PSYCHOLOGICAL SCIENCE

Research Article

DISSOCIABLE NEURAL SUBSYSTEMS UNDERLIE ABSTRACT AND SPECIFIC OBJECT RECOGNITION

Chad J. Marsolek
University of Minnesota

Abstract—*Participants named objects presented in the left or right visual field during a test phase, after viewing centrally presented same-exemplar objects, different-exemplar objects, and words that name objects during an initial encoding phase. In two experiments, repetition priming was exemplar-abstract yet visual when test objects were presented directly to the left cerebral hemisphere, but exemplar-specific when test objects were presented directly to the right cerebral hemisphere, contrary to predictions from single-system theories of object recognition. In two other experiments, stimulus degradation during encoding and task demands during test modulated these results in predicted ways. The results support the theory that dissociable neural subsystems operate in parallel (not in sequence) to underlie visual object recognition: An abstract-category subsystem operates more effectively than a specific-exemplar subsystem in the left hemisphere, and a specific-exemplar subsystem operates more effectively than an abstract-category subsystem in the right hemisphere.*

What would you name each of the two objects in Figure 1? Most people would name them both "piano," even though they obviously are different exemplars of pianos. This is a simple, but interesting, observation because it indicates that the two shapes are recognized as the same in one sense, but different in another. If so, the visual system is confronted with contradictory recognition problems: How can it recognize that those objects belong to the same (abstract) category, but also to different (specific) categories? Contemporary theories of object recognition ignore the opposing natures of these abilities and posit that a single, undifferentiated system accounts for the visual-structural processing underlying object recognition. However, computational reasoning and functional hemispheric asymmetries suggest that the human brain may solve the dilemma by implementing dissociable subsystems to underlie abstract and specific recognition (Marsolek & Burgund, 1997). This article reports experiments directly supporting the dissociable-subsystems theory.

The two relevant abilities may be defined as follows. Abstract-category recognition refers to the ability of the visual system to learn to map different input shapes, even fairly dissimilar ones, to the same output representation. In contrast, specific-exemplar recognition refers to the ability to learn to map different input shapes, even fairly similar ones, to different output representations.

Why hypothesize that dissociable subsystems underlie abstract-category and specific-exemplar object recognition? Recent evidence indicates that at least relatively independent subsystems underlie abstract and specific recognition of word forms (Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996; Marsolek, Squire, Kosslyn, & Lulenski, 1994), pseudoword forms (Burgund & Marsolek, 1997), and letterlike forms (Marsolek, 1995). An *abstract-category subsystem* that operates effectively in the left cerebral hemisphere (LH) stores such forms in an exemplar-abstract manner, whereas a *specific-exemplar subsystem* that operates effectively in the right cerebral hemisphere (RH) stores such forms in an exemplar-specific manner. For example, letter-case-abstract repetition priming (i.e., equivalent same- and different-case word priming) is observed when test items are presented directly to the LH, whereas letter-case-specific repetition priming (i.e., greater same- than different-case word priming) is observed when test items are presented directly to the RH. Presumably, these subsystems operate within the occipital-temporal visual stream that underlies shape processing but not spatial-location or action-guidance processing of visual forms (e.g., Buckner et al., 1995; Goodale & Milner, 1992; Ungerleider & Mishkin, 1982).

The computational reasoning for why dissociable subsystems underlie word-form, pseudoword-form, and letterlike-form recognition also applies to object-form recognition. A features-based processing strategy (features of an input form are represented independently in the subsystem's internal representations) should be useful for abstract-category recognition (Marsolek, 1995). This strategy is efficient for storing the information that is common to dissimilar inputs that are categorized together, because such information typically is found in a subset of the features in one input form (e.g., nonaccidental properties of the edges of an input image with high tolerance in their activations; Lowe, 1985). In contrast, a whole-based processing strategy (features of an input form are not represented independently in the subsystem's internal representations) should be useful for specific-exemplar recognition (Marsolek et al., 1996). This strategy is efficient for storing the information that distinguishes similar exemplars in one abstract category as well as exemplars from other categories, because such information typically is found in information close to the undifferentiated whole of one input form. By this reasoning, useful strategies for abstract-category and specific-exemplar recognition are contradictory and should be performed by different subsystems more efficiently than by a unified system (for evidence from neural network modeling, see Marsolek & Burgund, 1997). This reasoning concerns how visual forms in general may be abstractly and specifically categorized, hence it applies to object recognition. Yet, to date, no reported evidence directly dissociates abstract and specific object recognition subsystems. Indeed, for evidence inconsistent with such a dissociation, see Biederman and Cooper (1991).

A distinctive aspect of the present theory is that an abstract-category subsystem is a visual subsystem, one that processes only visual-structure information. This is an important point because it is at least implicit in many object recognition theories that different exemplars in the same abstract category of objects can activate the same mental representation, but only at postvisual stages of processing (e.g.,

---

Address correspondence to C.J. Marsolek, Department of Psychology, University of Minnesota, 75 East River Rd., Minneapolis, MN 55455; e-mail: chad.j.marsolek-1@umn.edu.

Edelman, 1998; Hummel & Biederman, 1992). For example, after differential visual recognition takes place for the objects in Figure 1, they may be treated similarly in phonological or conceptual subsystems. The mapping then would be at least partially nonvisual. However, if different input shapes (even dissimilar ones) very commonly lead to accessing the same name and common semantic information in postvisual subsystems, then a part of the visual system may become sensitive to any interactive feedback from these postvisual subsystems. Such feedback may lead a visual subsystem to learn to categorize those input shapes together and activate the same output. This aspect of the theory was tested in the following experiments. Note that a specific-exemplar subsystem also should be influenced by feedback from postvisual subsystems. However, in this case, if two input shapes (even two exemplars in the same abstract category) are associated with distinctive postvisual information, then feedback should lead a visual subsystem to learn to differentiate the two and produce different outputs.

