

Category Specificity in Normal Episodic Learning: Applications to Object Recognition and Category-Specific Agnosia

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Studies of patients with category-specific agnosia (CSA) have given rise to multiple theories of object recognition, most of which assume the existence of a stable, abstract semantic memory system. We applied an episodic view of memory to questions raised by CSA in a series of studies examining normal observers' recall of newly learned attributes of familiar objects. Subjects first learned to associate arbitrarily assigned colors or textures to objects in a training phase, and then attempted to report the newly learned attribute of each object in a recall task. Our subjects' pattern of recall errors was similar both quantitatively and qualitatively to the identification deficits among patients with CSA for biological objects. Furthermore, errors tended to reflect conceptually and structurally based confusions. We suggest that object identification involves recruitment and integration of information across distributed episodic memories and that this process is susceptible to interference from objects that are structurally similar and conceptually related.

The notion of a categorically organized semantic knowledge system is a fascinating topic of speculation and investigation, inspired in part by patterns of category-specific impairment in visual object recognition among patients with certain kinds of neurological damage. Beginning with a thought-provoking series of papers by Warrington and co-workers (McCarthy & Warrington, 1988; Warrington & McCarthy, 1987; Warrington & Shallice, 1979, 1984), a growing body of literature documents cases of category-specific agnosia (CSA). Patients with CSA have great difficulty identifying visually presented objects from certain categories, even though there is nothing wrong with their ability to derive a geometric structure from an image on the retina. This deficit affects performance in a variety of tasks that require retrieval of object knowledge, including object naming or retrieving particular semantic features. The overwhelming majority of cases show a disproportionate impairment of recognition and naming of visually presented biological objects (such as mammals, fruits, and vegetables), with relatively preserved performance on nonbiological categories such as clothing and furniture. The reverse pattern of CSA, in which it is primarily performance on nonbiological objects that is impaired, is very infrequent and (as further elaborated in a subsequent section) there are a number of alternative views on the question of how this pattern is related to CSA for biological objects.

Despite the potential interest of CSA, this phenomenon has had little impact on current theories of normal object identification developed outside the neuropsychological domain. We attribute this situation in part to the lack of a

theoretical framework that would provide a clear analogue between the labeling errors of CSA patients and identification errors made by normal observers operating under processing constraints. An important goal of this article is to create such a bridging framework and to demonstrate that under certain conditions, the performance of normal subjects bears a clear similarity to that of patients with CSA of the biological type.

We begin by presenting a summary of data from published cases of CSA to identify the semantic categories that show the strongest pattern of dissociation. We then briefly review existing theories of CSA and we comment on the status of attempts to emulate category-specific effects in the identification performance of normal subjects. We argue that such attempts have not provided a convincing analogue of CSA, and we suggest that the principal reason behind this failure is a basic assumption common to all theories of CSA, that categorical knowledge is characterized in the form of stable semantic representations. We provide an alternative proposal in which semantic knowledge is the outcome of a collection of previously experienced episodes and is subject to continuous modification as new episodes accrue (Jacoby, Baker, & Brooks, 1989; Jacoby & Brooks, 1984; Kahneman & Miller, 1986). We introduce an experimental paradigm derived from this episodic framework that yields a pattern of performance in normal subjects strikingly congruent with the most common pattern of impairment seen in CSA.

Modal Patterns of CSA

To characterize the nature of underlying differences in the representation of objects allowing for dissociations in CSA patients, we need to establish a consistent pattern of performance across a large number of categories. This task is difficult, unfortunately, because of the incomplete and inconsistent nature of case testing and reporting. Among the

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published reports of CSA cases, we found a sample of 20 cases for which performance on a range of individual categories was reported. Of these, we classified 15 cases as CSA for biological types, and classified 5 as CSA for nonbiological types. Among these cases, category and item selection varied widely.

To examine these cases, we constructed plots representing performance of individual cases across the categories that were most commonly tested. The ordering of categories along the abscissa for the data shown in Figure 1 is based on mean accuracy for patients with CSA of the biological type. Performance is shown separately for patients with CSA of the biological and nonbiological types.

As can be seen from Figure 1, for each category there is substantial variability across the patients in each group. Such variability is common in neuropsychological samples and probably reflects factors such as different etiologies, inconsistencies in test procedures and stimuli, and individual differences in specific experiences with objects (for evidence regarding the importance of this latter factor, see Dixon, Desmarais, Gojmerac, Schweizer, & Bub, 2002). The figure also illustrates well-known exceptions from a literal biological/nonbiological distinction (e.g., patients with CSA of the biological type tend to do poorly on musical instruments and well on body parts). Nevertheless, it is clear that patients classified as impaired on biological objects perform fairly well on certain nonbiological categories (e.g., clothing, furniture, and kitchenware), whereas their performance on particular biological categories (e.g., vegetables, fruit, animals, and birds) is relatively poor. For patients in the nonbiological group, performance on biological categories such as vegetables, animals, birds, and fruit, is generally better than for patients in the biological group, whereas the reverse is true for nonbiological categories such as tools, kitchenware, furniture, and clothing. These dissociations are particularly clear in the group averages for these categories presented in Figure 2.

The pattern of performance across categories for the two types of patients with semantic deficits provides compelling evidence for a dissociation between categories broadly classified as living and nonliving. It is also evident from differences in the patterns of the two patient types that a single principle cannot account for both types of CSA. Therefore, it is likely that damage to separate processes underlies CSA for living and nonliving things (Cree & McRae, in press).

Theoretical Approaches to CSA

Theories of CSA can be classified into two broad categories: (a) accounts that emphasize differences in semantic representations themselves and (b) accounts that view CSA as an emergent phenomenon contingent on interactions between structural form and semantic representations.

Semantic representation accounts. A number of

interpretations of CSA view semantic knowledge as being structured in ways that can lead to differences in performance between biological and nonbiological objects following neural damage. According to the dominant view, sensory information is processed separately from functional information. Category-specific effects are attributed to the relative salience of perceptual versus functional information in distinguishing exemplars of biological and nonbiological objects. For example, visual information is conjectured to be more critical for the identification of biological objects, whereas functional information is more critical for identification of nonbiological objects. On this account, damage to the visual semantic subsystem results in a disproportionate impairment in recognition of biological objects, whereas damage to the functional subsystem results in a disproportionate impairment in recognition of nonbiological objects (Farah & McClelland, 1991; Warrington & McCarthy, 1983; Warrington & McCarthy, 1987). Other variants of this approach emphasize the degree to which form (e.g., has wings) and function (e.g., can fly) are correlated across exemplars within a category. Tyler and Moss (1997; see also Moss, Tyler, Durrant Peatfield, & Bunn, 1998) proposed that biological categories have form-function correlations that are nondistinctive in that they are shared by many exemplars (e.g., has legs and can walk), whereas form-function correlations in nonbiological categories are distinctive in that they tend to be restricted to a small number of exemplars (e.g., has blade and used for cutting). They argue that correlated features are more likely to survive brain damage, and that identification of objects will depend on the distinctiveness of these surviving correlations. A similar explanation was proposed by McRae and Cree (2002) whose analysis of attributes associated with living and nonliving objects revealed that a greater number of distinctive features are associated with objects from nonbiological categories whereas the features of objects from biological categories tend to overlap. Features that survive neurological damage, therefore, would more likely be distinctive in the case of nonbiological categories.

Another semantic representation account draws on evolutionary claims to argue that domain-specific neural circuits are dedicated to processing objects from categories that have particular relevance for survival. On this account, animals form a distinct category, as do plants, conspecifics, and perhaps tools (Capitani, Laiacona, Mahon, & Caramazza, in press). It follows that there is no necessary association, then, between the impairment of animals and fruits and vegetables so often seen in CSA for biological objects because animals and plants are presumed to be represented in different neural systems. Indeed, Capitani et al. note that in some cases, patients may be more impaired on animals than fruits and vegetables, or vice versa. The question is whether such variation between patients can at this point be taken as reasonable evidence for completely separate neural systems for plants and animals. We have already noted that a number of incidental factors might account for the differences seen between individual cases of CSA. Although Capitani et al.

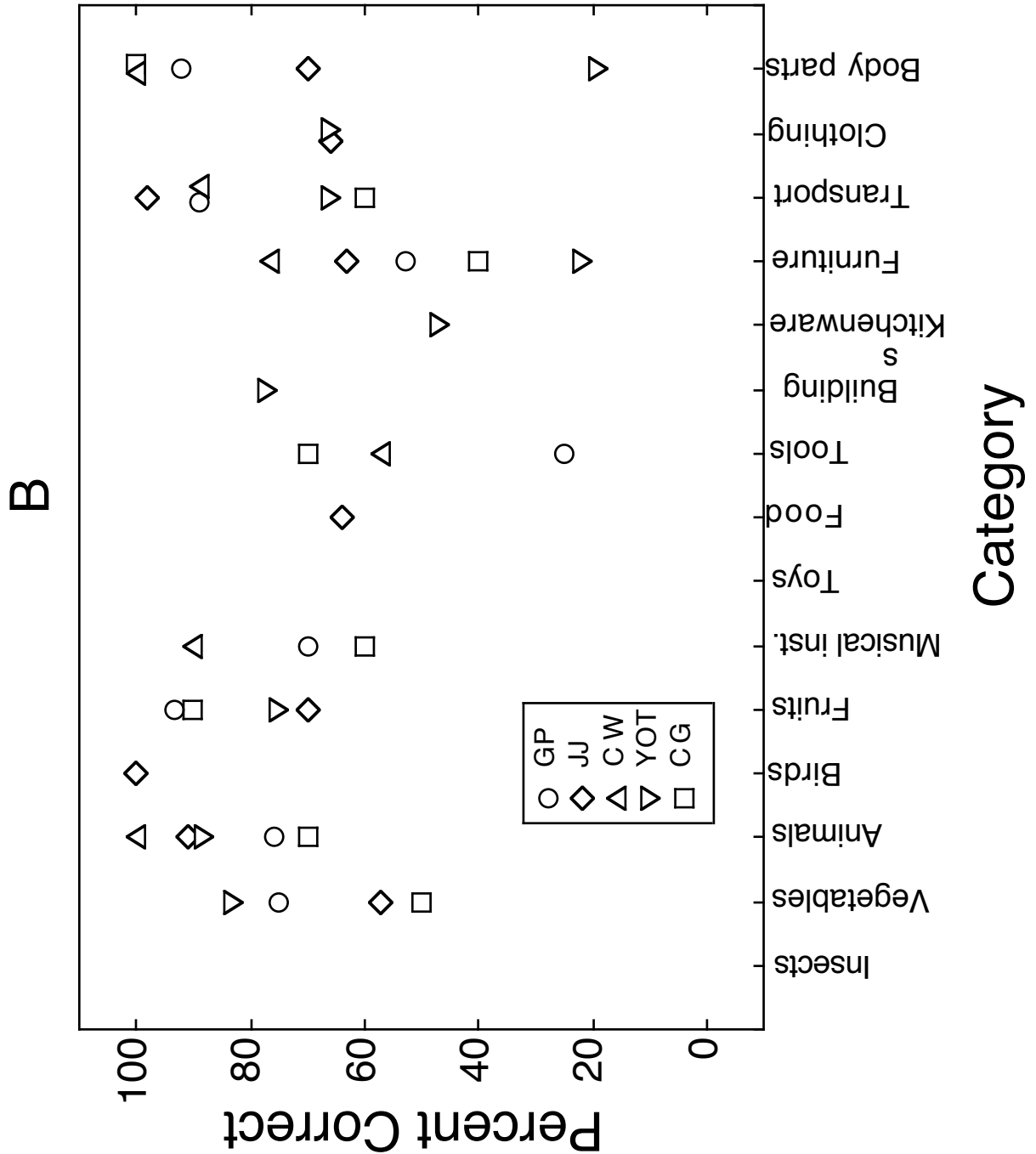


Figure 1. Object identification performance of CSA patients demonstrating selective deficits for biological objects (panel A) or nonbiological objects (panel B). Patient initials in panel A correspond to the following case studies: ELM - Arguin et al. (1996), JBR - Bunn et al. (1998), Felicia - DeRenzi et al. (1994), SBR - Forde et al. (1997), LA - Gainotti et al. (1996), KR - Hart et al. (1992), PS - Hillis et al. (1991), FM and GR - Laiacona et al. (1993), JMC - Magnie et al. (1999), RC - Moss et al. (1996), JB - Riddoch et al. (1987, 1988), Jennifer - Samson et al. (1998), Michaelangelo - Sartori et al. (1993), HO - Stewart et al. (1992). Patient initials in panel B correspond to the following case studies: GP - Cappa et al. (1998), JJ - Hillis et al. (1991), CW - Sacchett et al. (1992), YOT - Saffran et al. (1994), CG - Silveri et al. (1997).

