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Category-specific visual agnosia: Lesion to semantic memory versus extra-lesional variables in a case study and a connectionist model

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Abstract

There is a current debate on the causes of category-specific agnosia. The aim of this study was to examine the effects of lesional and extra-lesional variables on object recognition. Extra-lesional variables, such as visual complexity or familiarity, are factors that influence recognition. Using a connectionist model based on Farah and McClelland's (1991) study, we provide evidence that extra-lesional variables can yield dissociations in the recognition rate of different categories. Furthermore, it is shown that lesional and extra-lesional variables can interact ($p < .01$) when both are simultaneously modeled. Category-specific agnosia might thus result from complex interactions.

Keywords: Category-specific agnosia; Visual agnosia; Variables; Factors; Connectionist modeling

1. Introduction

Category-specific agnosia is defined as a recognition deficit for some object categories and not others in the absence of a primary sensory disorder. Many articles have been published as an attempt to explain the observed dissociations and several hypotheses have been proposed.

1. The deficit for one particular category can result from a lesion to a cortical area specialized in this category (Caramazza & Shelton, 1998; Goodglass, Klein, Carey, & Jones, 1966).
2. The deficit may result from a lesion to a cortical area specialized in the processing of one type of knowledge about the object, for example visual knowledge as opposed to functional knowledge (Warrington & Shallice, 1984), or figurative versus operative knowledge (Sirigu, Duhamel, & Poncet, 1991). Memory about objects knowledge would thus be divided into different functional modules, each specialized in the processing of one type of information rather than one object category (Allport, 1985).
3. Category-specific agnosia could result from a lesion of the access to a unique semantic memory system. According to this hypothesis, each object category would implicate different sensory channels at various levels, which, if lesioned, would impair recognition of certain categories more than others (Riddoch & Humphreys, 1987; Riddoch, Humphreys, Coltheart, & Funnel, 1988).
4. The observed dissociations could be related to or co-determined by different *variables* (Stewart, Parkin, & Hunkin, 1992; Takarae & Levin, 2001; Tranel, Logan, Randall, & Damasio, 1997). These variables include a number of factors which can explain the dissociation (familiarity, sensory ambiguity...), but exclude the neuropsychological factor per se, which is the anatomical localization of the lesion.

In 1984, Warrington and Shallice published a study of four cases with category-specific agnosia. For patient

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SBY in particular, variables such as name frequency and visual familiarity were controlled. Linguistic studies provided measures of name frequency. Normative values of the Snodgrass and Vanderwart (1980) picture battery were used as a measure of visual familiarity. SBY still recognized non-living objects better than living objects after controlling for these variables. Warrington and Shallice therefore suggested that semantic memory was fractionated.

On the other hand, Riddoch et al. (1988) proposed a model which explained dissociations as artifacts resulting from the impact of such variables on the access to semantic memory. This hypothesis received some support from authors like Stewart et al. (1992). They published a case with a category-specific dissociation on clinical examination, that disappeared when the variables "name frequency," "concept familiarity," and "visual complexity" were controlled for.

The debate thus opposes authors in favor of the anatomo-functional origin of category-specific deficits, according to whom dissociation depends upon the site of the lesion in a fractionated semantic memory system, to authors who postulate that dissociations result from artifacts related to uncontrolled extra-lesional variables. The latter support the notion of a unique semantic memory system.

Tranel et al. (1997) suggested an alternative view, in that both, variables and lesion site, could simultaneously co-determine category-specific dissociations. They analyzed nine variables for 215 pictures: homomorphy (shape similarity), familiarity, value for the subject, manipulability, characteristic movement, characteristic modality of perception (sight, touch, and audition) and age of acquisition. Using a principal component analysis, these authors demonstrated that three components could account for the variability in recognition rates among objects categories: the first component represents useful, practical, and common aspects of the object; the second concerns non-manipulable homomorphic objects; the third component groups objects with characteristic sounds. Physical and contextual characteristics of some categories (extra-lesional variables) could thus determine the regionalization of neural systems that are critical for the acquisition and recall of knowledge about these categories. In other words, there would be a link between these extra-lesional variables and neural systems specialized in their processing. Lesions of these specialized neural systems would impair recognition of the variables they are specialized in, which in turn would affect recognition of categories with a high ranking concerning these variables.