Another important characteristic of the present theory is that it does not necessarily posit that only an abstract-category subsystem operates in the LH and only a specific-exemplar subsystem operates in the RH. Both may operate in each hemisphere, with the abstract subsystem more effective than the specific subsystem in the LH, and the specific subsystem more effective than the abstract subsystem in the RH. Indeed, the following experiments produced results that support this possibility. Either way, the important claim is that these subsystems operate (in parallel) at least relatively independently, contrary to single-system theories of object recognition.

EXPERIMENT 1

These theories were tested using a repetition priming paradigm. First, objects and words that name objects were presented in the central visual field, so that high-quality information was projected directly to both hemispheres equally quickly. Participants processed each item without naming it. Then, objects were presented very briefly in the left or right visual field, ensuring that subsystems in one hemisphere received higher quality visual input and received that input before subsystems in the other hemisphere. The important effect was that subsystems in one hemisphere were given advantages in winning any race that may exist between LH and RH subsystems to guide motor responses.[1] Participants named these test objects, which were either unprimed or primed through previous viewing of the same exemplar, a different exemplar with the same name as the test object, or the word form associated with the name of the test object (see Fig. 1).

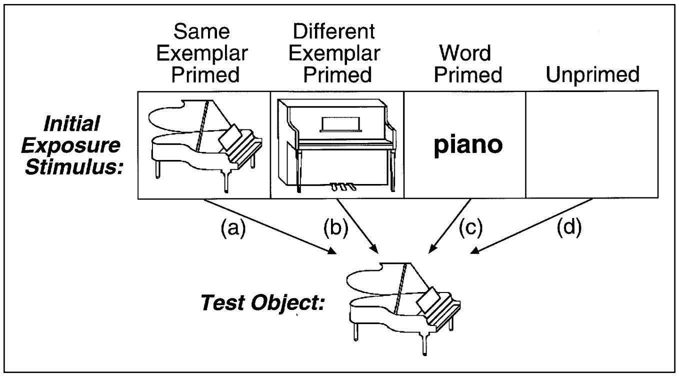

Fig. 1. Four types of priming examined in all experiments. Each test object was presented in one of four priming conditions: (a) same-exemplar priming, (b) different-exemplar priming, (c) word priming, or (d) no priming (baseline).

According to the dissociable-subsystems theory, repetition priming should differ qualitatively depending on the hemisphere of direct test presentation. When objects are presented directly to the LH, same-exemplar- and different-exemplar-primed objects should be named equally accurately, and both should be named more accurately than word-primed objects. However, when objects are presented directly to the RH, same-exemplar-primed objects should be named more accurately than different-exemplar-primed objects, which in turn should not be named more accurately than word-primed objects. Such results would indicate that the priming that is characteristic of information storage in an abstract-category subsystem (exemplar-abstract, yet visual) is observed when that subsystem is advantaged at test, whereas the priming characteristic of information storage in a specific-exemplar subsystem (exemplar-specific) is observed when that subsystem is advantaged at test. In contrast, according to single-system theories, repetition priming should not differ qualitatively depending on the hemisphere of direct test presentation.

Method

Participants

In each experiment, 48 female and 48 male undergraduate students at the University of Minnesota or the University of Arizona volunteered for course credit or cash payment. All participants were right-handed, as assessed through the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. None participated in more than one experiment.

Materials and design

The stimuli were 64 line drawings of objects, two exemplars for each of 32 abstract categories, as well as printed words of the names of the 32 categories. Stimuli were presented in black against a continuous gray background on an AppleColor High Resolution RGB display set to maximum luminance and contrast, with a Polaroid CP-50 filter placed over it to reduce glare. Objects subtended 4.0° of visual angle at their widest (horizontal or vertical), and words were presented in a 36-point bold Helvetica font. A chin rest was used to position participants' eyes approximately 86 cm from the display. For each participant, eight exemplar objects represented each of the eight test conditions formed by orthogonally combining the two within-participants independent variables: type of priming (same-exemplar priming, different-exemplar priming, word priming, and no priming) and hemisphere of direct test presentation (left and right). The two exemplars in each abstract category always were presented directly to different hemispheres for one participant. Counterbalancing ensured that each exemplar object (including left-right reflections) represented each condition an equal number of times across participants.

---

[1] Note that a change in location between central-visual-field prime presentations and lateralized test presentations ensured that any observed priming would not be due to low-level retinotopic representations operating prior to higher level object recognition processes.

Procedure

Each experimental session consisted of an initial encoding phase, during which prime presentations occurred, and a subsequent (and presumably unrelated) test phase. During the encoding phase, 16 objects and eight printed words (from 24 different abstract categories) were presented, intermixed in pseudorandom order. They appeared in the center of the display for 3 s each. A third of the participants judged how much they liked or disliked each item, a third free-associated to the first word that came to mind that did not name each item, and a third judged whether a greater number of black pixels appeared on each stimulus's left or right half. Filler items appeared at the beginning and end of the encoding phase to attenuate primacy and recency effects.

During the test phase, 64 objects were presented in pseudorandom order. Half appeared in the left and half appeared in the right visual field, for 17 ms each. The center of each object appeared 4.3° from central fixation, with an inner edge never closer than 2.3°. Participants were required to stare directly at a fixation dot that appeared for 500 ms immediately before the onset of an object, to ensure lateralization. Participants named each object as quickly and accurately as possible into a microphone triggering a voice key, using the first common name to come to mind. Seven additional trials appeared at the beginning of the test phase for practice and warm-up.