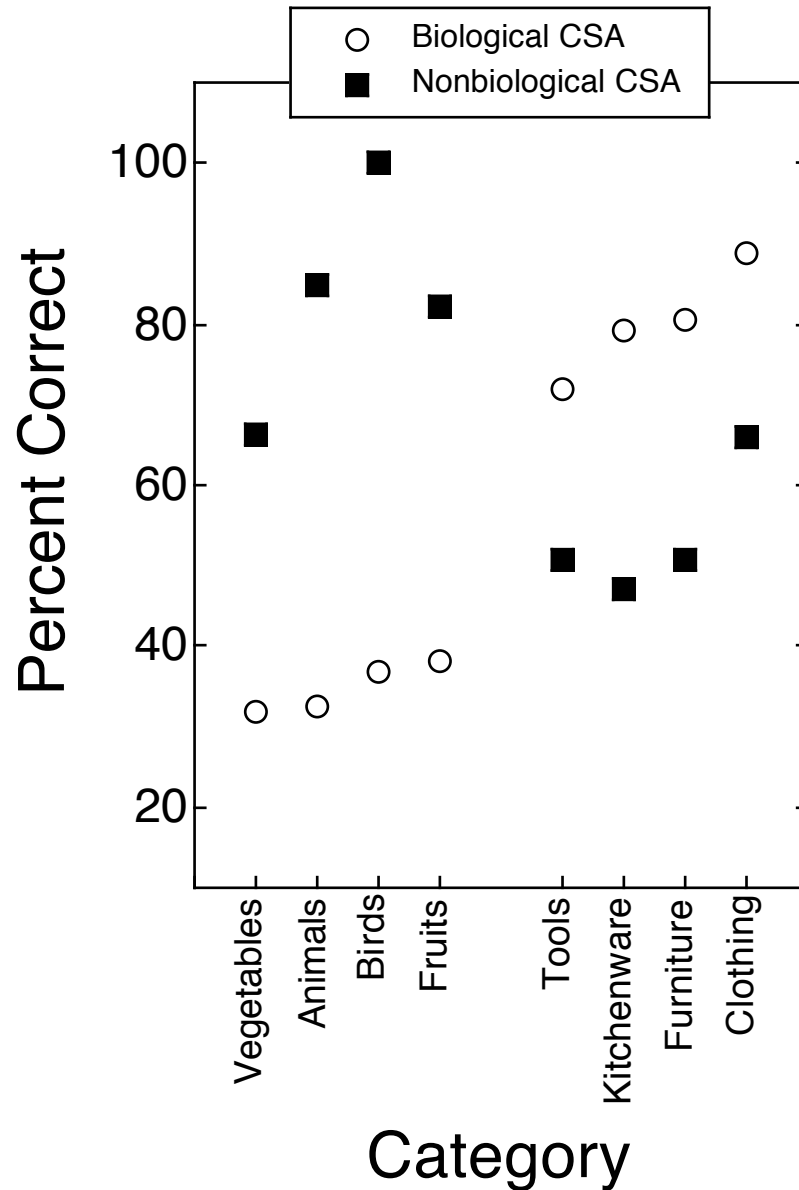


Figure 2. Performance on selected categories by CSA patients of the biological and nonbiological type, illustrating the double dissociation between the two category groups.

report a double dissociation between animals and plants, they also observe that especially severe deficits for fruits and vegetables are generally found only among male patients. A recent study of normal subjects by Barbarotto, Laiacona, Macchi, and Capitani (2002) found a similar gender difference favoring females for fruits and vegetables and a reverse difference favoring males for tools. Such premorbid differences, in our view, may be the result of differences in life experience and must be taken into account when interpreting the effects of neurological damage responsible for CSA (Dixon et al., 2002).

A virtue of semantic representation accounts is that they

offer a possible interpretation of the pattern of double dissociation shown in Figure 2. A weakness is that the distinctions on which they are based are sufficiently vague that details of performance documented in individual cases are not easily accommodated without additional assumptions. For example, CSA patient ELM produced a pattern of errors in a picture-word matching task with fruits and vegetables that revealed a failure to retrieve all of the shape features necessary to uniquely specify an item (Arguin, Bub, & Dudek, 1996). Thus, labeling errors invariably reflected confusions between fruits and vegetables sharing values on perceptual dimensions like thickness, tapering, and curvature

(e.g., carrot confused with cucumber, but not with onion). These confusions were clearly not due to an inability on the part of ELM directly to perceive these structural dimensions. Thus, he could readily judge in what way a line drawing of a cucumber differed from a drawing of a carrot. But he could not use his perceptual representation to map from vision to the specific identity of each object. Neither the accounts of CSA that assume distinctions between structural and functional knowledge nor those that argue for distinctions between semantic categories on evolutionary grounds can provide a ready explanation for this pattern.

Interactive accounts. Rather than emphasizing distinctions between semantic features or their correlations as the basis for patterns of impairment in CSA, a number of accounts view category-specific effects as emerging from an interaction between structural form and semantic knowledge. Humphreys and Forde (Humphreys & Forde, 2001) proposed such a model in which any class of objects that shares a high degree of structural and semantic similarity will show disproportionate impairment when damage occurs at any of a number of stages that map between form and meaning or between meaning and naming. Arguin, Bub, and Dudek (1996; see also Dixon, Bub, & Arguin, 1997; Dixon, Bub, & Arguin, 1998) developed an account that is similar in some ways to the Humphreys and Forde model. Arguin et al. proposed that shape dimensions of an object act as retrieval cues during identification. Objects in certain categories share multiple shape dimensions that must all be represented when memory for shape is mapped to an appropriate point in conceptual space. Such objects also tend to share many conceptual dimensions in memory. In CSA, the deficit affects the ability to use the full set of diagnostic shape dimensions when mapping from shape representations of objects to points that are close together in conceptual space (this could be simulated in a connectionist model as a loss of hidden units that intervene between shape and conceptual representations). The ability to distinguish between structurally similar objects that are conceptually unrelated is not affected as severely by this impairment.

Selective difficulty in identifying biological objects occurs because they often share perceptual and conceptual features with their category neighbors. In addition, even objects in certain nonbiological categories pose the same problem. In particular, some classes of musical instruments overlap with each other in a similar way to biological objects and should be impaired along with animals and fruits and vegetables (see cases LA and JMC in Figure 1). Certain CSA cases apparently show relatively preserved ability to identify musical instruments concomitant with impaired identification of animals and fruits and vegetables (see our Figure 1 and Capitani et al., in press). We suggest that for many of these cases, the preservation of musical instruments is due to (a) the fact that not all musical instruments have substantial structural and conceptual overlap with other instruments and (b) differences between patients in familiarity or even expertise with musical instruments (see our discussion of gender differences

regarding tools and fruits and vegetables in the previous section). With respect to the first point, many studies of CSA have relied exclusively on line drawings taken from the set of objects published by Snodgrass and Vanderwart (1980). For example, Barbarotto, Capitani, and Laiacona (2001) tested a mixed group of patients (most with Alzheimer's disease and some with focal lesions) on 80 items from Snodgrass and Vanderwart. They reported that although accuracy was lower for musical instruments than for other nonbiological objects, this difference disappeared after statistical correction for age of acquisition, lexical frequency, and name agreement. Many of the musical instruments in this set, however, are structurally and conceptually unique (e.g., drum, harp, piano) and so do not have the potential to generate the same degree of competition between exemplars as do mammals and fruits and vegetables. It is not surprising, therefore, that no disadvantage was seen, especially given the mixed nature of the patient sample used by Barbarotto et al. With respect to the second point, differences in experience with musical instruments vary widely between individuals and clearly play a role in determining whether a deficit is observed. For example, case ELM readily identified brass instruments, because of his extensive experience with these instruments, but showed consistent impairment on stringed instruments (Dixon et al., 2002; see also case C reported by Wilson, Baddeley, & Kapur, 1995).

An appealing aspect of interactive accounts is their ability to explain patterns of identification errors made by CSA patients like ELM. For him, fruits and vegetables sharing shape dimensions were confused because he could not adequately map from structural representations of these objects to conceptual knowledge. Thus, errors were largely confusions between objects such as carrot and cucumber or apple and tomato, but not between cucumber and tomato. A limitation of interactive accounts, however, is that they do not readily provide an explanation of the dissociation in which CSA patients show relatively intact identification of biological objects and impairment on nonbiological objects. To accommodate this additional pattern, further assumptions are required regarding interactive processes between specialized components of semantic memory. For example, the representation of manipulable objects may include manual actions that play a role in their identification (see Humphreys & Forde, 2001). Damage to the representation of actions or the mapping between this representation and other kinds of representation may selectively affect identification of tools and other manipulable objects. We return to the question of the deficit responsible for selective impairment of nonbiological objects in the General Discussion.

An Episodic Framework

It is apparent that the study of CSA has provided evidence that categories respond differently to the effects of neurological damage, yet the fundamental principles that

govern these dissociations remain a matter of theoretical debate. Interpretation of various neurologically based impairments has benefited in the past from methodologies that provide a link between dissociations observed in brain damage and analogous dissociations in neurologically intact individuals. For example, understanding of dissociations between explicit and implicit tests of memory among amnesic patients is considerably enhanced by similar patterns in the performance of normal subjects. Likewise, dissociations in acquired dyslexia between orthographically regular and exception words can be induced in normal readers tested with appropriate procedures. Such convergent operations illuminate both the mechanisms underlying patients' deficits and their implications for theories of normal cognition.

Unfortunately, attempts to demonstrate relevant differences between categories in the identification performance of normal subjects have met with little success. Some studies have attempted to demonstrate differences in the perception of biological and nonbiological objects by degrading stimulus quality. For example, Gaffan and Heywood (1993) asked normal subjects to name perceptually degraded pictures that were briefly presented. Significantly more naming errors were made to biological items (\square 42%) than to nonbiological items (\square 34%). Musical instruments also were relatively difficult, resulting in a 52% error rate. By contrast, Laws and Neve (1999) matched line drawings for visual complexity, concept familiarity, and name frequency and found that identification of briefly presented nonbiological objects was somewhat worse than biological objects. These conflicting results make it difficult to draw any firm conclusions regarding the effects of category structure on identification of objects presented under degraded viewing conditions. In addition, it is doubtful that tasks requiring identification of perceptually degraded objects can provide a useful normal analogue of CSA, given that low-level perceptual processing is generally intact in these patients, and they therefore have no problems in deriving a percept from a visual stimulus.

Other studies have examined the effect of structural and semantic similarity on patterns of errors in naming objects under response deadline. Vitkovitch and Humphreys (1991; Vitkovitch, Humphreys, & Lloyd Jones, 1993) divided pictures from the Snodgrass and Vanderwart (1980) set into categories that were structurally similar or dissimilar. Structurally similar categories were biological in nature and included birds, fruits, and vegetables, whereas structurally dissimilar were nonbiological and included items from clothing, furniture, kitchen utensils, and tools. The structurally similar categories produced more naming errors overall, suggesting a form of category specificity. The causal roles of conceptual and structural similarity are not entirely clear in these studies because we do not know the relative degree of conceptual similarity among items within sets, nor do we know whether visual similarity alone in a set of conceptually unrelated objects would produce the same level of naming difficulty as a set of visually similar,

conceptually related objects. We explicitly address this issue in Experiments 1 through 4. Furthermore, it is not output of an object's name per se, that is affected in CSA. The deficit prevents the retrieval of attributes such as particular facts about objects in affected categories (e.g., this animal eats meat), whereas the inability to retrieve the name of an object is an indirect consequence of this more general deficit.

We believe that one important reason for the failure to obtain relevant evidence from normal subjects that would clarify our understanding of CSA lies in the broad conceptual framework within which the phenomenon of CSA has been considered. In general, theories of CSA are based on the assumption that category knowledge is represented by stable, abstract entities in a fixed architecture. As a consequence of viewing object meaning as a collection of stable representations, researchers of category-specific effects have limited manipulations to variables affecting input to and output from stored knowledge of objects.

In contrast to this view of semantic memory, a number of researchers have argued that semantic knowledge is based on a collection of previously experienced episodes (Jacoby et al., 1989; Jacoby & Brooks, 1984; Kahneman & Miller, 1986). In support of this alternate view, it has been shown that perceptual and categorical processes are influenced by specific episodes (e.g., Jacoby & Brooks, 1984). For example, there is evidence that normal subjects integrate new attributes with existing semantic knowledge and that this integration influences retrieval of pre-existing attributes (Lewis & Anderson, 1976). In addition, Jacoby and Brooks (1984) demonstrated that a single prior encounter with an object can substantially affect the speed or accuracy with which that item is later classified or identified and concluded that both perception and categorization are acts of memory that can rely on one or more prior episodes.

The conceptualization of semantic memory as an episodically based system has led to the creation of exemplar-based models of categorization in which concepts are dynamically recreated by activating and integrating stored episodic traces of past events at the time of retrieval (e.g., Estes, 1994; Hintzman, 1984, 1986; Kruschke, 1992; McClelland & Rumelhart, 1985; Medin & Ross, 1989; Nosofsky, 1986). These models have been shown to simulate a variety of phenomena in human categorization judgements (e.g. category typicality effects, error patterns, etc.).

It is interesting to note that an episodic view of object identification appears to be what Lissauer (1988) had in mind when discussing one of the first instances of agnosia in the neuropsychological literature:

...the recognition of an object can only occur when at the time of its perception a number of ideas are evoked which relate to that object. These bring into consciousness those characteristics which the mind has learned to associate with it and those conditions in which it has been previously experienced. ...They

usually relate to the object's name and those events which have been experienced most frequently and vividly in connection with it (p. 182).

To summarize our position, retrieval of semantic knowledge depends on the reinstatement of relevant aspects of prior episodes pertinent to the task demands of, for example, naming an object, typically cued by its visual form, or retrieving some other attribute of the object, typically cued either by the name or form (see Carbonnel, Charnallet, David, & Pellat, 1997, for a similar explanation). These attributes concern both stored visual and non-visual features of an object that are maintained in memory through encounters with that object across a variety of contexts. The precise information recruited on a particular occasion will depend not only on the context and goal of the situation, but also on the nature of the cue and its similarity to past episodes (Barsalou, 1993). One may therefore expect some difference in the nature of information recruited from an object's name or word form, versus the object's visual form (see Carr, McCauley, Sperber & Parmelee, 1982, for example). When presented with a visual form of an object, stored visual features such as structure, color, and texture will be contacted first and through these, other semantic features not directly present in the current stimulus will be retrieved. In this sense, visual semantic features have a privileged role in visual object recognition.

