomorphic across different modalities. This means that object boundaries in any particular sensorimotor modality may not overlap boundaries in the other modalities; thus, two different dog breeds might have distinct visual representations but share more general auditory or tactile representations. Of course, word meanings need not exactly overlap modality-specific representations. Thus, as we suggested in a previous work (Zannino, Perri, et al., 2011), in the animal domain basic level words are likely non isomorphic with their "corresponding" structural descriptions because taxonomic classification seems to be more fine grained in the verbal than in the visual domain. Non isomorphism is a challenge we need to address if we want to think of an object as *the same* object, irrespective of the sensory channel we use to perceive it. Sensory feature duplication in a supramodal (verbal) format is an effective cognitive tool for obtaining a mental representation of coherent object boundaries despite non isomorphic superficial representations.

Our proposal regarding the functional architecture of semantic memory makes other predictions that are beyond the scope of the present paper but are probably worth discussing briefly to better frame our proposal within the relevant literature. In particular, our claim that verbal knowledge has a special status in semantic memory suggests that the left hemisphere may contribute greatly to this function. Indeed, in patients suffering from SD, cerebral atrophy, which sustains functional impairment, "nearly always involves both temporal lobes, although its distribution is often strongly asymmetric, with the majority of reported cases characterized by more extensive atrophy on the left" (Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001). The prevalence of left skewed atrophic changes in SD is in keeping with our hypothesis of a semantic hub based on word meanings, which evolved in humans as part of the language system. At variance with the symmetric bilateral representation of meanings, proposed by the semantic hub hypothesis, a differential left and right contribution to conceptual knowledge, due to the evolution of a left lateralized language system in humans, was proposed by Gainotti (2011), Gainotti (2012, Gainotti (2013). In a series of recent papers, this author reviewed different lines of research supporting the view "that the format of the semantic representations may be different at the level of the right and left hemisphere, the former being mainly characterized by a convergence of highly processed perceptual properties of objects and the latter by verbally coded sensorimotor, functional and encyclopaedic information" (Gainotti, 2011, p. 300). The claim that a double format exists for coding object knowledge leading to left/right asymmetries in semantic processing is totally in keeping with our proposal. Our views are less in agreement concerning the behavioral consequences of a selective disruption of either the perceptual or the verbal format of information. In fact, most of the research work reviewed by Gainotti in support of the claim of a double information format consists of evidence for material-specific impairments. In this vein, for example, this author claimed that "when the right temporal lobe is damaged, patients typically show a loss of person specific information *from face stimuli.* On the contrary, when the anterior parts of the left temporal lobe are selectively damaged, patients show a prevalent impairment in retrieving person specific information *from the people's names*" (Gainotti, 2011, p. 304, emphasis added). By contrast, as noted above, in our proposal the two information formats have less to do with the kind of stimulus material than with the kind of cognitive strategy one adopts to categorize it. A verbal knowledge format allows for the aware, explicit, arbitrary way of applying categories to incoming percepts. This is a typically human ability, which likely coevolved in humans with natural languages, based on their productivity (Lyons, 1981). Productivity of natural languages, in fact (see introduction), allows humans to think of, express and apply to their environment a potentially infinite number of categories. By contrast, sensorimotor representations allow humans, as well as other animals, to have an unaware, implicit, mostly species–specific, categorization of the environment.

References

Beauvois, M. F. (1982). Optic aphasia: A process of interaction between vision and language. *Philosophical Transactions of the Royal Society of London B, 298*, 35–47.

Coltheart, M. (2004). Are there lexicons. *The Quarterly Journal of Experimental Psychology, 57*(7), 1153–1171.

Coltheart, M., Inglis, L., Cupples, L., Michie, P., Bates, A., & Budd, B. (1998). A semantic subsystem for visual attributes. *Neurocase, 4*, 353–370.

De Saussure, F. (1916). In C. Bally, & A. Sechehaye (Eds.), *Cours de linguistique générale*. Lausanne and Paris: Payot.

Gage, N., & Hickok, G. (2005). Multiregional cell assemblies, temporal binding and the representation of conceptual knowledge in cortex: A modern theory by a "classical" neurologist, Carl Wernicke. *Cortex, 41*(6), 823–832.

Gainotti, G. (2011). The organization and dissolution of semantic-conceptual knowledge: Is the 'amodal hub' the only plausible model. *Brain and Cognition, 75*, 299–309.

Gainotti, G. (2012). The format of conceptual representations disrupted in semantic dementia: A position paper. *Cortex, 48*, 521–529.