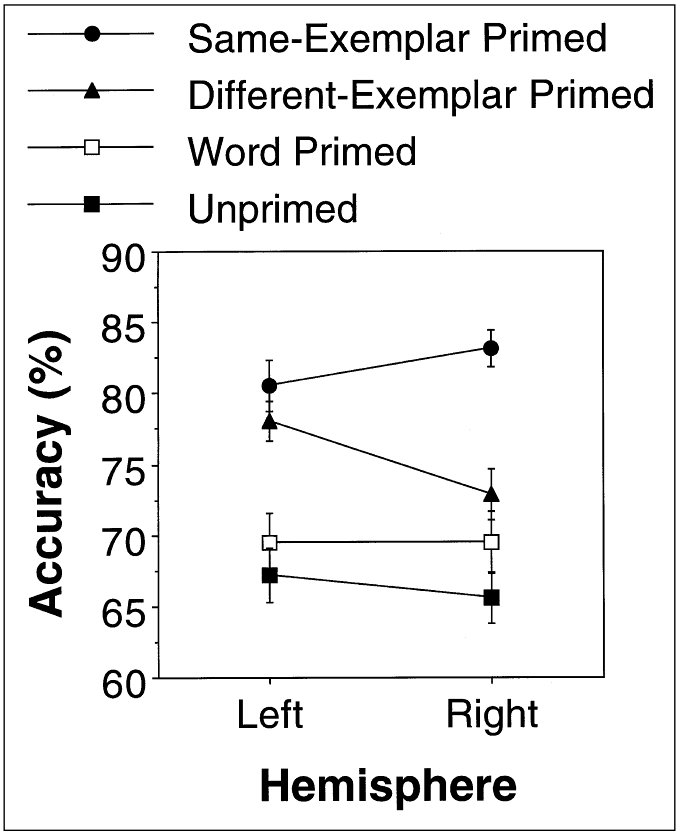

Fig. 2. Mean rates of naming accuracy as a function of type of priming and hemisphere of direct test presentation in Experiment 1. Error bars indicate standard errors of the mean.

Results

In all experiments, neither gender of participant nor encoding task entered into any significant effects in preliminary analyses; thus, these variables were not included in the following analyses. Two-way repeated measures analyses of variance were conducted for each experiment, with type of priming (same-exemplar priming, different-exemplar priming, word priming, and no priming) and hemisphere of direct test presentation (left and right) as within-participants factors. Separate analyses were conducted with participants (F_1) and object category (F_2) as the random variable.

Figure 2 displays the results for naming accuracy in Experiment 1. Most important, the interaction between type of priming and hemisphere of direct test presentation was significant, $F_1(3, 285) = 3.06$, $p < .05$, $MSE = 161.7$; $F_2(3, 285) = 3.38$, $p < .05$, $MSE = 146.4$. When test objects were presented directly to the LH, same-exemplar-primed objects (80.5%) and different-exemplar-primed objects (78.0%) were not named with differing accuracy, $F_1(1, 285) = 1.82$, $p > .15$; $F_2(1, 285) = 2.01$, $p > .15$; however, different-exemplar-primed objects were named more accurately than word-primed objects (69.5%), $F_1(1, 285) = 21.3$, $p < .001$; $F_2(1, 285) = 23.5$, $p < .001$. In contrast, when test objects were presented directly to the RH, same-exemplar-primed objects (83.1%) were named more accurately than different-exemplar-primed objects (72.9%), $F_1(1, 285) = 30.6$, $p < .001$; $F_2(1, 285) = 33.8$, $p < .001$; yet different-exemplar-primed objects were named only marginally more accurately than word-primed objects (69.5%), $F_1(1, 285) = 3.40$, $p < .07$; $F_2(1, 285) = 3.76$, $p < .06$. In addition, the main effect of type of priming was significant, $F_1(3, 285) = 29.5$, $p < .001$, $MSE = 300.0$; $F_2(3, 285) = 28.5$, $p < .001$, $MSE = 310.0$; but the main effect of test hemisphere was not, $F_1(1, 95) = 1.04$, $p > .30$, $MSE = 187.3$; $F_2(1, 95) = 1.55$, $p > .20$, $MSE = 126.0$.

A similar analysis of response times for correctly named test objects (range for condition means: 930–1,038 ms) revealed a main effect of type of priming, $F_1(3, 285) = 5.39$, $p < .01$, $MSE = 23{,}926$; $F_2(3, 285) = 9.72$, $p < .001$, $MSE = 22{,}991$. This effect was similar to the effect for accuracy. The main effect of test hemisphere was marginally significant by participants, $F_1(1, 95) = 3.46$, $p < .07$, and significant by items (LH: 979 ms vs. RH: 999 ms), $F_2(1, 95) = 4.71$, $p < .05$, $MSE = 15{,}994$. But the interaction between type of priming and test hemisphere did not approach significance, $F_1 < 1$, $F_2 < 1$, belying a trade-off between speed and accuracy with regard to that interaction.

Discussion

Three important conclusions may be drawn. First, contrary to predominant single-system theories of object recognition, these results support the theory that an abstract-category subsystem and a specific-exemplar subsystem operate at least relatively independently. When LH subsystems were advantaged via right-visual-field test presentations, exemplar-abstract priming (equivalent same-exemplar-primed performance and different-exemplar-primed performance, and both greater than word-primed performance) was observed. The stored information supporting priming did not distinguish between object exemplars associated with the same name, as predicted for an abstract-category subsystem. However, when RH subsystems were advantaged via left-visual-field test presentations, exemplar-specific priming (greater same-exemplar-primed performance than different-exemplar-primed performance, and equivalent different-exemplar-primed and word-primed performance) was observed. The stored information supporting priming did distinguish between object exemplars with the same name, as predicted for a specific-exemplar subsystem. Thus, an abstract-category subsystem operates more effectively than a specific-exemplar subsystem in the LH, and a specific-exemplar subsystem operates more effectively than an abstract-category subsystem in the RH.