The relevance of an episodic framework to the understanding of CSA becomes important in light of the neglected but crucial fact that patients not only fail to identify certain classes of objects, but they also fail to relearn object classifications even after repeated experiences. We have already noted that CSA patient ELM cannot use the full set of shape dimensions of fruits and vegetables to identify individual exemplars. He also cannot learn new mappings between novel forms and conceptual representations that capture the same kind of variation between exemplars as do fruits and vegetables. Importantly, ELM's deficit was evident regardless of the type of information that was to be associated with the visual object, whether it was labels or other types of knowledge such as object location or sound. All of these mappings entail learning novel attributes or labels to shapes.

In general, then, we account for the deficit seen in the modal pattern of CSA for biological objects as a failure to make use of the full set of representational dimensions needed to accurately name the object or retrieve other specific attributes. We consider a particular kind of input (e.g., the shape of an object) as evoking a modality specific representation that is the retrieval cue for other aspects of semantic knowledge. Connectionist models of categorization (e.g., Kruschke, 1992) and CSA (e.g., Gale, Done, & Frank, 2001) are compatible with this account. In such models, the mapping between a modality specific representation and other semantic knowledge depends on connection weights that can be continually updated through episodic experience. These weights connect processing units between and, in some cases within, specialized domains of

knowledge, each of which has its own multidimensional representational space. A modality specific representation that directly responds to input is connected to other multidimensional spaces representing additional attributes of the objects that define their meaning. Neural damage can affect connection weights within a specialized domain or weights that provide a mapping between domains, either by reducing their number or adding noise. This damage will decrease the distance between points in one or more multidimensional spaces, and for classes of objects that have similar representations, this reduction in distance will lead to errors of identification. For example, damage to connection weights or hidden units that mediate between units in a modality specific space representing the shape of an object and units representing other semantic features will result in confusion between objects that are similar in their shapes and other semantic attributes.

In this article, we introduce an experimental procedure designed to produce an error pattern in normal observers similar to that of patients with CSA of the biological type, so that factors underlying confusions in identifying objects from the categories typically affected in cases of CSA can be examined. This paradigm was designed to tap the same kind of retrieval processes that are impaired in patients with CSA, who not only have difficulty naming objects of particular categories, but also have impaired ability to retrieve diagnostic information referring to objects in these categories. The connection between learning new information about objects and tasks such as object naming and definition has already been clearly demonstrated in the performance of CSA case ELM (Arguin et al., 1996; Dixon et al., 1997, 1998). An important advantage of an episodic account is that acquisition of new information can also be investigated in normals in a laboratory setting.

Successful retrieval of a name or any learned attribute of an object depends on the ability to evoke episodic information from prior encounters with that object and to overcome competition from episodic information associated with similar objects. Thus, for example, a picture of a cow will recruit a host of episodic memories associated with cows; it will also evoke memories associated with similar objects (e.g. horses, goats—the more similar to a cow, the more evoked). In the context of a well-practised task such as naming, normal individuals quickly resolve the ambiguity among evoked memories and settle on the correct name, making it impractical to use simple naming tasks as a methodology for investigating category specific effects in normals. Learning a new attribute to classify objects under appropriate experimental conditions, however, may reveal evidence for competition between members of the categories that are especially compromised in cases of CSA for biological objects when carrying out a more conventional identification task such as naming. Classifying an object based on a new attribute that differentiates it from other members of its category therefore provides a close analogy to recalling other identity-based features of an object such as an object's name and the diagnostic attributes

listed in object definition tasks.

Object-Attribute Learning as a Method for Exploring Category Specificity

Our method, adapted in part from Stefurak and Boynton (1986) and Humphreys, Lloyd-Jones, and Fias (1995), measures the retrieval of newly learned object attributes in an incidental learning paradigm. In our task, subjects are first exposed to colored line drawings of objects from various categories in a training phase. In each trial of the training phase, a pair of differently colored objects was simultaneously and briefly displayed on the computer screen, after which participants were cued with a black-and-white line drawing of one of the objects and asked to name the color of that object in the preceding display. Unknown to subjects, each line drawing was always consistently colored. This task trained subjects to associate a particular color with a particular object under incidental learning conditions.

After training, subjects were given a surprise recall task in which they were asked to report the color associated with each object. According to our episodic framework, this task involves the recruitment and integration of information from multiple episodic records. The recall phase of the experiment should therefore be susceptible to potential interference from other category members encountered in the training phase. If the retrieval of newly learned attributes taps the same processes as are involved in object recognition, then performance in the recall phase should fit the pattern of category-specific deficits typically observed in CSA.

In the studies reported below, we examined performance in normal subjects across various natural object categories using the above procedure. In Experiment 1, we tested whether the paradigm was sensitive to category structure by comparing recall accuracy for mammals and musical instruments (two categories that cross the biological/nonbiological division, yet are both known to be highly vulnerable among patients with CSA) to accuracy for items that were both conceptually unrelated and structurally dissimilar. We also included an item set that was conceptually unrelated but *structurally similar* as a second baseline to ensure that the recall test was sensitive to conceptual as well as structural similarity. In Experiments 2 and 3, we investigated whether extraneous factors in the learning paradigm (such as the incidental nature of the learning task, within-category pairing, or poor learning) were responsible for category-specific performance on the recall task. In Experiment 4 we regressed independent ratings of the structural and conceptual pairwise similarity of items in each of the categories used in Experiments 1 through 3 on the pairwise confusion data generated in the recall phase of these experiments. This regression analysis provided supporting evidence that the combination of conceptual and visual similarity does a better job of predicting recall performance than either factor alone. In

Experiment 5, we provided a closer link to the CSA literature by comparing categories drawn from the entire range of patient performance. That experiment included two categories that are typically very poorly recognized by CSA patients (mammals and birds) and two categories on which CSA patients typically perform relatively well (furniture and clothing). In Experiment 6, we replicated these findings using texture, rather than color, as the critical attribute to demonstrate that our findings are not an artifact of some peculiarity of color per se. Finally, in Experiment 7, we extended our findings to a broader range of categories, in an effort to extend our investigation of the factors underlying performance on this task. That experiment included an error analysis of the category of fruits and vegetables and we document a close correspondence between the pattern of errors obtained for normal subjects learning color as a novel attribute and the labeling errors of the CSA patient ELM (Arguin et al., 1996).

Experiment 1

In Experiment 1, we examined the suitability of the episodic learning paradigm to investigate category specificity by comparing color recall of mammals and musical instruments to recall of items that were only structurally similar (but conceptually unrelated) and to color recall for items that were completely unrelated (both structurally and conceptually). Accuracy in the color recall phase was expected to be poorer for mammals and musical instruments than for structurally similar or unrelated objects. By our account, it is assumed that the recall task will be sensitive to the combination of structural and conceptual similarity and not merely to structural similarity alone.

Method

Subjects. The subjects tested in all experiments reported here were undergraduate students from the University of Victoria who volunteered in return for optional bonus points in an introductory psychology course. All subjects had normal or corrected vision. Twenty-five subjects were tested in Experiment 1.

Materials. A total of 40 line drawings was used, 8 from each of the four categories (mammals, musical instruments, structurally similar, and unrelated), as well as 8 practice items. Most of the line drawings were taken from the Snodgrass and Vanderwart set of normed pictures (1980). The structurally similar objects were a variety of conceptually unrelated long, narrow implements oriented at a 45-degree angle for maximal contour overlap (see Appendix 1 for a list of stimuli used). All pictures were edited to fit a presentation box 4.52 cm X 4.52 cm, and colored using Adobe Photoshop 5.0. The eight colors used in this experiment were red, green, blue, pink, yellow, brown, gray, and turquoise. All stimuli were presented on a black background with a Macintosh desktop computer using Psychlab (Bub & Gum, 1990) software. A voice key was

used to measure response latency.

Design and procedure. A within-subjects design was used, with color assignment to items within categories counterbalanced across subjects. Events for each trial in the training phase were as follows: a central fixation point for 260 ms, an inter-stimulus interval (ISI) of 500 ms, a pair of differently colored line drawings of two objects from one of the four categories for 260 ms, an ISI of 106 ms, a white pattern mask for 60 ms, an ISI of 260 ms, a cue consisting of a white line drawing of one of the previously viewed objects. Upon seeing the white object, subjects were given 1500 ms to respond with the color in which that object had appeared in the preceding pair of stimuli, after which the white line drawing disappeared and a beep indicated that the trial was over. The next trial began after a 500-ms pause.

Subjects first completed an initial practice block of 32 trials with a practice set of objects that changed color every time they were presented. Each test object was then briefly presented in white and named by the experimenter, to familiarize the subject with the stimuli. Subjects then completed four training blocks, in which each object was presented twice per block, once as the cued item and once as the noncued item. Thus subjects viewed each colored object eight times. The objects in the training phase were consistently colored. Object pairs were presented one above the other and randomly to the right or left of a central fixation dot to make the task perceptually demanding. Cued and noncued items appeared equally often in the upper and lower locations. A voice key recorded response latencies for each trial, and the experimenter recorded the subject's response on a keyboard.

After completing 128 training trials, the subject was informed that some of the objects might have been consistently colored. The experimenter asked whether the subject had noticed this, and then asked the subject to estimate how many of the objects were consistently colored. Subjects were then informed that all 32 objects were consistently colored, and asked to complete a surprise object-color association recall task. In the recall task, the 32 white objects were presented one at a time in random order in the middle of the computer screen, and the subject attempted to recall the color associated with each object. Subjects were told to guess if they did not recall a color. No deadline was used in this recall test, and stimuli remained on the screen until a response was given.

Results

A 60% accuracy level on the last block of the training phase was established as a criterion for inclusion in the study. Of the 25 subjects, 24 reached criterion and were included in the study. We discuss the results in two subsections: the training phase, in which subjects learned a new color attribute for each object, and the recall phase in which we expected category-specific patterns of results in retrieval of color-form associations across episodes.

Training phase. Separate one-way repeated measures

analyses of variance (ANOVA) were performed on accuracy and response times for the last block of the training phase. Alpha level was set at .05 for all statistical tests, with a Bonferroni adjustment for multiple pair-wise post hoc tests. For Experiment 1 and subsequent experiments, trials in which subjects failed to respond within the 1500-ms deadline were coded as errors. Trials in which response times fell below 300 ms (1.6% of block 4 trials across all experiments) were excluded from all analyses. Reaction time analyses were based on the remaining correct trials only.

By the fourth block of training, accuracy was high for all four categories (mammals: 84%, instruments: 89%, structurally similar: 90%, unrelated: 94%). A one-way repeated measures ANOVA revealed an effect of category, $F(3, 69) = 3.16$, $MSE = 1.21$, $\eta^2 = .121$. Post hoc pair-wise comparisons yielded only an advantage for unrelated items over mammals. Similar category effects were found in an ANOVA on block 4 mean response times, $F(3, 69) = 3.41$, $MSE = 4,382$, $\eta^2 = .129$. Post hoc pair-wise comparisons revealed an advantage for unrelated items ($M = 745$ ms) relative to mammals ($M = 790$ ms) and instruments ($M = 802$ ms).

Recall test. Of the 24 subjects, 18 reported that they had noticed that at least some of the line drawings were consistently colored, but the average estimate of the percentage of objects that were colored consistently was only 33% ($SD = 23$). The mean recall accuracy and the associated 95% within-subjects confidence intervals (Loftus & Masson, 1994) are displayed graphically in Figure 3, and statistical tests for the recall phase are reported in Appendix B. For Experiment 1 and subsequent experiments, planned repeated contrasts were conducted with the alpha level set at .05. As Figure 3 shows, color recall was best for unrelated objects ($M = 81\%$), followed by structurally similar objects ($M = 70\%$). Performance was substantially worse for mammals and instruments, which did not reliably differ from one another ($M = 39\%$ and 36% , respectively). The difference in recollection between structurally similar (but conceptually unrelated) items and the two conceptually related categories was almost three times greater than the difference between structurally similar items and the unrelated category.

Discussion

The training phase was highly sensitive to perceptual factors presumably due to the brief time available to disambiguate the two stimuli and bind color to form. This was evident in an overall advantage in both accuracy and response time measures for unrelated items, the only category that was structurally dissimilar. The training task was relatively insensitive to conceptual factors (i.e., no differences between the coherent conceptual categories and the visually similar, conceptually unrelated category).