Gainotti, G. (2013). The contribution of language to the right-hemisphere conceptual representations: A selective survey. *Journal of Clinical and Experimental Neuropsychology, 35*, 563–572.

Hillis, A. E., Rapp, B., & Caramazza, A. (1995). Contrasting claims about theories of semantic memory: More in unitary versus multiple semantics. *Cognitive Neuropsychology, 12*(2), 175–186.

Hodges, J. R., Patterson, K., Oxbury, S., & Funnell, E. (1992). Semantic dementia: Progressive fluent aphasia with temporal lobe atrophy. *Brain, 115*(6), 1783–1806.

Hodges, J. R., Salmon, D. P., & Butters, N. (1991). The nature of the naming deficit in Alzheimer's and Huntington's disease. *Brain, 114*(4), 1547–1558.

Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology, 5*, 67–103.

Lambon Ralph, M. A., McClelland, J. L., Patterson, K., Galton, C. J., & Hodges, J. R. (2001). No Rright to speak? The relationship between object naming and semantic impairment: Neuropsychological evidence and a computational model. *Journal of Cognitive Neuroscience, 13*(3), 341–356.

Lambon Ralph, M. A., & Patterson, K. (2008). Generalization and differentiation in semantic memory: Insights from semantic dementia. *Annals of the New York Academy of Sciences, 1124*, 61–76.

Lissauer, H. (1890). Ein Fall von Seelenblindheit nebst einem Beitrag zur Theorie derselben. *Archiv für Psychiatrie, 21*, 222–270.

Lyons, J. (1981). *Language and linguistics*. Cambridge: Cambridge University Press.

Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: Structure and processes. *Current Opinion in Neurobiology, 11*(2), 194–201.

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA Work Group under the auspices of the Department of Health and Human Service Task Force in Alzheimer's disease. *Neurology, 34*(7), 939–944.

Measso, G., Cavarzetan, F., Zappalà, G., Lebowitz, B. D., Crook, T. H., Pirozzolo, F. J., et al. (1993). The Mini Mental State Examination: normative study of a random sample of the Italian population. *Developmental Neuropsychology, 9*(2), 77–85.

Patterson, K., Lambon Ralph, M. A., Jefferies, E., Woollams, A., Jones, R., et al. (2006). "Presemantic" cognition in semantic dementia: Six deficits in search of an explanation. *Journal of Cognitive Neuroscience, 18*(2), 169–183.

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience, 8*(12), 976–987.

Price, C. J., & Humphreys, G. W. (1989). The effects of surface detail on object categorization and naming. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 41*(4), 797–828.

Riddoch, M. J., & Humphreys, G. W. (1987a). Visual object processing in optic aphasia: A case of semantic access agnosia. *Cognitive Neuropsychology, 4*, 131–185.

Riddoch, M. J., & Humphreys, G. W. (1987b). A case of integrative visual agnosia. *Brain, 110*(6), 1431–1462.

Rogers, T. T., Hodges, J. R., Lambon Ralph, M. A., & Patterson, K. (2003). Object recognition under semantic impairment: The effects of conceptual regularities on perceptual decisions. *Language and Cognitive Processes, 18*(5/6), 625–662.

Rogers, T. T., Lambon Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., et al. (2004). Structure and deterioration of semantic memory: A neuropsychological and computational investigation. *Psychological Review, 111*(1), 205–235.

Rogers, T. T., Lambon Ralph, M. A., Hodges, J. R., & Patterson, K. (2004). Natural selection: The impact of semantic impairment on lexical and object decision. *Cognitive Neuropsychology, 21*(2/3/4), 331–352.

Shallice, T. (1988). *From neuropsychology to mental structure*. Cambridge: Cambridge University Press.

Shallice, T., & Jackson, M. (1988). Lissauer on Agnosia. *Cognitive Neuropsychology, 5*(2), 153–192.

Warrington, E. K., & James, M. (1991). *Visual object and space perception battery*. Bury St. Edmunds, England: Thames Valley Test Company.

Wernicke, C. (1900). *Grundriss der Psychiatrie*. Leipzig: Georg Thieme.

Zannino, G. D., Barban, F., Macaluso, E., Caltagirone, C., & Carlesimo, G. A. (2011). The neural correlate of object familiarity and domain specificity in the human visual cortex: An fMRI study. *Journal of Cognitive Neuroscience, 23*(10), 2878–2891.

Zannino, G. D., Perri, R., Caltagirone, C., & Carlesimo, G. A. (2011). Spared structural knowledge in a case of semantic dementia: Implications for models of object recognition, semantic memory and structural description. *Neuropsychologia, 49*(7), 2112–2120.