Second, the results from LH presentations indicate that an abstract-category subsystem stores visual object information, of the sort that is shared between different exemplars in the same abstract category but not found in the printed word associated with that category. If the priming in this subsystem had been postvisual in nature, there should have been no difference between the different-exemplar- and word-primed conditions following LH test presentations, yet there was one.

Third, the results also strongly suggest that abstract-category and specific-exemplar subsystems operate in parallel, not in sequence. Following LH test presentations, exemplar-abstract visual priming was exhibited, in a pattern that involved no greater performance with same-exemplar-primed objects than with different-exemplar-primed objects. Thus, processing in a specific-exemplar subsystem apparently was not a necessary first step before processing in an abstract-category subsystem. If it had been, behavioral evidence of this first step (exemplar-specific priming) should have been observed in addition to abstract priming. Analogous reasoning disconfirms the possibility that following RH test presentations, processing in an abstract-category subsystem was a necessary first step before processing in a specific-exemplar subsystem. These are important findings because some object recognition theories (e.g., Edelman, 1998; Hummel & Biederman, 1992; Ullman, 1996) are amenable to specific and abstract processes, but only if they are performed in sequence. The theory here, stemming from the analogous pattern of results in nonobject experiments (e.g., Marsolek et al., 1992), is that abstract-category and specific-exemplar subsystems operate in parallel, albeit with differing relative efficiencies across the two hemispheres. The next two experiments examined whether these differing relative efficiencies could be influenced by stimulus quality and task demands, in predictable ways.

EXPERIMENT 2

A well-established finding in the hemispheric-asymmetry literature is that degrading visual inputs (presenting them quickly, introducing masks or noise to stimuli, blurring inputs, etc.) typically impairs processing in the LH to a greater degree than processing in the RH (for reviews, see Christman, 1989; Sergent & Hellige, 1986). Thus, if an abstract-category subsystem operates effectively in the LH, then it may be affected by degradation to a greater degree than a specific-exemplar subsystem. The features-based processing strategy of an abstract-category subsystem likely makes it less able to utilize the power of distributed representations to effectively categorize distorted inputs (see Marsolek & Burgund, 1997). Experiment 2 was conducted to test this idea, by examining whether brief presentations of stimuli during initial encoding would selectively affect an abstract-category subsystem's contribution to subsequent expressions of priming.

Method

This experiment was conducted in the same manner as Experiment 1, with the exception that objects and words were presented for 500 ms, instead of 3 s, during initial encoding.

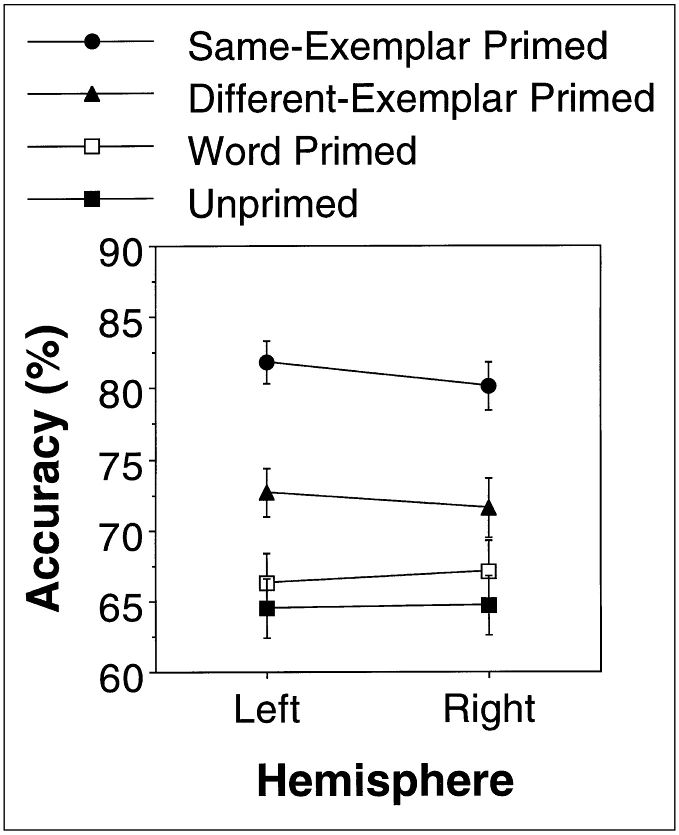

Fig. 3. Mean rates of naming accuracy as a function of type of priming and hemisphere of direct test presentation in Experiment 2. Error bars indicate standard errors of the mean.

Results

Figure 3 displays the results for naming accuracy in Experiment 2. Unlike in Experiment 1, the interaction between type of priming and hemisphere of direct test presentation was not significant, $F_1 < 1$, $F_2 < 1$. The only significant effect in the accuracy analysis was the main effect of type of priming, $F_1(3, 285) = 34.6$, $p < .001$, $MSE = 295.6$; $F_2(3, 285) = 32.8$, $p < .001$, $MSE = 311.5$.

Similarly, an analysis of response times for correctly named test objects (range of condition means: 943–1,043 ms) revealed no interaction between type of priming and test hemisphere, $F_1(3, 285) = 1.67$, $p > .15$; $F_2(3, 285) = 1.88$, $p > .10$. As was the case for accuracy, response times showed a main effect of type of priming, $F_1(3, 285) = 4.61$, $p < .01$, $MSE = 21{,}387$; $F_2(3, 285) = 6.39$, $p < .001$, $MSE = 26{,}826$. As in Experiment 1, analysis of response times also revealed a main effect of test hemisphere (LH: 979 ms vs. RH: 1,009 ms), $F_1(1, 95) = 10.5$, $p < .01$, $MSE = 17{,}609$; $F_2(1, 95) = 4.07$, $p < .05$, $MSE = 24{,}035$.