More striking, in the episodic recall task, normal observers had difficulty retrieving newly learned color associations for musical instruments and mammals, analogous to the recognition deficits displayed by most

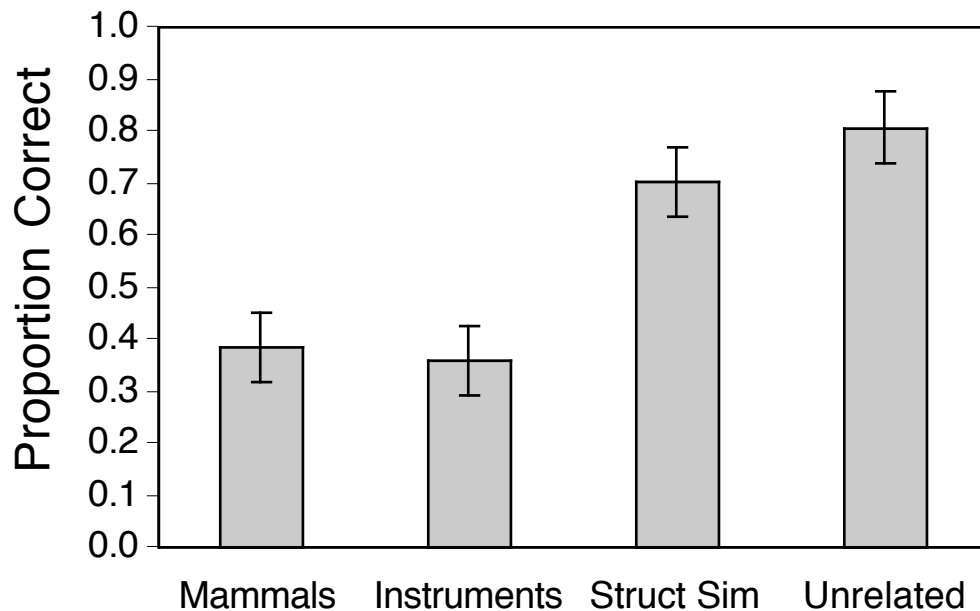


Figure 3. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 1.

patients with CSA. One possible explanation for these results is that uncontrolled stimulus variables such as familiarity and visual complexity were responsible for the poor color recall of mammals and musical instruments relative to the unrelated category. In another version of this task, however, in which the unrelated and mammal categories were matched for these factors, recall of the unrelated category remained very high (78%), whereas color recall of mammals remained low (46%). Moreover, the deficit in the episodic recall task was not due to structural similarity alone, as recall accuracy for items that were only structurally similar was nearly double that for mammals and musical instruments. This is consistent with the hypothesis that object categories that share both conceptual and structural features are more vulnerable to interference from other activated category exemplars (Arguin et al., 1996; Humphreys, Riddoch, & Quinlan, 1988; Vitkovitch et al., 1993). We provide more evidence for this interpretation in Experiments 4 and 7.

The results of the recall task support the utility of our episodic learning paradigm as a method for examining category specificity with normal individuals. Category-specific effects emerged when recall depended on retrieval of object information from memory in the context of multiple encounters with similar objects. The pattern of performance in the recall test contrasts with that found in the training phase, in which accuracy and response times were not reliably different for musical instruments, mammals, and objects that were only structurally similar. Whereas the training phase involves an immediate response to only one of a pair of items, with no intervening trials, the

recall test requires the subject to retrieve the color of a particular exemplar from the entire set. Consequently, subjects must distinguish memories of one item from memories of the other seven in the set (as opposed to distinguishing between only the target and distractor items in the training phase). Because the recall test is subject to competition from all category exemplars included in the experiment, this paradigm is well suited to examining category specificity with normal subjects.

Experiment 2

Experiment 1 showed a large deficit in episodic retrieval of incidentally learned attributes for mammals and musical instruments, relative to categories that share only structural similarity or are both structurally and conceptually distinct. To obtain a better understanding of the nature of the circumstances in which these category effects emerge, we investigated whether the results obtained using an intentional learning paradigm would be comparable to those found in the incidental learning task of Experiment 1. Our working assumption was that the learning task would have to be sufficiently demanding to avoid ceiling performance levels on the subsequent recall task. The encoding task was designed to elicit relatively superficial encoding by using a brief exposure duration and imposing a response deadline. We also conjectured that an incidental learning paradigm would ensure that subjects would be unlikely to apply strategies in their effort to learn color-form bindings, as previous research has suggested that memory for bound item and color is poorer after incidental color encoding than

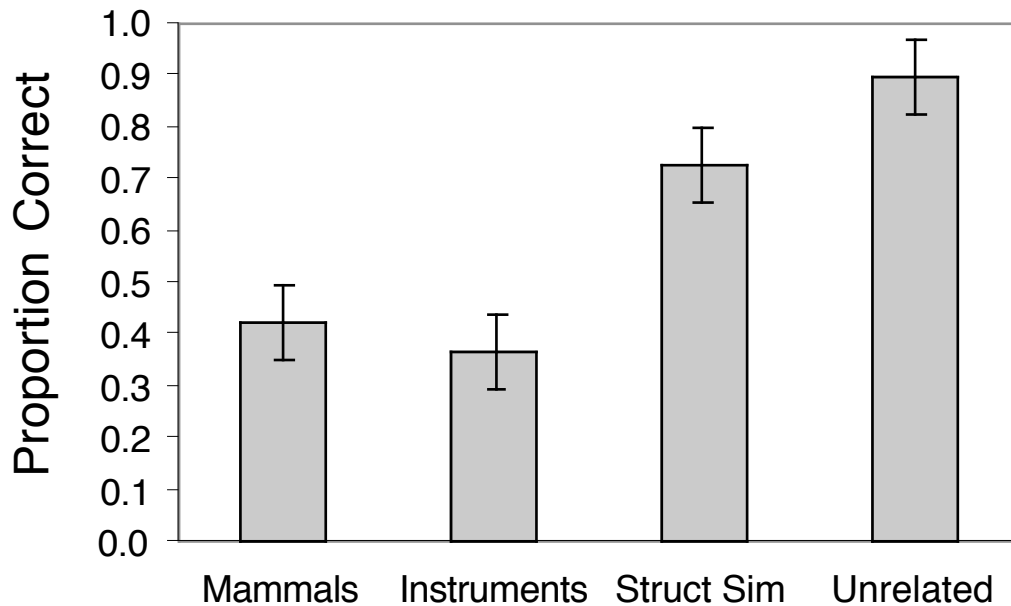


Figure 4. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 2.

intentional color encoding (Chalfonte & Johnson, 1996). In Experiment 2, we told subjects in advance that color-form associations would be consistent, and that there would be a recall test at the end of the training phase. We anticipated that this intentional learning paradigm would boost performance on the recall test. The question of central interest was whether the category effects observed in Experiment 1 would nonetheless be obtained.

Method

Subjects. Sixteen subjects were tested.

Design and procedure. The materials and procedure of Experiment 2 were the same as those of Experiment 1, with the exception that subjects were informed after the practice phase that all of the items in the training phase would be consistently colored and that following the training phase they would be tested on their ability to recall the colors of the 32 objects.

Results

All 16 subjects exceeded the 60% accuracy criterion for block 4 of the training phase. We again present the results of the training phase and recall phase separately, and in addition we present the comparison of Experiment 1 and 2 in a third subsection.

Training phase. Block 4 training accuracy was similar to that of Experiment 1: Mean accuracy ranged from 83% to 92%, indicating that colors and forms were adequately perceived and perceptually bound. Statistical tests revealed

an effect of category, $F(3, 45) = 2.99$, $MSE = 0.99$, $\eta^2 = .166$, but post hoc tests again revealed only a marginally significant superiority of unrelated items relative to mammals, $p = .08$. This pattern was evident in response time measures as well: There was a significant effect of category, $F(3, 45) = 6.15$, $MSE = 5,915$, $\eta^2 = .291$, with a large advantage for unrelated items ($M = 773$ ms) relative to mammals ($M = 870$ ms) and instruments ($M = 877$ ms).

Recall test. Figure 4 displays the mean accuracy and confidence intervals for the recall test of Experiment 2. Statistical results of the planned contrasts are reported in Appendix B. The episodic recall test showed large category differences in retrieval of color associations. As Figure 4 shows, unrelated items were very accurate (90%), structurally similar objects were less accurate (73%), and mammals and instruments were least accurate (42% and 37%, respectively).

Comparison to Experiment 1. Accuracy and response time measures for block 4 of the training phase were compared to those of Experiment 1 in a 2 (experiment) X 4 (category) mixed factorial ANOVA. No significant differences in accuracy were found. In the response time analysis, the main effect of experiment was significant, $F(1, 38) = 4.38$, $MSE = 32,314$, $\eta^2 = .103$. Responses during the training phase were significantly slower in the intentional learning condition (Experiment 3, $M = 839$) than in the incidental learning condition (Experiment 1, $M = 778$). Despite the differences in response times for the training phase, a similar analysis of accuracy in the recall test revealed no significant differences between intentional and incidental learning.

Discussion

Converting the experiment from an incidental learning paradigm to an intentional learning paradigm did not affect accuracy or category effects in the recall of color associations. The longer reaction times in the intentional training phase suggest that subjects dedicated more processing time to association binding, but this did not result in significant improvement on the recall test. Presumably, the conditions of the training phase were sufficiently demanding that subjects could not profit from explicit instructions to learn the object-color pairs, and were unable to overcome the retroactive interference from structurally and conceptually related category members. These results contrast with those of Chalfonte and Johnson (1996), perhaps because in their incidental learning condition the color dimension was completely ignored, whereas in our incidental training condition subjects had to attend to both color and form. Our results are concordant with Wattenmaker's (1999) finding that the influence of prior knowledge and conceptual relatedness does not differ between intentional and incidental concept learning tasks. The category effect found in episodic recall of learned attributes thus is quite robust, and suggests that confusions of attributes among objects that are both structurally similar and conceptually related emerge naturally from the way episodes are retrieved by people with normal cognitive functioning.

Experiment 3

We hypothesized that category-specific effects in our episodic recall paradigm occur as a result of confusions during retrieval. Errors in color recall are also likely to be related to object-color encoding during training, however, which raises the possibility that our results reflect category-specific differences in encoding during training rather than in retroactive interference during recall. Because the training items were paired within-category, similarity (structural and conceptual), or contiguity, or some combination of the two might have made the training task harder for mammals and instruments than for the other categories, and this in turn might have resulted in weaker color-form associations for mammals and instruments. The dissociation between training-task and recall performance in Experiments 1 and 2 challenges this account, but Experiment 3 eliminated it by randomly pairing all items across categories during training, with the constraint that an item never appeared with another exemplar from its own category. Stimulus pairs in all training trials were therefore both structurally and conceptually distinct, which should make the training task relatively easy and, more importantly, equates the difficulty of the training task across categories during learning.

Method

Subjects. Twenty-one subjects were tested.

Materials and procedure. The materials and procedure of Experiment 3 were the same as those of Experiment 1, with the exception that items were paired across category during the training phase.

Results

All 21 subjects exceeded the 60 % accuracy criterion for block 4 of the training phase.

Training phase. Block 4 training accuracy was high for all categories: Mean accuracy ranged from 89% to 92%, indicating that color-form associations were perceptually bound. An ANOVA revealed no differences in accuracy between categories. There was a significant effect of category for Block 4 response times, $F(3, 60) = 3.47$, $MSE = 5,517$, $\eta^2 = .148$, with faster response times for unrelated items ($M = 725$ ms) than for mammals ($M = 796$ ms).

Recall test. Figure 5 displays the mean accuracy and confidence intervals for the recall test of Experiment 3. Statistical outcomes of the planned contrasts are presented in Appendix B. As in previous experiments, there were large category effects in episodic retrieval of color associations. As Figure 5 shows, unrelated items were most accurate (82%), structurally similar objects were less accurate (59%), and mammals and instruments were least accurate (28% and 27%, respectively).

Comparison to Experiment 1. Accuracy and response time measures for block 4 of the training phase of Experiment 3 were compared to those of Experiment 1 in a 2 (experiment) X 4 (category) mixed factorial ANOVA. There was no significant difference in block 4 accuracy or response time between Experiments 1 and 3. Recall accuracy for Experiments 1 and 3 also was not significantly different.

Discussion

Training accuracy was virtually identical for all four categories, but recall of color associations for mammals and musical instruments was very poor relative to the other categories. This dissociation between training and recall is consistent with that found in Experiments 1 and 2. The persistent disadvantage for mammals and musical instruments in the recall stage therefore emerges from confusion *across* similar episodes during episodic retrieval. Thus we can be certain that the recall errors were not due to encoding factors such as poorer learning or pair-wise contiguity for mammals and instruments in the training phase. Rather, the locus of interference effects is in the process of retrieving object attributes from memory for past episodes.

Experiment 4

So far, we have assumed that the sets of objects we have selected differ in specified ways with respect to their structural and conceptual relatedness. If these assumptions

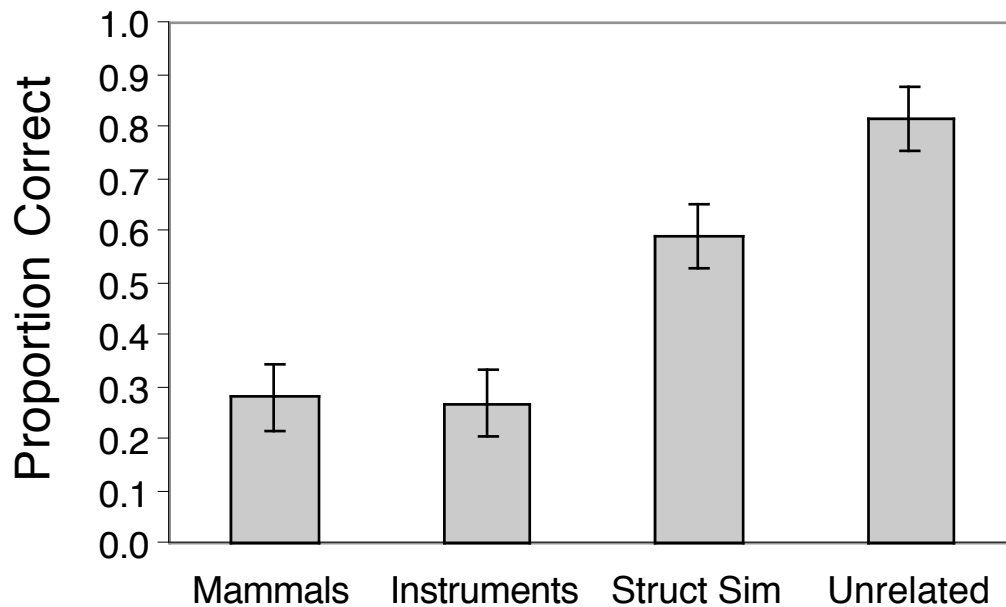


Figure 5. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 3.

are correct, then the findings of Experiments 1-3 suggest that it is more difficult to recall attributes of objects from categories that are both structurally and conceptually similar than it is to recall attributes of objects from categories that are structurally similar but conceptually unrelated, or from categories that are both structurally and conceptually unrelated. This pattern of results is consistent with the hypothesis that recall of object information from categories that share both conceptual and structural features is highly vulnerable to interference from other studied category exemplars. In the next experiment we obtained further evidence for this claim by taking a closer look at the nature of errors produced in Experiments 1-3 and their relationship to independent ratings of the structural and conceptual similarity of objects within each of the categories. We first gathered pairwise ratings of the structural and conceptual similarity for objects within each of the four categories used in the prior experiments. We then used a regression analysis to test whether structural similarity and conceptual similarity both make significant contributions to the pattern of confusions produced in the color recall phase of Experiments 1-3.