Taking all this into consideration, several questions remain unanswered:

1. What is the role of these extra-lesional variables? These variables are controlled for in many experiments, based upon the hypothesis that they could be responsible for the dissociations. However, this has never been formerly demonstrated to our knowledge.
2. As mentioned before, there are two main hypotheses concerning category-specific agnosia. According to one, lesion site is primordial, and according to the other, uncontrolled variables can explain the observed dissociations. Are these two hypotheses really conflicting as some authors suggest or can both, lesion site and variables, result in recognition deficit?

2. Case study

We studied a patient with category-specific agnosia and report on an analysis of the potential influence of two extra-lesional variables.

Patient DF, a warplane pilot, suffered from brain injury due to a car accident at the age of 27. We examined him four years after his accident. Attention was preserved (digit span forwards: 8 and digit span backwards: 7) and he performed well on tests evaluating executive functions that do not depend on the use of semantic knowledge (Modified Card Sorting Test: seven categories). A CT-scan made two years after his accident revealed bilateral anterior and inferior temporal lesions that predominated on the left, bilateral orbito-frontal lesions, as well as bilateral ventricle enlargement. DF had severe difficulties recognizing and naming objects. There was no deficit of elementary visual perception (Visual Object and Space Perception battery (VOSP) incomplete letters subtest: 19/20), shape perception or comparison (VOSP's shape detection subtest: 20/20, Thurstone's identical shape test: 60/60), or mental shape manipulation (VOSP's cube subtest: 10/10).

We studied DF's responses to the pictures of the Snodgrass and Vanderwart battery (1980). This battery contains 260 pictures in which two variables, familiarity and visual complexity, are controlled. Normative scores were obtained by asking 219 students to rate these two variables on a scale ranging from 1 to 5. We only used the 202 pictures of the 260 that can be sorted into 16 different categories, corresponding to those chosen by Battig and Montague (1969). The 58 remaining pictures cannot easily be attributed to any specific category (snowman, cigarette, thimble,...). The 16 categories can further be classified in two broad groups: manufactured (inanimate man-made) and natural. This classification respects the classic living versus non-living dichotomy, and it also enabled us to take into account other more specific categories such as body parts or natural elements (mountains, sun, clouds,...).

We presented all 202 pictures, one at a time, to DF. The size of each picture was 4×5 cm. We considered that DF recognized a picture if he found the correct name for it. If he could not, the experimenter investigated through various questions if DF had recognized the picture or not. This procedure was easy to perform as the patient was eager to participate and had no anosognosia.

2.1. Results

Results are presented in Table 1.

Recognition of manufactured objects was globally better than for natural objects, although there were some categories of man made objects that were relatively poorly recognized (such as musical instruments). However, some categories of natural objects were relatively well recognized by DF (such as body parts or natural elements). The fact that some categories are perfectly recognized and named (means of transportation) whereas others are not at all (birds) supports the category specific aspect of the deficit.

What is the explanation of this category-specific pattern? According to what we developed in our introduction, three different hypotheses can be suggested:

1. The lesion site may explain this dissociation. Our patient's lesions are located primarily in the left inferior temporal lobe. It has been shown in other brain-injured patients that such lesions can result in poorer recognition of natural objects than manufactured objects (Ferreira, Giusiano, & Poncet, 1997). Damasio, Grabowski, Tranel, Hichwa, and Damasio (1996) have shown in a PET study of patients, that important difficulties in naming animals where correlated with lesions to the left inferior temporal lobe, whereas difficulties in naming tools was associated with lesions to the temporo-occipito-parietal junction. Our patient's results are thus consistent with these two studies and can be interpreted as being the result of his lesion's site.
2. Familiarity and visual complexity variables could be responsible for the observed dissociation. We evaluated the influence of type (natural or manufactured), familiarity and visual complexity rate according to the Snodgrass and Vanderwart battery (1980) on picture recognition, using a logistic regression analysis. Familiarity was found to have a significant effect ($p < .01$). There was also an interaction between visual complexity and familiarity ($p < .05$) and an interaction between visual complexity, familiarity and type ($p < .01$). These results suggest that the recognition rate of our patient is influenced by several extralesional variables, as those that have been studied, but probably also by others.
3. There is an interaction between the lesion site and other variables, as suggested by Tranel et al. (1997). This last hypothesis could account for both, the site of DF's lesions, and the effects of the familiarity and visual complexity variables.

As the results of our case study are compatible with all three hypotheses, we used a connectionist model to make different simulations of these three possibilities.

Table 1
Recognition and naming rates ranked by category obtained by patient DF when presented with pictures from the Snodgrass and Vanderwart (1980) battery

Category	Recognition (%)	Naming (%)	*n*
Transportation means	100	100	10
Tools	92	92	13
Kitchen utensils	88	75	16
Clothes	83	72	18
Furniture	74	63	19
Food	67	67	3
Toys	62	54	13
Buildings	50	50	4
Musical instruments	36	18	11
Total manufactured objects	76	67	107
Body parts	83	83	12
Natural elements	80	80	5
Fruits	73	65	11
Insects	50	38	8
Animals	28	22	36
Vegetables	15	0	13
Birds	0	0	10
Total natural objects	40	33	95

3. Experiment 1: Connectionist modelling of the visual complexity variable

Different authors have used connectionist modeling in order to study category-specific agnosia (Devlin, Gonnerman, Andersen, & Seidenberg, 1998; Durrant-Peatfield, Tyler, Moss, & Levy, 1997; Farah & McClelland, 1991; Humphreys, Lamote, & Lloyd-Jones, 1995; Small, Hart, Nguyen, & Gordon, 1995). The most important value point of these models is to allow for a learning process in which all parameters can be controlled. Different hypotheses can thus be tested by lesioning different parts of the network and observing the resulting effect on the recognition rate of previously learned patterns. We were thus able to model the visual complexity and familiarity variables that we have been studying in our previous experiment.

We used the connectionist model of semantic memory developed by Farah and McClelland (1991). It is a network which consists of three different modules (see Fig. 1): a visual input–output module, a verbal input–output module and a semantic module itself divided in two parts: a visual part and a functional part. After learning, the network is able to produce a verbal output following a visual input or a visual output following a verbal input.

The network consists of 128 units. A unit is connected to all other units, except for the input–output units of

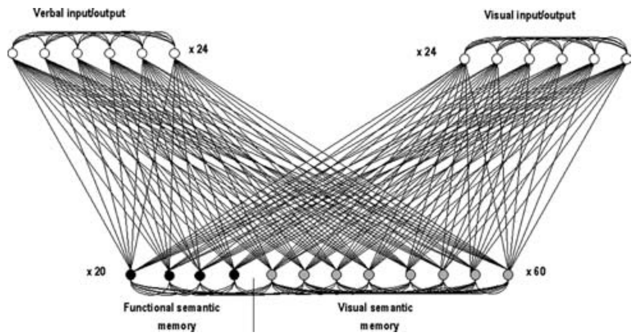

Fig. 1. Graphic representation of Farah and McClelland's (1991) model.

the visual module which are not connected to the verbal units and vice-versa. It is an auto-associative network with supervised learning using the classic delta-rule. The "objects" in this network are vectors of dimension 128. Each dimension can have one of three values: −1 or 1 which represent activated units and 0 which has no effect. All our tests have been run using 200 epochs. After learning of the different vectors, we always studied different lesions rates: 20, 40, 60, 80, and 99% or no lesion of the unit of a given part of the network. We used recognition procedures similar to those described by Farah and McClelland (1991) and replicated their results in order to verify that the model was correctly implemented.