Discussion

These results support the hypothesis that an abstract-category subsystem is selectively affected by visual degradation during initial encoding. Unlike in Experiment 1, the pattern of priming that is characteristic of an abstract-category subsystem was not observed, even when LH subsystems were advantaged at test.

This finding may help to explain a curious result from a previous object priming study. Biederman and Cooper (1991) reported a nonsignificant interaction between type of priming (same-exemplar vs. different-exemplar) and test hemisphere in an experiment much like Experiment 1. They found exemplar-specific priming in both LH and RH test presentations, as was found in Experiment 2 but not in Experiment 1. The reason may be that they presented objects very briefly during initial encoding, as was done in Experiment 2 but not in Experiment 1.

EXPERIMENT 3

The initial-encoding procedure in Experiment 2 apparently decreased an abstract-category subsystem's contribution to priming. Another manipulation that should have a similar effect is modifying the demands of the test task so that the outputs from an abstract-category subsystem would not be useful. Experiment 3 examined whether requiring participants to sketch each test object as it appeared, before naming it, would result in little opportunity for an abstract-category subsystem to contribute to priming effects in the naming task. Presumably, a specific-exemplar subsystem, but not an abstract-category subsystem, would be useful for processing objects in order to copy them.

Method

This experiment was conducted in the same manner as Experiment 1, with the exception that participants sketched each test object before naming it during the test phase. They were asked to draw each object as closely to how it appeared on the display as possible.

Results

Figure 4 shows the results for naming accuracy in Experiment 3. Unlike in Experiment 1, but as in Experiment 2, the interaction between type of priming and test hemisphere was not significant, $F_1 < 1$, $F_2 < 1$, and the only significant effect was the main effect of type of priming, $F_1(3, 285) = 25.1$, $p < .001$, $MSE = 289.6$; $F_2(3, 285) = 31.7$, $p < .001$, $MSE = 229.3$. Lengthy and highly variable sketching performance prohibited useful measures of "naming" times.

Discussion

These results support the hypothesis that an abstract-category subsystem is not utilized when objects must be processed in a highly specific manner before being named. As in Experiment 2, the pattern of priming characteristic of an abstract-category subsystem was not observed, even when LH subsystems were advantaged at test.

It is important to note that in both Experiments 2 and 3, exemplar-specific priming was observed following LH test presentations. Apparently, a specific-exemplar subsystem operates in the LH, but is evidenced only when the stimuli or task demands create situations in which an abstract-category subsystem in the LH cannot contribute substantially to priming. If so, these results illuminate a critical aspect of the relevant architecture: These subsystems may not be strongly lateralized with only one subsystem in each hemisphere; rather, each subsystem may operate with different relative efficiencies in the two hemispheres. Moreover, specific-exemplar subsystems may operate equally effectively across hemispheres; specific priming was large in both LH and RH presentations. This could help to explain why same-exemplar object priming typically does not produce asymmetric deactivation in neuroimaging studies (e.g., Buckner et al., 1998). Differing relative efficiencies of subsystems may produce detectable asymmetries when (a) both subsystems contribute and (b) exemplar-abstract and exemplar-specific priming can be teased apart.

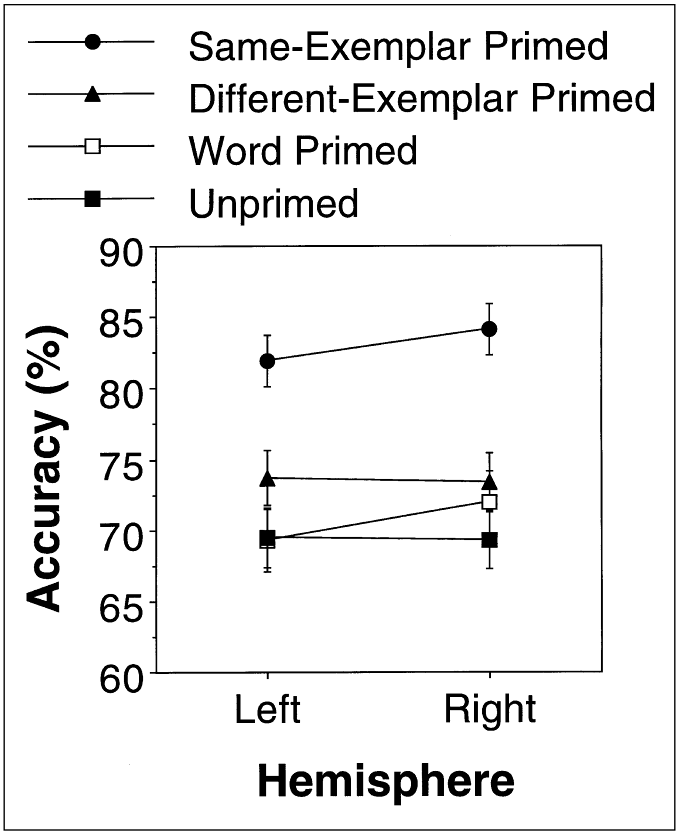

Fig. 4. Mean rates of naming accuracy as a function of type of priming and hemisphere of direct test presentation in Experiment 3. Error bars indicate standard errors of the mean.

EXPERIMENT 4

The experiments reported thus far support the dissociable-subsystems theory by demonstrating a significant interaction between type of priming and test hemisphere (Experiment 1) and by demonstrating two nonsignificant interactions (Experiments 2 and 3) that were predicted from the theory but relied on accepting the null for that interaction. Thus, Experiment 4 was conducted to replicate the important interaction in a new experiment that, like Experiment 1, should not disadvantage either subsystem. Participants wrote the name of each test object instead of speaking it aloud. This change from Experiment 1 should affect only postvisual processing—how the name is reported—after visual subsystems make their normal contributions to object recognition at test.