Method

Subjects. Two groups of 20 subjects each participated in the structural and conceptual ratings conditions. None of the subjects participated in any other the other experiments presented in this paper.

Materials. The stimuli from Experiments 1 through 3 were converted to black line drawings on a white background to obtain structural similarity ratings. Black

words on a white background were used to obtain conceptual ratings.

Design and procedure. For both structural and conceptual ratings, trials consisted of all possible pairwise combinations of items within each category (28 trials per object category, for a total of 112 trials). Subjects were instructed to rate the similarity of the two line drawings (structural condition) or two words (conceptual condition) presented on each trial using a scale from 1 to 7, with 1 indicating very dissimilar pairs, and 7 indicating very similar pairs. Members of pairs were presented simultaneously side-by-side on the screen, and items appeared randomly to the right or left. A numerical scale from 1 to 7 with the anchor points labeled “dissimilar” and “very similar” was also displayed on each trial. Subjects indicated their response by pressing the appropriate number key on the keyboard. Subjects were given unlimited time to respond, and stimuli remained on the screen until a response was given. Order of trials was random.

Because of the difficulty in getting “pure” measures of structural and conceptual similarity (structural ratings are likely to be influenced by conceptual factors and vice versa), we developed instructions specifically designed to ensure that structural ratings reflected *mainly* structural factors, and conceptual ratings reflected *mainly* conceptual factors (see Carr et al., 1982, for a similar procedure). In the structural ratings condition, subjects were instructed to rate the visual similarity of object pairs independent of how conceptually related the two objects might be. They were further instructed to consider only the structural properties of the line drawings, ignoring all other knowledge of the objects such as color, texture, function, and any other

Table 1

Summary of the Step-wise Forward Regression Analysis of Structural and Conceptual Pairwise Similarity Ratings on Pairwise Confusion Probabilities in the Recall Data of Experiments 1 to 3.

	Model Statistics			Standardized Coefficient Statistics		
	F	p	R ²	β	t	p
Model 1	137.4	<.001	.555			
Conceptual Similarity				.754	11.7	<.001
Model 2	91.4	<.001	.626			
Conceptual Similarity				.650	10.5	<.001
Structural Similarity				.283	4.6	<.001
Model 1 vs. Model 2	20.7	<.001	.071			

Note. Statistics for Model 1 and for Model 2 represent tests of the overall model. Predictors included in the respective models and their associated statistics are listed directly below each model. Statistics for Model 1 vs. Model 2 represent change statistics, and are a test for the improvement of a model including only conceptual similarity to one that includes both conceptual and structural similarity (F change, R² change, and their associated probability value).

conceptual information. Likewise, in the conceptual ratings condition, subjects were instructed to rate the conceptual similarity of the word pairs independent of how visually similar the two items might be. They were told to ignore any visual similarity the two objects may have in common, but to consider such factors as whether the two objects are associated in their experience, whether they are treated in similar ways or tend to be used to perform similar functions, and whether they are members of the same category.

Recall data from Experiments 1 through 3 were aggregated to produce pairwise confusion probabilities for each possible item pair within the four object categories. Each incorrect color response was recoded to the name of the object (from within the same category) that was associated with that color during training. For example, if the line drawing of the goat was colored red and the line drawing of the cow was colored blue in the color-training phase, an incorrect response “goat – blue” generated during recall would then be recoded “goat – cow”. An 8 X 8 confusion matrix for each category was constructed showing the probabilities of confusing an item with every other exemplar in its category (frequency of errors/N, where N = 61). Both halves of the matrix were then summed to yield a set of 28 pairwise confusion scores for each category. Each cell therefore represents the probability, given one member of a pair, of incorrectly producing the color of the other object in the pair, or vice versa. In other words, each pairwise datum represents the probability that two items will be confused during recall. These probabilities reflect accuracy differences both between items and between categories. Moreover, pairwise confusion data are a much

finer-grained analysis than either of these two measures and therefore the ability of structural and conceptual ratings to predict these data is a particularly strong test of our hypothesis.

Results

The structural and conceptual pairwise ratings data were regressed onto the combined pairwise confusion data from the recall phase of Experiments 1 through 3 using a forward regression procedure with probability to enter set at $p < .05$. This procedure enters each predictor in a stepwise fashion providing it meets the criterion for entry, starting with the variable that is most strongly correlated with the dependent variable, and at each new step adding the predictor that, from the remaining predictors, has the largest partial correlation with the dependent variable. We did not include an interaction term in the regression analysis as our theory does not specify what statistical form the interaction should take. Rather, we tested the more general claim that both structural and conceptual factors should account for unique variance in recall performance. The statistics for the resulting models are presented in Table 1. Conceptual similarity was most correlated with recall data, accounting for 55% of the variability. Importantly, however, the addition of structural similarity to this model accounted for a further, significant amount of variability ($p < .001$). Together, these two predictors accounted for 63% of the variability in the recall confusion data, providing clear evidence that a model including both structural and conceptual similarity factors does a better job of predicting

pairwise recall confusions than either of these factors alone.

Discussion

The results of the regression analysis show that both structural and conceptual similarity are important factors in attribute recall, and support our claim that retrieval of object knowledge is susceptible to interference from prior episodes with other objects that share a high degree of structural and conceptual overlap. We note that although we attempted to obtain pure estimates of conceptual and structural similarity using ratings, it is likely that subjects were not able to provide pure assessments of these dimensions. For example, previous work using multidimensional scaling of similarity ratings of animal names has consistently shown primary dimensions that are both perceptual and conceptual in nature, such as size and ferocity (Chan, Butters, Paulsen, Salmon, Swenson, & Maloney, 1993; Cooke, 1990; Henley, 1969). Such primary dimensions may be very difficult to ignore even under specific instructions to do so, and thus either structural or conceptual measures of similarity based on subjective ratings probably include elements of both types of knowledge. Consistent with this idea, we found that our two measures of similarity were significantly correlated ($r(110) = .34$). We should be cautious, therefore, in interpreting the relative contributions made by each of these measures to statistical prediction of the recall data. Despite this limitation, the fact remains that both types of similarity make unique contributions in accounting for the pattern of recall successes and errors.

Importantly, the principle underlying the recall of object attributes in our task (both conceptual and structural similarity contribute to errors) has also been shown to operate in a picture-word matching task with CSA patient ELM (Arguin et al, 1996). The similarity of our findings to this prior research provides further evidence for the utility of our episodic recall paradigm as a laboratory analogue to at least certain forms of CSA and its ability to shed light on processes of normal object recognition.

Experiment 5

Experiments 1-4 showed a “natural” difficulty in episodic retrieval of learned attributes for mammals and musical instruments, in the absence of any neurological damage. These category effects were independent of learning paradigm (incidental vs. intentional) and level of difficulty during encoding. Conclusions regarding the relationship between normal performance in this episodic retrieval paradigm and object recognition of patients with CSA are constrained, however, by the fact that we included only two semantically coherent object categories (mammals and instruments) in Experiments 1-4. In Experiment 5, we attempted to establish a clearer relationship between these two phenomena by examining performance across a broader range of categories. We therefore included both biological

and nonbiological categories that are typically dissociated among patients with CSA. We based our choice of categories both on our summary of cases and on the “double dissociation” reported by Hillis and Caramazza (1991), such that categories clearly dissociated in both instances. We included birds and mammals as biological categories, and furniture and clothing as nonbiological categories. If our task is sensitive to factors underlying CSA of the biological type, then recall of color attributes for birds and mammals should be poor relative to recall of color attributes for furniture and clothing. We also used two different drawings of each object (e.g., two owls), to reduce the likelihood that category-specific effects were due merely to specific aspects of the objects' structural form.

Method

Subjects. Sixteen subjects were tested.

Materials. In addition to the eight practice exemplars used in Experiments 1–4, stimuli consisted of two sets of eight line drawings in each of the following categories: birds, mammals, furniture, and clothing. Individual items were chosen according to the following criteria: bird exemplars had to be nameable at the “basic level” (cf. Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) and had to be easily distinguishable from one another. Furniture and clothing exemplars were chosen to maximize coherence within the category, so that performance would not be artificially inflated. Therefore, distinctive exemplars such as ashtray, doorknob, and lamp (for furniture) and belt, ring, and watch (for clothing) were avoided. See Table A2 in Appendix A for a complete list of stimuli. Two sets of line drawings were used (counterbalanced across subjects) to avoid stimulus specific effects. All line drawings were designed to match the quality of the Snodgrass and Vanderwart (1980) set.

Design and procedure. The design and procedure of Experiment 5 were the same as those of Experiment 1.

Results

All 16 subjects exceeded the 60% accuracy criterion for block 4 of the training phase.

Training phase. Block 4 training accuracy was highest for clothing ($M = 88\%$), followed by furniture ($M = 84\%$), birds ($M = 79\%$) and mammals ($M = 76\%$). Statistical tests of the accuracy data revealed a marginally significant effect of category, $F(3, 45) = 2.71$, $MSE = 1.9$, $p = .056$, $\eta^2 = .153$, but post hoc tests failed to reveal a significant difference between clothing and mammals. Response time means did not significantly vary by category.

Recall test. Mean accuracy and confidence intervals for the recall test of Experiment 5 are displayed in Figure 6. Results of the planned contrasts can be found in Appendix B. As is evident in Figure 6, recall of color associations for birds and mammals ($M = 30\%$ and 27% , respectively) was significantly poorer than color recall for either furniture or clothing ($M = 51\%$ and 63%).

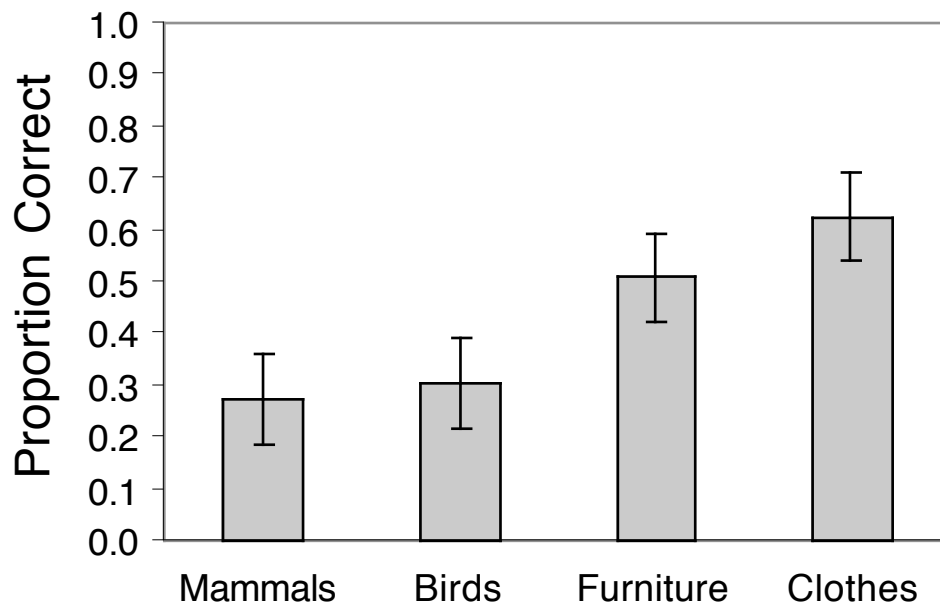


Figure 6. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 5.

Discussion

The results of the recall test were clear: not only was recall of biological categories significantly poorer than either of the nonbiological categories, the ordering of individual categories within these dichotomies matched that shown in Figure 2 as well, with birds slightly more accurate than mammals, and clothing substantially more accurate than furniture. The alignment of performance across categories between patients with CSA of the biological type and normal subjects on the recall task strongly suggests that common factors underlie both phenomena. We also noted that the pattern of accuracy in the training phase of Experiment 5 was similar to the pattern of accuracy in the recall phase. We have shown in Experiment 3, however, that performance on the learning phase cannot account for performance on the recall test. Nonetheless, to confirm that this dissociation holds for these particular categories, we reverted to a cross-category pairing design in the training phase of Experiment 6.

Experiment 6

Thus far, we have shown that an episodic recall paradigm of newly learned color associations is capable of producing category-specific recall deficits among normal subjects analogous to those present among patients with CSA of the biological type. We have also found evidence that these confusions occur during the retrieval of color information from past episodic encounters, and can be accounted for by a combination of structural and conceptual similarity

between exemplars. It is yet unclear, however, whether category specificity is a property of newly learned attribute retrieval in general, or is peculiar to color. For example, it may be argued that biological objects tend to have more consistent or stronger real-world color associations. In Experiment 6, therefore, we attempted to replicate the findings of Experiment 5 using texture associations so that we could test the generalizability of category-specific recall to object attributes other than color. The textures used were visual patterns that bore no resemblance to surface qualities inherent in the biological objects or in the majority of the nonbiological objects included in the experiment. We also employed cross-category pairing in Experiment 6, as we did in Experiment 4, to confirm that the category-specific recall was due to interference at retrieval, not to object pairings learned in the training phase.