In their study, Farah and McClelland (1991) conducted a first experiment in which they showed that both living and non-living objects contain more visual than functional features. However, living objects contain five times more visual features than non-living objects. Farah and McClelland's results show the same trend as those found by Snodgrass and Vanderwart (1980) who define visual complexity as "the amount of detail or intricacy of line in the picture." In the 202 pictures used in this study, natural objects have a mean rate of visual complexity of 3.26 ($SD = 0.95$), whereas manufactured objects have a mean rate of 2.84 ($SD = 0.83$). On the whole, natural categories have thus been found to have more visual details than manufactured objects. Tranel et al. (1997) have studied the visual variable under the name of homomorphy (similarity of form), which is a composite z-score of three different measures: curvilinearity/rectilinearity, within-category overlap of shape and visual ambiguity. They therefore suggest that structural characteristics of objects might be crucial for recognition, not so much because the structure of an object is more or less complex but because correct visual recognition depends on the number of other objects that are similar to the object to be recognized. The more objects there are that are similar to the target object, the difficulty for recognizing this object increases when the recognition system is not efficient, as is the case when it is lesioned. They found that natural objects (animals and fruits/vegetables) have a higher homomorphy rate than manufactured objects (tools and musical instruments). These results are consistent with the general view that natural object recognition relies most upon visual components.

3.1. Method

On the basis of Farah and McClelland's (1991) and Tranel et al.'s (1997) studies, two categories of natural objects (N1 and N2) and two categories of manufactured objects (M1 and M2) were defined. These objects respect the visual/functional ratio defined by Farah and McClelland (1991), but also have been designed to have different homomorphy levels as proposed by Tranel et al. (1997): natural objects are more homomorphic in their visual input–ouput and in their visual semantic component than manufactured objects. Each category was derived from a prototype respecting the above mentioned ratio. The prototype was then randomly modified to create 10 objects for each category. Category N1 also includes an 11th object which is an exception to the category. According to Tranel et al. (1997), exceptions are those objects which, while belonging to a formal category, have many features that are distinct from the other objects in this category (an elephant or a starfish for example). A cluster analysis based on the correlation between each pattern ((1 − Pearson r) $*$ 100) was run to check the proximity of the different patterns on their visual input/output and their visual semantic part (Fig. 2). The cluster analysis correctly classified the different objects by category on the basis of their similarity. This analysis furthermore confirmed that natural objects share more features in each of the two natural categories when compared with objects from manufactured categories (correlations between patterns of natural categories are higher).

Our hypothesis, following the work by Tranel et al. (1997), is that, within a category, increasing homomorphy will be related to decreasing recognition, when the semantic memory system is lesioned.

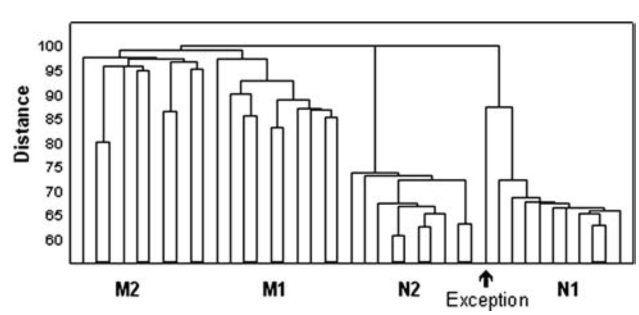

Fig. 2. Cluster analysis: Classification according to the homomorphy level.

3.2. Results

Fig. 3 shows the mean results obtained for five consecutive learning and trials procedures for different lesion rates to the semantic module.