Method

This experiment was conducted in the same manner as Experiment 1, with the exception that participants wrote the name of each test object, without speaking it, during the test phase.

Results and Discussion

Figure 5 displays the results for naming accuracy in Experiment 4. Most important, the main results from Experiment 1 were replicated. The interaction between type of priming and test hemisphere was significant, $F_1(3, 285) = 3.11$, $p < .05$, $MSE = 209.0$; $F_2(3, 285) = 3.61$, $p < .05$, $MSE = 179.8$. When test objects were presented directly to the LH, same-exemplar-primed objects (78.9%) and different-exemplar-primed objects (76.4%) were named with equivalent accuracy, $F_1(1, 285) = 1.41$, $p > .20$; $F_2(1, 285) = 1.63$, $p > .20$; yet different-exemplar-primed objects were named marginally more accurately than word-primed objects (72.8%), $F_1(1, 285) = 3.05$, $p < .09$; $F_2(1, 285) = 3.55$, $p < .07$. However, when test objects were presented directly to the RH, same-exemplar-primed objects (81.6%) were named more accurately than different-exemplar-primed objects (70.4%), $F_1(1, 285) = 28.8$, $p < .001$; $F_2(1, 285) = 33.5$, $p < .001$; yet different-exemplar-primed objects were not named more accurately than word-primed objects (69.8%), $F_1 < 1$, $F_2 < 1$. Finally, the main effect of type of priming was significant, $F_1(3, 285) = 20.2$, $p < .001$, $MSE = 300.0$; $F_2(3, 285) = 25.3$, $p < .001$, $MSE = 239.0$; the main effect of test hemisphere was not significant by participants, $F_1(1, 95) = 2.03$, $p > .15$, but was significant by items, $F_2(1, 95) = 4.11$, $p < .05$, $MSE = 144.2$.

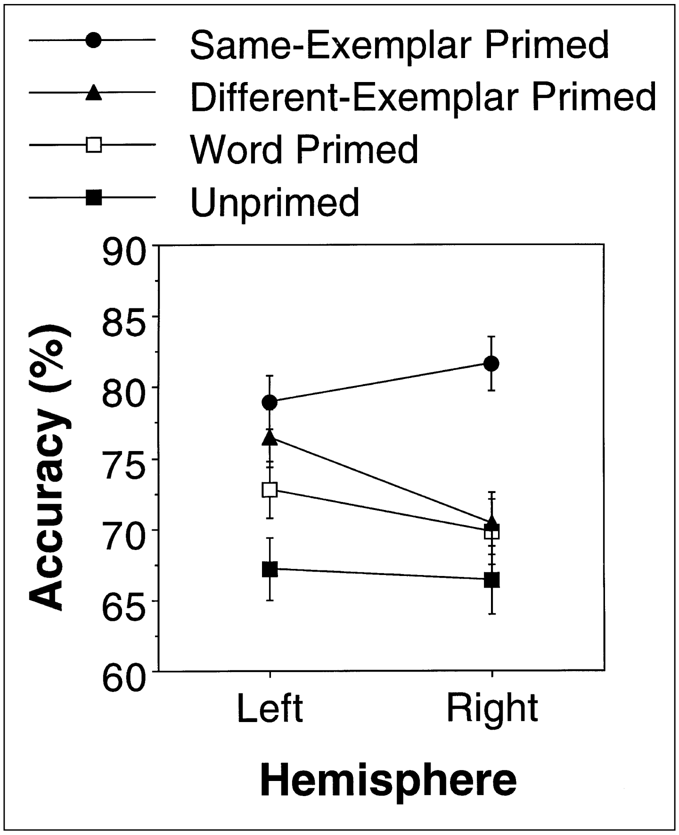

Fig. 5. Mean rates of naming accuracy as a function of type of priming and hemisphere of direct test presentation in Experiment 4. Error bars indicate standard errors of the mean.

GENERAL DISCUSSION

The results support the theory that dissociable neural subsystems, operating in parallel, underlie abstract-category and specific-exemplar object recognition. In particular, an abstract-category subsystem operates more effectively than a specific-exemplar subsystem in the LH. Exemplar-abstract visual priming, without accompanying exemplar-specific priming, was observed when LH visual subsystems were advantaged at test. In contrast, a specific-exemplar subsystem operates more effectively than an abstract-category subsystem in the RH. Exemplar-specific priming, without accompanying exemplar-abstract priming, was observed when RH visual subsystems were advantaged. Furthermore, this pattern of results was modified in predicted ways when stimuli were degraded during encoding and when task demands were specific during test.

Apparently, an abstract-category subsystem learns to map even fairly dissimilar input shapes to the same output representation when interactive feedback indicates that the inputs are associated with the same name and conceptual information. However, a specific-exemplar subsystem learns to map even fairly similar input shapes to different outputs when postvisual feedback distinguishes the inputs. It may be important to note that the abstract-specific distinction, although similar to the basic-level/subordinate-level distinction in categorization research, does not completely correspond to it. An important criterion for a basic-level object category is that its members are highly similar in shape (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), unlike the claim for abstract-category classes (e.g., pianos). Also, subordinate-level categories generalize across exemplars, unlike specific-exemplar representations (Marsolek, 1995). Furthermore, abstract and specific subsystems normally operate in parallel to provide input to postvisual subsystems. Thus, neither is privileged in terms of entry into semantic memory, and neither stores entry-level (Biederman, 1987; Jolicœur, Gluck, & Kosslyn, 1984) categories per se.

