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Priming and Recognition of Transformed Three-Dimensional Objects: Effects of Size and Reflection

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In 2 experiments exploring memory for unfamiliar 3-dimensional objects, Ss studied drawings under conditions that encouraged encoding of global object structure. Implicit memory for objects was assessed by a judgment of structural possibility; explicit memory was assessed by recognition. The principal manipulation was the relationship between the sizes or the left–right parities of the studied and tested objects. Priming was observed on the possible–impossible object decision task despite transformations of size or reflection. Recognition, by contrast, was significantly impaired by the transformations. These results suggest that a structural description system constructs representations of objects invariant over size and reflection, whereas a separable episodic system encodes these transformations as properties of an object's distinctive representation in memory.

A phenomenon of considerable theoretical importance and vigorous experimental investigation is the dissociation between performance on explicit and implicit tests of memory. Explicit tests typically require conscious recall or recognition of previously presented material, whereas on implicit tests the effects of such material are demonstrated without requiring the conscious recollection of a specific study episode (e.g., Graf & Schacter, 1985; Schacter, 1987). Implicit effects are generally inferred from performance facilitation in the form of priming in which the beneficial influence of exposure to a particular stimulus is manifested in the absence of explicit instructions to remember the stimulus (e.g., Cofer, 1967; Tulving & Schacter, 1990). One source of evidence for the dissociation between implicit and explicit forms of remembering comes from laboratory studies with intact, adult subjects in whom a variety of experimental manipulations produce differential or even opposite effects on performance on implicit and explicit tasks (for reviews, see Richardson-Klavehn & Bjork, 1988; Schacter, 1987). Another source of evidence comes from reports of essentially normal priming effects in amnesic patients who exhibit severely impaired explicit memory (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Gabrieli, Milberg, Keane, & Corkin, 1990; Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982; Moscovitch, 1982; Schacter, 1985; Schacter & Graf, 1986; Shimamura & Squire, 1984; Warrington & Weiskrantz, 1968, 1974; for a review, see Shimamura, 1986).

Two primary theoretical interpretations of dissociations between performance on implicit and explicit memory tasks and of priming effects themselves have been advanced. One view, which we favor, holds that dissociations between priming and performance on explicit tasks reveal the operation of separable underlying memory systems (cf. Gabrieli et al., 1990; Hayman & Tulving, 1989; Squire, 1987; Schacter, 1987). In particular, Schacter and his associates (Schacter, 1990; Schacter, Cooper, & Delaney, 1990a, 1990b; Tulving & Schacter, 1990) proposed that priming on implicit tests of memory is mediated by a presemantic perceptual representation system. An alternative, although not mutually exclusive, theoretical account holds that dissociations between priming and explicit memory are attributable to different processes operating within a single memory system (e.g., Jacoby, 1983; Mandler, 1985, 1988; Roediger, Weldon, & Challis, 1989).

One version of this latter account proposes that the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977) can serve as a basis for understanding dissociations between performance on implicit and explicit tasks (e.g., Roediger & Blaxton, 1987; Roediger et al., 1989). The general idea is that performance on a memory test is related to the degree to which the processing operations by which an item was initially encoded are reinstated at the time of test; most implicit tests of memory rely strongly on perceptual processing, whereas explicit tests require more semantic or conceptual processing. Evidence supporting this proposal comes from the reported specificity of priming effects to conditions in which the modality and other surface characteristics of study and test items are congruent (e.g., Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987).

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Although most of the research on dissociations between implicit and explicit tests of memory have used verbal materials as stimuli, a number of studies of priming of familiar and unfamiliar nonverbal stimuli have been reported (e.g., Bentin & Moscovitch, 1988; Biederman & Cooper, 1991, in press-a, in press-b; Durso & Johnson, 1979; Gabrieli et al., 1990; Jacoby, Baker, & Brooks, 1989; Kersteen-Tucker, 1991; Kroll & Potter, 1984; Mitchell & Brown, 1988; Musen & Treisman, 1990; Warrington & Weiskrantz, 1968; Weldon & Roediger, 1987; for a review, see Schacter, Delaney, & Merikle, 1990). Of particular relevance to the present experiments are a series of studies described by Schacter et al. (1990a) and Schacter, Cooper, Delaney, Peterson, and Tharan (1991). The stimuli in these experiments were line drawings of unfamiliar, three-dimensional objects. Although all of the drawings depicted novel, meaningless objects that did not have preexisting representations in memory, only half of the objects were possible in the sense of corresponding to structures whose surfaces were arranged such that they could exist in the three-dimensional world. The other half of the drawings depicted impossible structures whose surfaces and edges contained local violations and ambiguities that made is impossible for them to exist as actual three-dimensional objects (cf. Draper, 1978; Penrose & Penrose, 1958).

The purpose of the Schacter et al. (1990a; Schacter, Cooper, Delaney, et al., 1991) experiments was to assess the relationship between performance on implicit and explicit tests of memory for these unfamiliar, three-dimensional objects as a function of a variety of different conditions of encoding. Explicit memory was evaluated by performance on a standard "yes–no" recognition test; implicit memory was assessed by performance on a version of an object decision task (cf. Kroll & Potter, 1984). Specifically, after studying half of the objects, subjects were required to indicate whether individual objects presented for 100 ms were possible or impossible. Facilitation of performance on previously studied compared with nonstudied objects constitutes evidence for implicit memory or priming on this object decision task.