On the sole effect of the homomorphy variable, the two categories of manufactured objects are better recognized than the two categories of natural objects. The recognition rate of the exception is higher than that of other objects in the N1 category (not shown here), which supports the assertion formulated by Tranel et al. (1997) and corroborates clinical observations. It thus adds some weight to this model. It further elucidates the visual variable that we studied, as it confirms that visual recognition not only depends on visual complexity per se but on how much an object visually differs (or has a distinct neuronal trace) from other objects.

4. Experiment 2: Connectionist modelling of the familiarity variable

4.1. Method

The familiarity variable has been defined by Snodgrass and Vanderwart (1980) as "the degree to which you come in contact or think about the concept." We have modeled it more specifically as the relative frequency of learning of a given object during the learning phase (Steckler, Drinkenburg, Sahgal, & Aggleton, 1998). A very familiar object will thus be regularly learned at each epoch whereas a less familiar object will be learned less:

Example of a familiar object presented 50 epochs out of 50 (X = presentation):

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Example of a less familiar object presented 25 epoch out of 50:

xx . . xxx . . xxx . . xx . . . x . . xxx . . xxx . . xx . . . xxx . . . xx . . . x

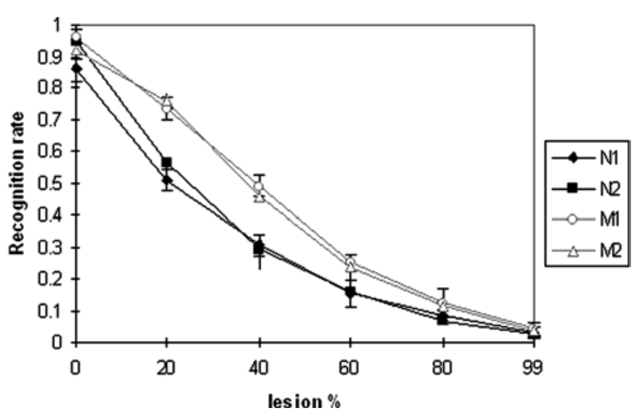

Fig. 3. Results obtained upon modeling and testing the homomorphy variable.

Learning epochs for less familiar objects were randomly chosen. For this experiment, we used 10 natural and 10 manufactured objects. Each object was defined independently but respected the ratio between visual and functional features, such as described by Farah and McClelland (1991). Using a Student's t test, we verified that the recognition rate was exactly the same for all of these patterns, regardless of the lesion rate, when the familiarity variable was not implemented (that is when all patterns of both categories are learned at all epochs).

Tranel et al. (1997) found a higher familiarity rate for manufactured objects than for natural objects, as did Vanderwart and Snodgrass (1980) (for the sample of 202 pictures: mean rate for natural objects: 2.94, $SD = 0.98$, mean rate for manufactured objects: 3.56, $SD = 0.82$). Our hypothesis was that more familiar objects are better recognized than less familiar objects. The manufactured category was learned in 200 epochs out of 200, the natural category was learned in 100 epochs out of 200.

4.2. Results

Fig. 4 shows the mean results obtained for five consecutive learning and trial procedures for different lesion rates to the semantic module.

The manufactured objects category was better recognized than the natural objects category on the sole basis of the familiarity variable as it was the only difference between the two categories.

5. Experiment 3: Extra-lesionnal effects vs lesions effects

Since we have demonstrated that the visual complexity and familiarity variables can yield a dissociation, we proceeded to study the relationship between this possible cause of dissociation and the other one that is usually mentioned, which is localised lesion. In other terms, are these two causes mutually exclusive or can they interact?

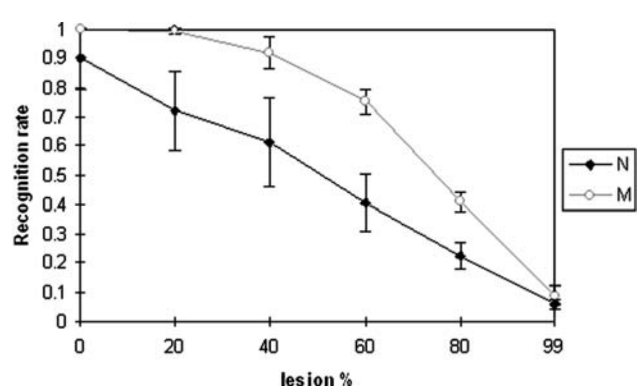

Fig. 4. Results obtained upon modeling and testing the familiarity variable.