Method

Subjects. Twenty-four subjects were tested.

Materials. The stimuli were grayscale versions of the exemplars from Set 2 of Experiment 5. Stimuli were textured with each of eight greyscale textures using various filters from Photoshop®5.0. A texture palette was designed to collect subjects' responses. The texture palette was 24 cm long by 3 cm high, and consisted of a row of 3-cm squares of each texture separated by thin black lines. Eight different texture palettes were created showing each of the textures in a different random order. Figure 7 shows a sample texture palette. The experiment was programmed using RSVP 4.0.5 software (Williams & Tarr,), so that mouse click responses

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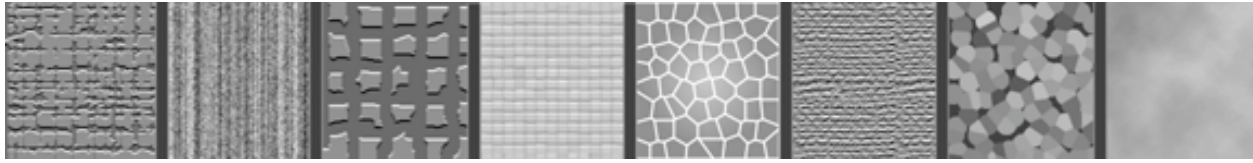


Figure 7. Sample texture palette used in Experiment 6.

could be collected.

Design and procedure. Assignment of items to textures was counterbalanced across subjects. Events in the training phase were as follows: a central fixation point for 250 ms, a pair of differently textured stimuli from different categories for 1500 ms to allow adequate processing of the stimuli, a pair of pattern masks for 60 ms, a cue consisting of a white line drawing of one of the previously viewed objects presented centrally, with a texture palette presented simultaneously at the bottom of the screen. Assignment of the eight different texture palettes (representing eight different random orderings of the eight textures) to each item in a category was randomized for each training block. Upon seeing the white object and texture palette, subjects were given 5,000 ms to move the mouse cursor over the appropriate texture box and make a mouse click response, after which the white line drawing and texture palette disappeared and a beep indicated that the trial was over. The next trial began after a 500-ms pause.

Subjects first viewed all eight textures using eight textured practice items, and indicated the texture of each item by pointing to the appropriate texture in the texture palette. Subjects then completed two initial practice blocks of 16 trials each, with accuracy feedback after each block. If accuracy in the second block did not exceed 12/16, another block of 16 practice trials was given to a maximum of four training blocks. Prior to the training phase, all experimental objects were briefly presented as nontextured white line drawings and named by the experimenter, to familiarize the subject with the stimuli. Subjects then completed six training blocks in which each object was presented once as a cued item and once as a distractor. The objects in the training phase were consistently textured. Objects were paired with exemplars from different categories, and were presented to the left and right of the fixation point. Cued and noncued items appeared equally often in the left and right locations.

The design and procedure of the recall phase of the experiment were the same as in prior experiments, with the exceptions that the white nontextured objects appeared with a texture palette and responses were collected via a mouse click.

Results

All 24 subjects exceeded the 60% accuracy criterion for block 6 of the training phase.

Training phase. An ANOVA on block 6 training

accuracy revealed a significant effect of category, $F(3, 69) = 4.34$, $MSE = 1.29$, $\eta^2 = .159$. Post hoc tests approached significance only for the comparison of birds ($M = 85\%$) and clothing ($M = 77\%$), $p = .07$. Response times for mouse clicks were not analyzed.

Recall test. Figure 8 displays the mean accuracy and 95% confidence intervals for the recall test of Experiment 6. Results of the planned contrasts are presented in Appendix B. As predicted, the pattern of texture recall matches that of Experiment 5, with accuracy for mammals and birds ($M = 34\%$ and 33%) significantly poorer than accuracy for either furniture ($M = 45\%$) or clothing ($M = 53\%$).

Discussion

Experiment 6 replicated category-specific effects in episodic recall of newly learned texture attributes. Thus category specificity in normal individuals is not an artifact of color typicality, but seems rather to be driven by factors involved in retrieving object information across similar prior episodes. Performance in the learning phase, in which clothing textures were the most poorly reported, clearly did not predict accuracy in the recall test, in which clothing textures were the most accurately recalled. The data in Experiment 6 are consistent with those of Experiment 3, in which cross-category pairing also failed to attenuate category specificity of recall in the final phase of the experiment. Experiment 6 thus provides additional evidence that category-specific interference emerges from similarity across individual episodes at the time of retrieval. The fact that attributes of objects in the clothing category are consistently better recalled than attributes of items in the furniture category for both patients with CSA of the biological type and in these experiments with normal subjects supports the hypothesis that a common set of factors underlies both phenomena.

Experiment 7

We have previously questioned the utility of a simple dichotomous distinction between biological and nonbiological items. Recall performance in our paradigm, as well as object identification performance of patients with CSA of the biological type, show that there is variation within as well as between this dichotomy. As noted earlier, the errors made by CSA patients of the biological type suggest that the categories most affected by this type of

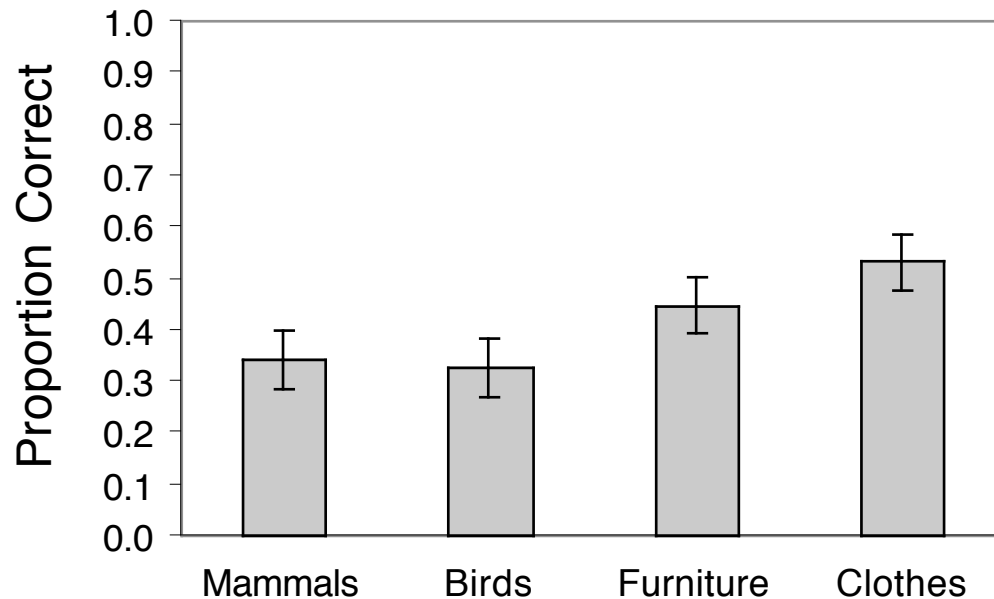


Figure 8. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 6.

brain damage are those that are both structurally and conceptually similar (Arguin et al., 1996; Humphreys et al., 1988). The results of Experiments 1-3 also indicated that retrieval of attribute associations in normal episodic recall is more difficult for conceptually and structurally similar categories than for categories that are only structurally similar, or that are unrelated both structurally and conceptually. Experiment 4 provided further evidence for the combined role of structural and conceptual factors in predicting pairwise confusions in our episodic recall task. This result is reminiscent of the pattern found in the picture-word matching performance of CSA patient ELM. A detailed analysis of his confusion data to the category of fruits and vegetables also revealed the importance of structural dimensions in producing semantic errors. Arguin et al. (1996) found that the category of fruits and vegetables is ideally suited for this kind of analysis, because one can easily classify these items on a structural dimension (round vs. long, for example) as well as a conceptual dimension (fruit vs. vegetable). We therefore included the category of fruits and vegetables in Experiment 7 so that confusion data within this category could be coded explicitly for structural and conceptual dimensions. This provides another strong test of our hypothesis, and has the additional benefit of having a complete 2 (long vs. round) by 2 (fruit vs. vegetable) crossed design. If confusions are indeed driven by the interaction of structural and conceptual similarity in episodic recall, then subjects should tend to misremember the color in which one category exemplar had been studied as the color in which a structurally similar member of that same conceptual category had been studied. As in prior experiments, we also included other object categories

(mammals, kitchen utensils, and unrelated items) to prevent performance on the recall task from reaching ceiling.

Experiment 7 was also designed to provide further evidence that category specificity is not due to color typicality. We regressed recall accuracy for Experiment 7 onto color typicality ratings for each of the objects used in the experiment to determine whether any relationship exists between the ability to learn an arbitrary color association to an object that has a naturally occurring diagnostic color.

Method

Subjects. Twenty-seven subjects were tested. An additional 51 subjects filled out color typicality rating forms.

Materials. Most of the line drawings used in Experiment 7 were from Snodgrass and Vanderwart (1980). Drawings of the remaining items were commissioned to match the quality of the Snodgrass and Vanderwart set. Practice and unrelated items were the same as those used in Experiment 1. Eight kitchen utensils were chosen to comprise a coherent nonbiological set that shared a high degree of structural and conceptual similarity. The fruit and vegetables category included four fruits and four vegetables, with two of each of these being long and the other two round, so that errors could be examined for a structural (long vs. round) and conceptual (fruit vs. vegetable) interaction. To make the mammal set more similar to the fruit and vegetables, we replaced four of the items used in previous experiments to make two subsets of mammals (large vs. small). A complete list of stimuli is found in Table A3 in Appendix A. Colors were the same as in Experiment 1.

Design and procedure. The design and procedure for the

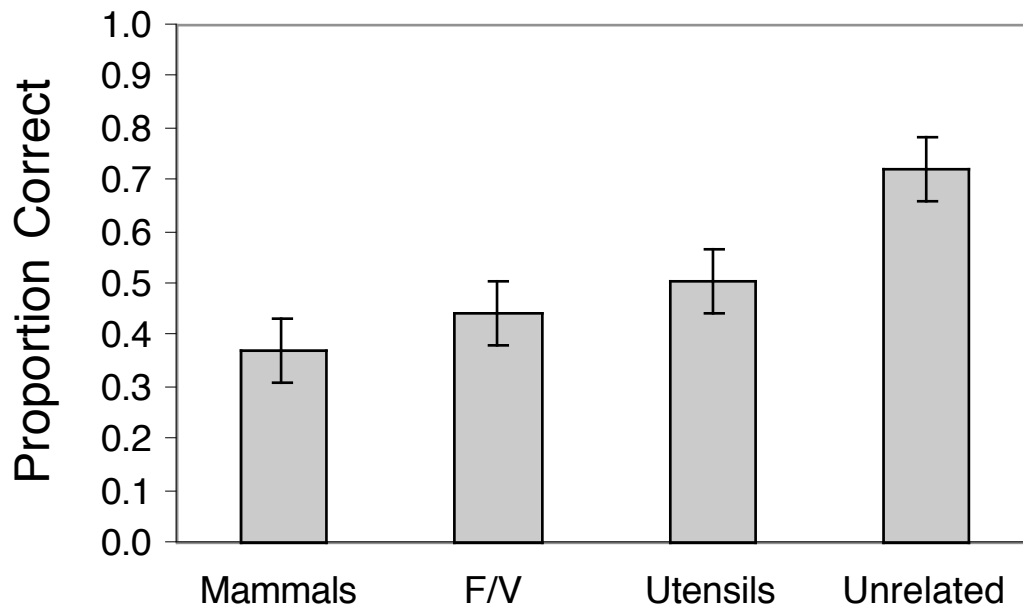


Figure 9. Mean proportion correct and 95% within-subjects confidence intervals for the color recall phase of Experiment 7.

training phase and recall test of Experiment 7 were the same as those of Experiment 1, except that fruits and vegetables and kitchen utensils were used in place of musical instruments and structurally similar items.

To analyze the recall errors for the fruit and vegetable category, each incorrect color response was recoded to the name of the fruit or vegetable associated with that color during training, as was done in Experiment 4. The errors were then classified along two dimensions: conceptually related versus unrelated (Con+ vs. Con-) and structurally similar versus dissimilar (Str+ vs. Str-). Errors were considered conceptually related if they came from the same fruit or vegetable subset as the probe (fruit error response to fruit probe, vegetable error response to vegetable probe). In the same way, errors were classified as structurally similar if the error came from the same structural subset as the probe (long error response to long probe, round error response to round probe). Calculation of chance probabilities differed for each error type and probe type due to unequal numbers of errors made to each of the stimuli, as well as unequal numbers of stimuli in the Str+ and Str- conditions; these calculations are explained in detail in Appendix C.

For the color typicality ratings, 51 respondents were given questionnaires that listed all of the items used in Experiment 7. Respondents were instructed to list all of the colors typically associated with each of the items listed on the questionnaires. They were told that some items may have only a few colors associated with them while others may have many (for example, milk may have only the color white associated with it, while juice may have the colors yellow, red, orange, purple, and green associated with it).

Results

For the episodic recall task, one subject was excluded due to participation in a previous version of the experiment. Two others failed to meet the 60% accuracy criterion for block 4 of the training phase. Data analysis was based on the remaining 24 subjects.

Training phase. By block 4, accuracy was quite high for all four categories, ranging from 80% to 88%. Statistical tests revealed no significant differences in accuracy among the four categories. As in previous experiments, the response time measure produced a main effect of category, $F(3, 69) = 4.60$, $MSE = 5,588$, $\eta^2 = .167$. Post hoc analyses revealed an advantage of unrelated items ($M = 748$ ms) relative to mammals ($M = 822$ ms).