The present theory posits dual subsystems, rather than a continuum or a set of subsystems ranging from abstract to specific recognition abilities. Neural-network modeling studies indicate that general and specific categorizations can be performed within a single, undifferentiated model when the exemplars in one category are similar (e.g., two exemplar grand pianos; Knapp & Anderson, 1984; Marsolek & Burgund, 1997; McClelland & Rumelhart, 1985). However, abstract-category and specific-exemplar representations are stored more effectively in separate subnetworks than in unified models when the abstract categories include both dissimilar and similar exemplars (e.g., multiple grand and upright pianos; Marsolek & Burgund, 1997). Also, features-based and whole-based processing are evident in these abstract-category and specific-exemplar subnetworks, respectively, suggesting that the contradictory natures of these processing strategies are responsible for the development of dual subsystems (Marsolek & Burgund, 1997).[2]

---

[2] Interestingly, semantic activation of only direct associates to a word tends to be observed in LH word presentations, whereas broader semantic activation tends to be observed in RH word presentations (e.g., Chiarello, 1991). Although this hemispheric distinction concerns postvisual processing, it may seem to contradict the present abstract-specific visual hemispheric distinction. However, a features-based process that restricts activation to one subset of semantic features may be useful for limiting semantic activation to a particular meaning in the LH, whereas a less restrictive whole-based process may be useful for broadly activating various meanings in the RH. If so, the semantic and visual asymmetries may be similar in terms of the processing strategies of the relevant subsystems.

Indeed, this may help to explain combinations of impaired and intact abilities, in individual patients, to recognize words, objects, and faces following damage to visual cortex (Farah, 1990, 1991). Two recognition capacities, not one or three, are susceptible to damage, one used for words and sometimes objects (but not faces) and the other used for faces and sometimes objects (but not words). Farah suggested that parts-based processing (useful for words and sometimes objects) marks the former capacity, whereas holistic processing (useful for faces and sometimes objects) marks the latter capacity, a claim consistent with the present theory (as is the general claim that analytic versus holistic processing distinguishes LH vs. RH processes; e.g., Bradshaw & Nettleton, 1981; Corballis, 1989). The present theory is unique, however, in positing that features-based and whole-based processes develop in dual subsystems for the purposes of underlying abstract-category and specific-exemplar recognition, respectively. The functions of the two subsystems are best characterized by the abstract-category and specific-exemplar natures of their recognition abilities; "features-based" and "whole-based" describe processing strategies used to serve those functions. Indeed, words can be recognized in an exemplar-specific manner under certain conditions (e.g., Marsolek et al., 1992, 1996), and faces can be recognized as belonging to the abstract category of face in other situations, although these are not typical neuropsychological testing conditions.

In addition, the present findings may help to clarify why functional asymmetries have been noted as volatile across studies of object recognition (for reviews, see Biederman & Cooper, 1991; Levine & Banich, 1982). If dual subsystems with different properties are involved, methodological differences across studies may produce variability in observed asymmetries (e.g., compare Experiments 1 and 4 against Experiments 2 and 3). Furthermore, the present findings may help to settle a debate between opposing approaches to object recognition. According to one, object recognition relies on viewpoint-invariant, parts-based processing of inputs (e.g., Biederman & Gerhardstein, 1995; Hummel & Biederman, 1992), and experimental evidence supports this approach (e.g., Biederman & Gerhardstein, 1993; Cooper, Biederman, & Hummel, 1992). According to another approach, object recognition relies on viewpoint-dependent, image-based processing of inputs (e.g., Tarr & Bülthoff, 1995; Ullman, 1996), and experimental evidence also supports this approach (e.g., Srinivas, 1993; Tarr, 1995). Dual object recognition subsystems with different properties may help to explain such empirical discrepancies (for recent supporting evidence, see Burgund & Marsolek, in press).

Finally, this dual-subsystems theory may seem to exacerbate an unattractive proliferation of perception and memory subsystems (e.g., Roediger, Rajaram, & Srinivas, 1990). However, converging evidence from different methodologies suggests this particular dissociation is highly warranted. The theory is consistent with neuropsychological findings, computational evidence, and behavioral dissociations between abstract and specific word-form, pseudoword-form, letter-like-form, and now object-form recognition. Accordingly, a fundamental aspect of the neural architecture of human vision and memory may be that abstract and specific subsystems underlie visual-form recognition.

Acknowledgments—I sincerely thank Eric Cooper for the use of his line drawings of objects; Darcy Burgund, Dan Kersten, and Kelly Snyder for helpful comments on an earlier draft of this manuscript; Tom Carlson, Phuong Chung, Christian Herro, Mike Hillenbrand, Jacquelyn Lesure-Croteau, Yolandia Rodland, Kelly Snyder, Ryan Van Wyhe, and Wes West for assistance with data collection; Dave Andresen, Lisa Elo, and Dom Qualley for help with data scoring and analysis; and Chris Azorson for insightful discussion. This work was supported by the National Institute of Mental Health, Grant MH53959-01; by the McDonnell-Pew Cognitive Neuroscience Center and the Arizona Cognitive Science Program of the University of Arizona; and by the Center for Cognitive Sciences in conjunction with the National Science Foundation (GER 9454163) and the Office of the Vice President for Research and the Dean of the Graduate School of the University of Minnesota. An earlier report of this research was presented at the annual meeting of the Psychonomic Society, Philadelphia (November 1997).

REFERENCES

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94,* 115–147.

Biederman, I., & Cooper, E.E. (1991). Object recognition and laterality: Null effects. *Neuropsychologia, 29,* 685–694.

Biederman, I., & Gerhardstein, P.C. (1993). Recognizing depth-rotated objects: Evidence and conditions for three-dimensional viewpoint invariance. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 1162–1182.