5.1. Method

We used the four categories of objects with controlled homomorphy defined in Experiment 2. The network learns the different objects exactly as it did in Experiment 2 but lesions are this time limited to regionalized parts of the network that include either the visual part or the functional part of semantic memory (see Fig. 1).

The effect of a lesion to visual semantic memory combined with a diminished recognition rate for objects with high homomorphy should increase the discrepancy between the recognition rate for natural object categories and that for manufactured object categories, when compared to the sole effect of homomorphy (Experiment 2). The results of this simulation, obtained for five consecutive learning and trials procedures, are presented in Fig. 5. Following lesions to functional semantic memory, manufactured objects should be less recognized, but this effect should be counterbalanced with the inverse effect of a better recognition rate due a lower degree of homomorphy. The results of this simulation are presented in Fig. 6, for five consecutive learning and trial procedures.

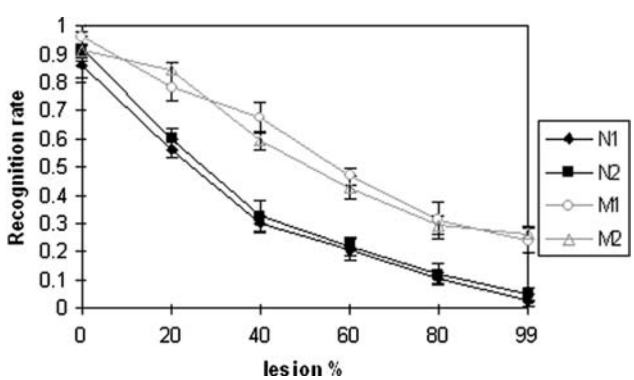

Fig. 5. Results obtained upon modeling and testing simultaneously the homomorphy variable and lesions to the visual part of the semantic memory.

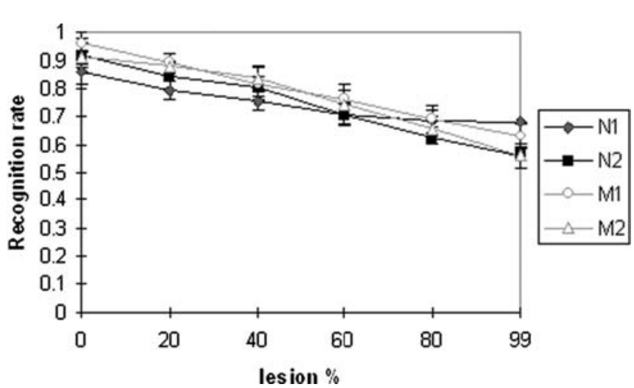

Fig. 6. Results obtained upon modeling and testing simultaneously the homomorphy variable and lesions to the functional part of the semantic memory.

5.2. Results

The results confirm our hypothesis. We studied the simultaneous effect of two independent variables: homomorphy and lesion type. As expected, a variance analysis on these two factors (dependant variable: mean recognition rate) indicates that both factors have a significant effect. But there is also an interaction between both factors. Results are the same ($p < .01$) whether these factors are studied at a lesion rate of 40 or 60% (which are lesion rates that result in recognition rates similar to what can be observed in a clinical setting, see for example Figs. 5 and 6 compared to Table 1).

The modeling of the familiarity variable with specific lesions of the semantic memory module yields similar results. It shows that variables (lesional or extra-lesional variables) that are very different in nature can both have an impact on object recognition and that what can be observed globally is the result of the intricacy of these different factors.