Recall test. Mean recall accuracy and 95% confidence intervals for Experiment 7 are displayed in Figure 9. Results of the planned contrasts are presented in Appendix B. As Figure 9 shows, accuracy was best for unrelated items ($M = 72\%$), followed by kitchen utensils ($M = 51\%$), and then by fruits and vegetables and by mammals ($M = 44\%$ and 37% , respectively). Planned contrasts revealed that, as predicted, color recall for fruits and vegetables did not reliably differ from color recall for mammals. In addition, color recall for kitchen utensils was significantly poorer than that for unrelated items.

Error pattern for fruits and vegetables. Figure 10 shows the error pattern for color recall for the fruits and vegetables, along with estimates of the chance base rates for such errors. As the confidence intervals in Figure 10 show, only errors that were both conceptually and structurally similar to probes

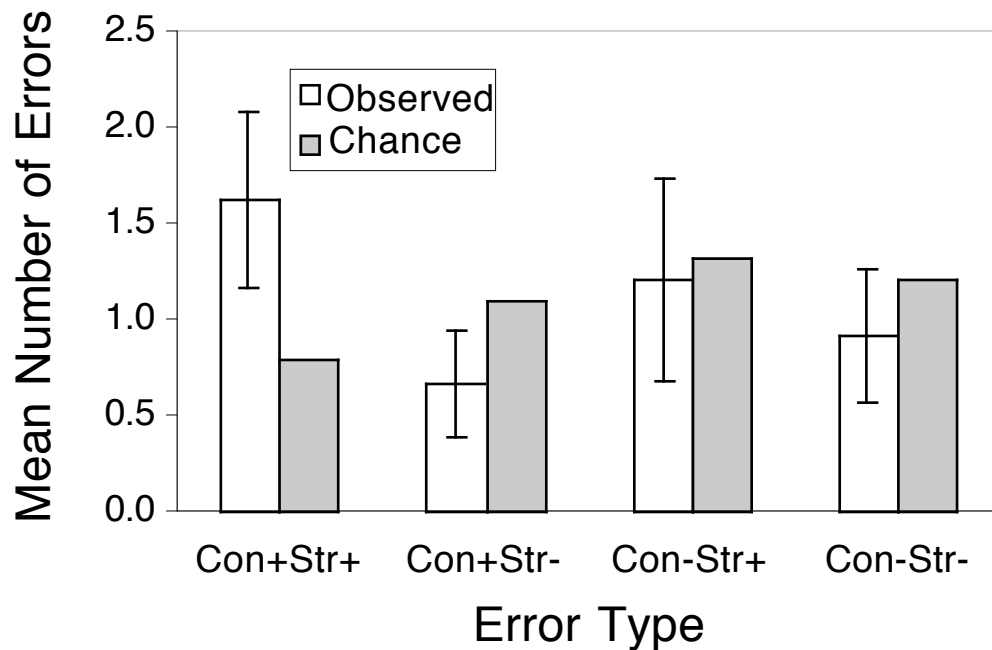


Figure 10. Observed mean number of errors broken down by error types for fruits and vegetables in the recall phase of Experiment 7. Dark bars represent the mean number of errors expected by chance. “Con” = conceptual; “Str” = Structural; “+” = similar; “-” = dissimilar. Error bars represent 95% within-subjects confidence intervals.

(the Con+Str+ condition) occurred significantly more frequently than would be expected by chance.

Color typicality ratings. The relationship between color typicality ratings and recall performance was examined in two ways. First, recall performance on each item was regressed onto the average number of colors listed for each item by respondents on the typicality questionnaire. This regression is graphed in Figure 11. As the figure shows, color typicality did not predict recall performance ($r^2 = .017$, $p = .478$). We then calculated the total number of typicality-questionnaire respondents who included the most commonly listed color for each item. Recall performance for each item in Experiment 7 was then regressed onto this new measure of color typicality (see Figure 12). Again, color typicality did not account for the category-specific pattern of color recall ($r^2 = .002$, $p = .804$).

Discussion

The pattern of intrusion errors obtained for fruits and vegetables enabled us to further examine the claim that factors affecting the retrieval of episodic associations includes the interaction of conceptual relatedness and structural similarity. According to this claim, the degree to which item sets share a combination of conceptual and structural features determines the probability that an item will be confused with another from the same set. A close examination of the errors to the fruits and vegetables in the recall test supports this hypothesis: only errors that were

both structurally similar and conceptually related occurred significantly more often than would be expected by chance. This pattern suggests that conceptual distinctiveness may help resolve competition among structurally similar competitors, as was found in previous studies with CSA patient ELM (Arguin et al., 1996; Dixon et al., 1997, 1998). The lack of a significant number of errors that could be classified as structural-only (defined as long vs. round) or as conceptual-only (fruit vs. vegetable) does not allow us to conclude that structural or conceptual similarity alone have no influence on confusion errors. Given a wider range of variation along either conceptual or structural dimensions, each of these types of similarity would affect recall performance, as shown in Experiment 4. The important point to be taken from the present analysis of errors is that, consistent with our theory, confusion errors in recall are especially likely to occur for pairs of items that are both structurally and conceptually similar.

Color typicality was ruled out as a competing explanation for the category-specific results of Experiment 7. No relationship was found between either of the two color typicality ratings and recall performance of individual items. Thus the interaction of structural and conceptual meaning in episodic recall remains a viable explanation for the category-specific pattern of color recall in normal observers.

Recall performance was poorest for categories that are known to be most difficult for patients with CSA for biological objects (mammals and fruits and vegetables),

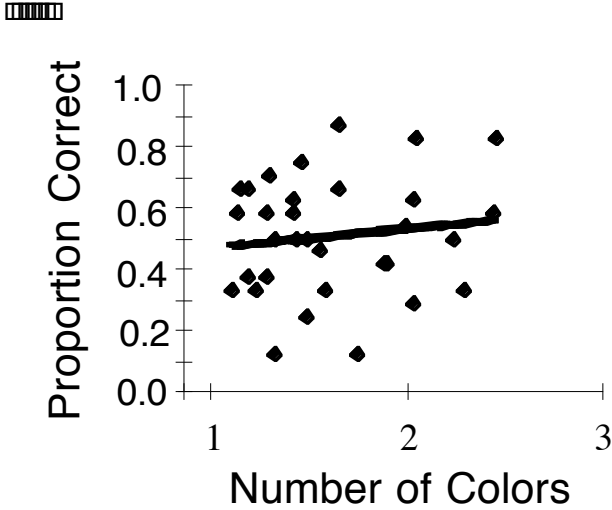


Figure 11. Regression of accuracy in the color recall phase of Experiment 7 on color-typicality ratings (as measured by average number of colors listed for each item, $p > .05$).

whereas accuracy was better for kitchen utensils than for mammals. Accuracy was not substantially greater for kitchen utensils than for fruits and vegetables, presumably because of the unusually high degree of structural and conceptual overlap across our set of kitchen utensils. Indeed, at the structural level, there was a high degree of similarity among the utensils (all were long and thin). Had we used a more heterogeneous set of kitchenware items (e.g., types of containers, appliances, and utensils, as are included in the Snodgrass & Vanderwart object set), recall performance on kitchen items would likely have been much better. This conjecture is supported by the superior recall performance for objects that were both structurally dissimilar and conceptually unrelated. Poor performance for

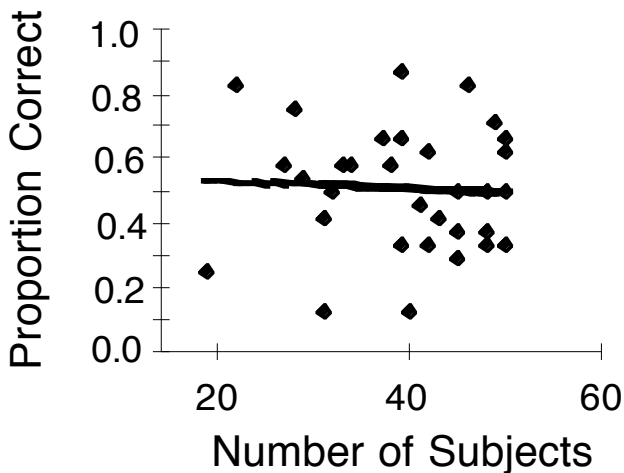


Figure 12. Regression of accuracy in the color recall phase of Experiment 7 on color-typicality ratings (as measured by the total number of subjects who included the most commonly listed color for each item, $p > .05$).

a particularly homogeneous set of utensils is consistent with our hypothesis that it is not category membership per se, but underlying factors such as structural and conceptual similarity, that determine performance on our task and, we believe, in CSA patients.

Our procedure generates substantial interference among the objects in the training set at the time of recall because of the highly similar nature of the training episodes and the specific demands of the recall test. We suspect that there is little interference at test from objects that were not in the learning set. Hence performance on our color recall task is likely heavily influenced by the exemplars used. In contrast, performance on an object-naming task is susceptible to interference from all known objects that are structurally and conceptually similar to the probe stimulus. Nonetheless, our results suggest that when object sets in our paradigm are representative of their respective categories, the pattern of results on our color recall task closely mirrors the pattern of most CSA patients' naming performance.

General Discussion

The results of the experiments presented here demonstrate that report of newly acquired information about objects reveals category-specific effects that parallel those observed in the modal form of CSA. In Experiment 1, we found that retrieval of color-form associations was most difficult for mammals and instruments, object classes typically affected in CSA. Objects in these categories share both structural and conceptual attributes. The results cannot be accounted for by structural similarity alone because accuracy for objects that were both structurally similar and conceptually related was significantly worse than accuracy for objects that were structurally similar but conceptually unrelated. In Experiment 2, we found that the category-specific effects of Experiment 1 were robust and were not attenuated when subjects were informed of the recall test in advance. This result implies that the learning conditions we imposed were sufficiently challenging that subjects were unable to engage in strategic encoding operations that could alter the pattern of category-specific effects. In Experiment 3, we found evidence that retrieval effects were not dependent on structural or conceptual similarity between pairs of items presented in the encoding phase; even when members of these pairs were unrelated, category-specific effects emerged in the final recall test. Instead, category-specific effects appear to arise at the time of recall from confusions across episodes between objects that are both structurally similar and conceptually related, regardless of whether they co-occurred during encoding. Experiment 4 provided a direct test of our hypothesis that both structural and conceptual factors are important determinants of recall performance. When pairwise structural and conceptual similarity ratings were regressed on the pairwise confusion data from the recall phase of Experiments 1 – 3, the model that best predicted recall performance included both structural and conceptual similarity.

Object sets in Experiments 5 and 6 were chosen to test a particularly robust dissociation between biological and nonbiological categories seen in CSA cases. The objects included within those categories were selected to be representative of their respective categories (see Appendix A). Indeed, we avoided atypical exemplars (such as ashtray and lamp in the furniture category) so that performance would not be artificially enhanced. Nevertheless, subjects found it much harder to recall the color of objects from the birds and mammals categories than from the furniture and clothing categories. By using texture instead of color as the critical attribute in Experiment 6, we showed conclusively that the difference between nonbiological and biological objects is not due to relative differences between objects with respect to color typicality that potentially could interfere with the learning of a new color association. This conclusion was further supported in Experiment 7 by a lack of correlation between color typicality ratings and performance on the recall test.

Finally, in Experiment 7, we compared recall for three object classes: two that are typically impaired (mammals and fruits and vegetables) and one that is relatively preserved (kitchen utensils) in most cases of CSA. Recall of color for the three object categories was impaired relative to recall of color for unrelated objects. Furthermore, color recall of mammals was impaired relative to that of kitchen utensils. Kitchen utensils, however, did not yield significantly better performance than fruits and vegetables. We explain this lack of dissociation by the greater confusability along conceptual and structural dimensions for the kitchen utensils used in our task compared to the more diverse set of exemplars typically included for patient testing. These results are consistent with our hypothesis that it is the structural and conceptual similarity of a category, rather than category membership per se, that determines recall performance. In addition, analysis of the intrusion errors in recalling the learned colors of fruits and vegetables revealed a pattern that is strikingly reminiscent of the labeling errors obtained from the CSA case ELM, the only patient for whom such data are currently available. For normal subjects, objects from the same conceptual category (e.g., vegetables) that also shared structural dimensions (e.g., carrot and cucumber) were much more likely to be confused than objects that did not share structural dimensions (e.g., carrot and turnip).

Knowledge Acquisition as a Methodology to Study Category-Specific Effects

Adopting an episodic approach to theories of object knowledge broadens the scope of inquiry to include the acquisition of new knowledge. Although we acknowledge that new associations may not have all of the properties of well-learned associations, we believe that factors that affect the retrieval of newly learned associations between objects and arbitrary attributes in normal subjects will be predictive of vulnerabilities in the use of established knowledge in

brain-damaged patients. That is, if normal individuals show a pattern of category specificity in our paradigm comparable to most patients with CSA, then common factors may be responsible in both situations. Given a task that yields such evidence, one can conduct studies with normal subjects to explore new predictions and refine theoretical models that subsequently can be tested in patients with CSA. For example, the use of natural objects provides only an imprecise measure of the relationship between form and conceptual similarity. We can, however, train subjects to associate semantic concepts with novel geometric forms that have well-defined structural relationships. These trained objects can then be used in the same way that we have used line drawings of natural objects to assess the factors influencing retrieval in episodic recall.