Biederman, I., & Gerhardstein, P.C. (1995). Viewpoint-dependent mechanisms in visual object recognition: Reply to Tarr and Bülthoff (1995). *Journal of Experimental Psychology: Human Perception and Performance, 21,* 1506–1514.

Bradshaw, J.L., & Nettleton, N.C. (1981). The nature of hemispheric specialization in man. *Behavioral and Brain Sciences, 4,* 51–91.

Buckner, R.L., Goodman, J., Burock, M., Rotte, M., Koutstaal, W., Schacter, D., Rosen, B., & Dale, A.M. (1998). Functional-anatomical correlates of object priming in humans revealed by rapid presentation event-related fMRI. *Neuron, 20,* 285–296.

Buckner, R.L., Petersen, S.E., Ojemann, J.G., Miezin, F.M., Squire, L.R., & Raichle, M.E. (1995). Functional anatomical studies of explicit and implicit memory retrieval tasks. *Journal of Neuroscience, 15,* 12–29.

Burgund, E.D., & Marsolek, C.J. (1997). Letter-case specific priming in the right cerebral hemisphere with a form-specific perceptual identification task. *Brain and Cognition, 35,* 239–258.

Burgund, E.D., & Marsolek, C.J. (in press). Viewpoint-invariant and viewpoint-dependent object recognition in dissociable neural subsystems. *Psychonomic Bulletin & Review.*

Chiarello, C. (1991). Interpretation of word meanings by the cerebral hemispheres: One is not enough. In P.J. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 251–278). Hillsdale, NJ: Erlbaum.

Christman, S. (1989). Perceptual characteristics in visual laterality research. *Brain and Cognition, 11,* 238–257.

Cooper, E.E., Biederman, I., & Hummel, J.E. (1992). Metric invariance in object recognition: A review and further evidence. *Canadian Journal of Psychology, 46,* 191–214.

Corballis, M.C. (1989). Laterality and human evolution. *Psychological Review, 96,* 492–505.

Edelman, S. (1998). Representation is representation of similarities. *Behavioral and Brain Sciences, 21,* 449–498.

Farah, M.J. (1990). *Visual agnosia: Disorders of object recognition and what they tell us about normal vision.* Cambridge, MA: MIT Press.

Farah, M.J. (1991). Patterns of co-occurrence among the associative agnosias: Implications for visual object representation. *Cognitive Neuropsychology, 8,* 1–19.

Goodale, M.A., & Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience, 15,* 20–25.

Hummel, J.E., & Biederman, I. (1992). Dynamic binding in a neural network for shape recognition. *Psychological Review, 99,* 480–517.

Jolicœur, P., Gluck, M.A., & Kosslyn, S.M. (1984). Pictures and names: Making the connection. *Cognitive Psychology, 16,* 243–275.

Knapp, A., & Anderson, J.A. (1984). A signal averaging model for concept formation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 616–637.

Levine, S.C., & Banich, M.T. (1982). Lateral asymmetries in the naming of words and corresponding line drawings. *Brain and Language, 17,* 34–45.

Lowe, D.G. (1985). *Perceptual organization and visual recognition.* Boston: Kluwer.

Marsolek, C.J. (1995). Abstract-visual-form representations in the left cerebral hemisphere. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 375–386.

Marsolek, C.J., & Burgund, E.D. (1997). Computational analyses and hemispheric asymmetries in visual-form recognition. In S. Christman (Ed.), *Cerebral asymmetries in sensory and perceptual processing* (pp. 125–158). Amsterdam: Elsevier.

Marsolek, C.J., Kosslyn, S.M., & Squire L.R. (1992). Form-specific visual priming in the right cerebral hemisphere. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 492–508.

Marsolek, C.J., Schacter, D.L., & Nicholas, C.D. (1996). Form-specific visual priming for new associations in the right cerebral hemisphere. *Memory & Cognition, 24,* 539–556.

Marsolek, C.J., Squire, L.R., Kosslyn, S.M., & Lulenski, M.E. (1994). Form-specific explicit and implicit memory in the right cerebral hemisphere. *Neuropsychology, 8,* 588–597.

McClelland, J.L., & Rumelhart, D.E. (1985). Distributed memory and the representation of general and specific information. *Journal of Experimental Psychology: General, 114,* 159–188.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9,* 97–113.

Roediger, H.L., Rajaram, S., & Srinivas, K. (1990). Specifying criteria for postulating memory systems. *Annals of the New York Academy of Sciences, 608,* 572–595.

Rosch, E., Mervis, C.B., Gray, W.D., Johnson, D.M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8,* 382–439.

Sergent, J., & Hellige, J.B. (1986). Role of input factors in visual-field asymmetries. *Brain and Cognition, 5,* 174–199.

Srinivas, K. (1993). Perceptual specificity in nonverbal priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 582–602.

Tarr, M.J. (1995). Rotating objects to recognize them: A case study on the role of viewpoint dependency in the recognition of three-dimensional objects. *Psychonomic Bulletin & Review, 2,* 55–82.

Tarr, M.J., & Bülthoff, H.H. (1995). Is human object recognition better described by geon structural descriptions or by multiple views? Comment on Biederman and Gerhardstein (1993). *Journal of Experimental Psychology: Human Perception and Performance, 21,* 1494–1505.

Ullman, S. (1996). *High-level vision: Object recognition and visual cognition.* Cambridge, MA: MIT Press.

Ungerleider, L.G., & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale, & R.J.W. Mansfield (Eds.), *The analysis of visual behavior* (pp. 549–586). Cambridge, MA: MIT Press.

(RECEIVED 1/21/98; REVISION ACCEPTED 5/7/98)