6. Discussion

We report on the study of a brain-injured patient who presented with a category-specific visual agnosia. We formulated three hypotheses concerning the possible causes of his dissociation. It could result either from the lesion site, from uncontrolled extra-lesional variables or from an interaction between them. Farah and McClelland (1991) have shown, using a connectionist model, that lesions to specific parts of semantic memory can yield dissociations. The different parts of their semantic model were not specialized by category, but according to features that are common across categories, which would argue against a pure category localization hypothesis. We showed in Experiments 1 and 2, using the same connectionist model, that extra-lesional variables could account for dissociations between different object categories, which is a fact that Farah and McClelland had overlooked. We finally provided evidence, in our last experiment, that these lesional and extra-lesional variables could interact in our connectionist model, which is more in line with the current hypothesis of co-determination, advanced by Tranel et al. (1997).

The connectionist model used in this article is very simple in its design and we do not pretend that it is a neuromimetic model [although some regions of the brain are hypothesized to work as an autoassociative network with similar properties (pattern completion) as those used in this model]. Our conception was that of a general information system able to encode parts of the external world through the repetition of learning in a distributed network. In this way, it shares some properties similar to the brain such as non-symbolic encoding and storing of information, which makes the network, in a similar way as the brain, robust to lesions (part of the information might be destroyed but the remaining information is sufficient to allow for proper recognition as it is distributed). This model nonetheless enables us to stress the effect of extra-lesional variables, which has so far rarely been studied. Two such variables have been modeled in a formal manner, which, to our knowledge, has never been done before. Other variables could have been modeled such as the age of acquisition of a concept using a procedure similar to the one used to model familiarity, or the value of an object for the person, using for example a higher learning rate for objects with a high ranking on this variable. In this study, the effect of such variables was the focus of our experiments, while these variables are usually ignored or simply controlled for in most studies.

It is important to note that the two extra-lesional variables studied in this paper, which represent only a low proportion of all possible variables, do not have the same status. Homomorphy is a variable related to the object category alone, it is a physical attribute of this category in the external world, independent of any observer. Familiarity does not exist by itself in the external world. It results from the interaction between a category and a viewer: in other words, it can be studied only in relation to an individual or a population. Other variables that have not been modeled here exist, and are, as opposed to external variables, internal to an individual (for example the variable "value for the subject" studied by Tranel et al., 1997). The differences between these variables and their implications are not very often studied or even mentioned although they certainly have implications on the neural substrates involved in the encoding, storing and retrieval of conceptual and lexical knowledge.

Studying variables also contributes to the understanding of why a lower recognition rate for natural objects is reported in category-specific agnosia. Lower recognition rates for manufactured categories than for natural objects were found in none of our simulations, particularly when both lesional and extra-lesional factors were implemented. This corroborates what has been reported in the literature, as a higher recognition rate for natural objects versus manufactured objects has very rarely been reported (but see Hillis & Caramazza, 1991; Warrington & McCarthy, 1983). This seems to result from variables that lead to better discrimination between objects (the extra-lesional effect) and from the fact that manufactured objects are known through both a visual (figurative) and a manipulating (operating) system, whereas natural objects are mainly known through the visual (figurative) system (Ferreira et al., 1997). No lesion can thus affect manufactured objects only. This is supported by the fact that extra-lesional variables such as homomorphy or familiarity both contribute to make manufactured objects more distinguishable (as they rank lower on homomorphy and higher on familiarity). Considering these facts, it is very unlikely to find a category-specific agnosia limited to manufactured objects.

We thus suggest that category-specific agnosia is the result of three simultaneous effects: (i) Effects of the lesion site. (ii) Effect of extra-lesional factors. This is in favor of controlling these extra-lesional variables in order to ascertain that only the lesion can account for the observed effect. (iii) Effect of the interaction between these two. These experiments thus provide evidence against the more basic view that the dissociation can be explained either by the lesion site or by uncontrolled factors. The debate opposing the tenants of these two theories might thus be irrelevant as a much more complex situation arises.

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