Throughout these experiments, we have been guided by the view that the modal pattern of CSA, in which biological kinds and musical instruments are selectively impaired, represents a valid characterization of the phenomenon. The neuropsychological data on CSA are variable in that some patients show dissociations between categories within biological kinds (e.g., KR in Figure 1). As we noted in the introduction, Capitani et al. (in press) view such cases as evidence for separate representations for animals and plants. They also dispute the association between musical instruments and biological objects that we claim is part of the modal pattern. In our view, some of the variability across cases depends upon testing conditions (e.g., which specific category exemplars are used) and the patients' background knowledge. To return to just one instructive example, consider the CSA case ELM. He was rather better than expected on musical instruments, given his deficits on biological objects, but detailed testing revealed a severe and consistent impairment on stringed instruments relative to brass instruments. Evidently, ELM's preserved ability with this subset of musical instruments reflected the expert knowledge he had accrued by playing for many years in a brass band (Dixon et al., 2002). Case C (Wilson et al., 1995) showed similar preservation of musical instruments, presumably because of his training as a world class musician.

We maintain that there is strong evidence for a causal relationship between impairment on animals, fruits and vegetables, and musical instruments in a large number of cases of CSA of the biological type. Our data show that these categories produce many more errors in the attribute recall performance of normal observers relative to categories like clothing, furniture, or even visually similar unrelated objects. A similar pattern can be seen in the identification errors of the most common form of CSA. Nevertheless, there is also evidence for a possible distinction between plants and animals as shown by CSA cases in which there is a dissociation between these two categories (Capitani et al., in press). A complete account of these different patterns of dissociation may require further differentiation within semantic memory in which certain types of knowledge specific to animals or to plants are

represented in different neural systems.

The Basis for Category Specificity in Agnosia

The similarity in performance patterns between patients with CSA and the normal subjects who took part in our experiments suggests that a common principle underlies both phenomena. We propose that when an object is encountered during the training phase of our paradigm, subjects create episodic memory records of the various aspects of that encounter (e.g., the structural form of the stimulus, the color of the stimulus, and internally generated information about the identity of the stimulus and its relationship to other things). At test, subjects are given the visual form of the stimulus as a cue and must then integrate episodic memories of that form with memories of the color (or texture in Experiment 6) in which that stimulus had been presented. That integration is susceptible to interference from episodic memories of the attributes of objects that are structurally similar and conceptually related to the target object, making it particularly difficult to recall the newly learned attributes with which biological objects had been associated. We suggest that this interaction between stored structural and conceptual elements in the episodic recall task provides a viable explanation for the category-specific effects we observed and has important implications for theories of normal object recognition and of semantic organization, as well as for CSA for biological objects.

As we have noted, an alternative class of theories of CSA emphasizes distinctions between various subsystems of semantic memory. These approaches are based on the assumption that semantic memory comprises a fixed set of representations that differ between biological (and perhaps also between plants and animals) and man-made objects. We account for the general pattern of dissociation as an emergent property of a dynamic semantic system in which stored structural and conceptual dimensions are retrieved and integrated in the course of object identification. Category-specific deficits occur as a result of the failure to resolve competition from other exemplars that share overlapping structural properties and event histories, and thus those categories that are most susceptible to errors are those whose exemplars are highly proximate along several dimensions in this multidimensional psychological space.

Why are patients with CSA particularly susceptible to interference from similar episodes? Our general proposal is that patients fail to use the full set of diagnostic features necessary to disambiguate objects with similar meaning and structural form. We emphasize that this is not a deficit in visual perception, nor even in the immediate memory for structural form. Rather, the problem is one that affects the retrieval of conceptual information in memory. To identify a visually presented object such as a carrot, for example, several dimensions of shape must be mapped onto other domains of conceptual knowledge that ultimately represent the semantic features of carrot (e.g., taste, color, where it is found, how it is used). In the context of a connectionist

architecture, this idea implies a set of connection weights and hidden units between representations of domains of conceptual knowledge and between these domains and representation of structural form. In the modal form of CSA, damage may occur either to the hidden units or connection weights between the representation of structural form and other conceptual domains, or to the hidden units or connection weights that mediate between the conceptual domains relevant to object identification. Damage to this architecture may produce a variety of subtle differences between cases, depending on its location.

If the problem lies specifically in the mapping between structural features in memory and other conceptual aspects of the object, there will be insufficient precision in the mapping operation to distinguish between objects that are close in conceptual and structural space. Objects that do not closely resemble one another in this way will be less likely to be confused. Thus, the patient will make identification errors that involve confusions between visually similar objects within a category (e.g., carrot more likely to be confused with cucumber than with onion). If there is also a failure in the mapping between conceptual elements, then errors should include retrieval of attributes across different objects, so that the patient produces “blends” involving an amalgamation of properties of similar objects (e.g., carrot retrieved as a soft vegetable that is round, orange, and grows on a vine). Finally, if structural knowledge is preserved, but the damage specifically affects the integration of conceptual elements, then the patient should succeed in performing reality decisions (e.g., in which real animals are reliably discriminated from plausible, but novel animals) but fail when knowledge of conceptual attributes is interrogated. The point to note in this last example is that we do not argue that the reality decision task is performed by consulting presemantic structural knowledge, as do Humphreys and Forde (2001). The ability to perform a reality decision requires access to semantic memory. Even though an amalgam of conceptual attributes from different exemplars is the result, accurate performance is possible if the patient is simply asked to judge that an object has been previously encountered.

A major objective for future research is to identify the principle that underlies category-specific deficits for nonbiological objects (i.e., better performance on categories such as birds and mammals than on furniture and clothing), the reverse of the dissociation we have studied here. Our account of CSA of the biological type makes no appeal to separate representations involving form and function, unlike many accounts of CSA (e.g., Farah & McClelland, 1991; Warrington, 1975). Conceivably, a complete account of the double dissociation may require an explicit distinction between representations, but other possibilities should be pursued as well.

In keeping with our current approach, we will briefly mention one idea regarding the nature of the principle that governs selective impairment for nonbiological objects. It has been suggested that certain nonbiological categories

have cultural status not because their members share any intrinsic qualities, but because they can be grouped together on the basis of co-occurrence--the fact that some objects are kept together for special reasons, sometimes having to do with their function (Wierzbicka, 1984). A category like furniture is formed, on this view, because its members frequently are experienced together for a common purpose even though the motor actions associated with each member are often very different.

We note that the notion of objects being related by contiguity is instantiated in a recent computational model of semantic priming (D. Plaut, 1995; D. C. Plaut & Booth, 2000). This model distinguishes associative relationships between contiguously occurring objects (e.g., cup-saucer) acquired during learning from semantic similarity based on shared features. When otherwise unrelated pairs of words co-occur frequently during training, the model learns to make a rapid transition between these two items. This learning is the basis for associative priming between these items. In addition, semantically similar items share features and priming between these items occurs because during processing of the prime, features relevant to the target are activated, giving identification of the target a head-start. Plaut's model produces qualitatively different patterns of priming effects for items that are related based on these two principles--contiguity during learning versus shared features. It is the latter principle that many researchers have argued underlies CSA for biological objects, the most common form of CSA.

We suggest that for nonbiological objects, similarity is more strongly determined by contiguity relationships and less by similarity of form and function (e.g., hammer and nail). This idea generates a specific prediction with respect to the kind of confusion errors that should be seen in patients with nonbiological CSA. That is, confusions should occur between objects that are strongly associated by contiguity within a category regardless of similarity of function as defined by motor action. Thus, a patient who is impaired on furniture should be more likely to confuse chair and table than chair and bench (assuming the latter pair is not strongly related on the basis of contiguity). For biological CSA, it is confusions between objects similar in form and meaning that characterize object identification errors, as we discussed in Experiment 7.

A well-developed program of research integrating the present episodic framework with evidence from CSA would require a much better understanding of the source of confusions in patients of different CSA types. In addition, if the broad distinction we have made between similarity and contiguity has any validity, then one is in a position to benefit from constructing a suitable episodic task in which normal subjects are no longer merely affected by the similarity of exemplars within a category, but are now susceptible to effects based on the contiguity relationships between category members. The development of such a task, in conjunction with the task we have used here, would be expected to yield the type of double dissociation between

certain biological and nonbiological categories that has been suggested in the literature on CSA.

Conclusion

We have shown that category-specific effects arise in normal subjects due to the interaction of structural and conceptual knowledge in episodic retrieval of object-specific information. Our approach differs from previous attempts to model CSA in that it emphasizes episodic memory processes, rather than object properties or naming, and thus is a more suitable analogue to a deficit that is, above all, an impairment of memory. Our results support the idea that CSA is the outcome of a failure to use diagnostic features to select among memory episodes of semantically related objects that share similar structures and event histories. The general approach we have developed should prove to be a useful method of investigating the nature of normal information retrieval and the interaction of object form and semantics.

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Appendix A
Stimulus Lists

The following four tables present the stimulus lists used in Experiments 1-7. Table A1 presents the stimuli used in Experiments 1-4. Table A2 lists the stimuli used in Experiment 5-6. Table A3 lists the stimuli used in Experiment 7.

Table A1
Stimulus List for Experiments 1-4

Practice Items	Mammals	Instruments	Struct Sim	Unrelated
cap	cow	bass	knife	wagon
sailboat	buffalo	tuba	cigarette	garbage can
tree	sheep	saxophone	nail file	bell
candle	horse	trumpet	toothbrush	umbrella
kite	donkey	trombone	screwdriver	traffic light
bird	bear	guitar	pencil	snowman
fish	deer	banjo	needle	glasses
book	goat	violin	baseball bat	chair

Table A2
Stimulus List for Experiments 5-6

Practice Items	Birds	Mammals	Furniture	Clothing
snowman	seagull	cow	dresser	shirt
sailboat	sparrow	pig	desk	pants
tree	owl	sheep	couch	sock
candle	eagle	horse	bed	glove
kite	heron	bear	table	dress
trombone	goose	buffalo	chair	skirt
fish	chicken	deer	stool	vest
book	duck	goat	bench	coat

Table A3
Stimulus List for Experiment 7

Practice Items	Mammals	Fruits & Veg	Utensils	Unrelated
cap	cow	turnip	knife	wagon
sailboat	cat	strawberry	spoon	garbage can
tree	dog	cucumber	spatula	bell
candle	horse	carrot	tongs	umbrella
kite	donkey	onion	scissors	traffic light
bird	squirrel	banana	ladle	snowman
fish	rabbit	apple	whisk	glasses
book	goat	lemon	fork	chair

Appendix B

Planned Contrasts for Mean Recall Accuracy in Experiment 1-3 and 5-7.

	MSE	F	p.	η^2
Experiment 1				
Mammals vs. Instruments	7.33	0.222	.642	.010
Instruments vs. Struct Sim	4.93	57.579	<.001	.715
Struct Sim vs. Unrelated	4.30	6.053	.022	.208
Experiment 2				
Mammals vs. Instruments	6.03	0.793	.387	.050
Instruments vs. Struct Sim	4.97	41.545	<.001	.735
Struct Sim vs. Unrelated	2.06	22.975	<.001	.605
Experiment 3				
Mammals vs. Instruments	2.95	.101	.754	.005
Instruments vs. Struct Sim	4.00	54.302	<.001	.731
Struct Sim vs. Unrelated	3.22	33.349	<.001	.625
Experiment 5				
Mammals vs. Birds	4.48	0.349	.564	.023
Birds vs. Furniture	6.43	10.263	.006	.406
Furniture vs. Clothing	8.64	2.543	.132	.145
Experiment 6				
Mammals vs. Birds	4.12	0.142	.709	.006
Birds vs. Furniture	3.33	10.355	.004	.310
Furniture vs. Clothing	3.76	4.434	.046	.162
Experiment 7				
Mammals vs. F/V	5.42	2.353	.139	.093
F/V vs. Utensils	4.08	2.300	.143	.091
Utensils vs. Unrelated	4.65	24.679	<.001	.518

Appendix C
Calculation of Chance Error Types for Fruits and Vegetables

In Experiment 7, the fruits and vegetables were classified along two dimensions: conceptual (fruits vs. vegetables) and structural (long vs. round). Errors were then classified as being conceptually related or unrelated to the black and white probe (Con+ or Con-) and also as structurally similar or dissimilar to the probe (Str+ or Str-).

Under the null hypothesis, we expected errors to be randomly distributed over all error types. However, because there were only 3 long items but 5 round items, the number of cells per error type in the raw confusion matrix varied, making it more likely that a random error would be round than long. Thus chance values for each error type were weighted by the proportion of cells per error type contributing to the confusion matrix. In addition, because the raw frequency of errors differed for each probe type, expectancies were also weighted by the number of observed frequencies for each probe type. Finally, these expected frequencies were divided by the number of subjects to obtain an average expected frequency for each error type.

For example, calculation of chance for the Con+Str+ condition involved summing the individual expectancies for the following four “error-probe”

conditions: round fruit error to round fruit probe; round vegetable error to round vegetable probe; long fruit error to long fruit probe; and long vegetable error to long vegetable probe. To calculate these four individual expectancies, we first determined the proportion of cells in the raw error matrix contributing to each error-probe condition. For example, three of the eight probes were round fruits. Each probe could have 7 possible error cells, making a total of 21 error cells for round fruit probes. However, only six of these could be classified as Con+ Str+ (apple-lemon, apple-strawberry, lemon-apple, lemon strawberry, strawberry-lemon, strawberry-apple). Thus the proportion of raw cells contributing to the Con+ Str+ condition for round fruit was $6/21 = 0.2857$. This proportion was then multiplied by the number of errors that were observed for round fruit probes (39 errors were observed), yielding 11.14. This procedure was repeated for the other three error-probe types in the Con+Str+ condition, and these four individual expectancies were then summed (yielding 19.00). Finally, this total was divided by the number of subjects (24) to obtain the average expected frequency for the Con+ Str+ condition (0.79), assuming a random distribution of errors.