Several key findings reported by Schacter et al. (1990a; Schacter, Cooper, Delaney, et al., 1991) are directly relevant to the present experiments. First, significant priming was obtained on the object decision task but only after study tasks that required the encoding of information about the global three-dimensional structure of individual objects. The structural encoding task that produced the most robust object decision priming required subjects to determine whether each object presented for study faced primarily to the left or to the right. Study conditions involving semantic or elaborative analysis (i.e., requiring subjects to think of a familiar object that each depicted structure reminded them of) as well as conditions involving the encoding of local visual features (i.e., requiring subjects to determine whether each drawing contained more horizontal than vertical lines) failed to produce any significant priming of performance on the object decision task. Second, priming, when observed, was always confined to structurally possible versions of the test objects. Priming for impossible objects was not observed under any conditions despite modifications of instructions emphasizing "impossible" over "possible" responses, minor changes in the nature of the stimulus materials, and manipulations of the number, quality, and duration of exposures to items on the study list (Schacter, Cooper, Delaney, et al., 1991). Finally, marked dissociations between performance on implicit (object decision) and explicit (recognition) tests of memory for these unfamiliar, three-dimensional objects were obtained. Study manipulations designed to enhance the distinctiveness of an object's encoding in memory (e.g., requiring semantic elaboration of each studied object, Schacter et al., 1990a, Experiment 2; repeating presentation of objects on the study list four times, Schacter, Cooper, Delaney, et al., 1991, Experiment 1) produced significant enhancement of recognition performance but either no priming or no change in the magnitude of priming compared with a single-exposure study condition.

The pattern of results just summarized led Schacter et al. (1990a, 1990b; Schacter, Cooper, Delaney, et al., 1991) to argue that priming on the object decision task is supported by a mental representation of the three-dimensional relations that define the structure of an object. Furthermore, the memory system that encodes and represents this structural description of an object is functionally separable from the episodic system that supports performance on explicit tests of memory. This latter system is supported by various sources of information about object properties, including semantic, associative, and functional information, as well as information about local visual features. The structural description system (cf. Riddoch & Humphreys, 1987), in contrast, is presemantic, is specialized for representing global information about visual form and object structure, and is part of a more general perceptual representation system (Schacter, 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990).

This theoretical framework provides a coherent account of the central findings from the Schacter et al. (1990a; Schacter, Cooper, Delaney et al., 1991) experiments described previously. In particular, the hypothesis of a separable structural description system is consistent with the Schacter et al. (1990a) findings that (a) priming on the object decision task was obtained only after study tasks requiring structural (left–right) encoding, and (b) priming of judgments of impossibility was never observed. Presumably this latter finding reflects computational constraints on the structural description system; impossible objects, by definition, cannot be modeled by an internal representation of global relations among components of objects in the three-dimensional world (cf. Schacter, Cooper, Delaney et al., 1991). Finally, we have also found that brain-damaged patients with episodic memory deficits show intact priming on the object decision task (Schacter, Cooper, Tharan, & Rubens, 1991).

Converging evidence for a system for the representation of information about global structural relations—that is distinct from the representational system for semantic, associative information—comes from research in cognitive and clinical neuropsychology on forms of visual object agnosia (for a review, see Farah, 1990). Most suggestive from the present perspective are reports of patients with intact access to knowledge about the structure of objects but with serious impairment in access to information about their semantic and functional properties (e.g., Riddoch & Humphreys, 1987; Warrington, 1982; Warrington & Taylor, 1978). Other patients apparently exhibit a complementary pattern of selective deficits, with impairment in the specific ability to represent the global structure of visual objects (e.g., Ratcliff & Newcombe, 1982). The similarity of these reports to the pattern of laboratory-induced dissociations between access to structural and semantic representations of visual objects (Schacter et al., 1990a; Schacter, Cooper, Delaney et al., 1991) provides converging support for the notion of a system for the representation of structural descriptions of objects, underlying priming on the object decision task, that is distinct from the episodic system mediating explicit recognition.

Our earlier experiments, summarized previously here, established a dissociation between the representational systems supporting implicit and explicit memory for unfamiliar, three-dimensional objects, and they explored the sensitivity of priming and recognition effects to manipulations in conditions of encoding. The aim of the experiments reported here is to go beyond these initial observations by exploring in detail the nature of the proposed underlying systems themselves. Of particular significance is the question of what forms of information about visual objects are represented in the hypothesized structural description and episodic memory systems. We address this question by introducing transformations in visual aspects of objects from the time of study to the time of test, rather than by manipulating the nature of the encoding task as in previous work.

In short, in the present experiments we are seeking to unite theoretical issues and experimental techniques in the area of memory with general considerations about the processes and representations underlying object perception and recognition. Like others (e.g., Biederman, 1987; Marr, 1982; Marr & Nishihara, 1978; Palmer, 1975; Reed, 1974; Sutherland, 1973), we view the computation of a representation of the structural relations among components of an object as a primary function of higher level vision. Our objective is to pose questions about the nature of the information embodied in such structural descriptions of objects that may be investigated *independently* of questions concerning the precise characterization of the components or primitive units, for example, elementary visual features (Sutherland, 1968), generalized cones (Marr, 1982; Marr & Nishihara, 1978), or geons (Biederman, 1987), among which structural relations are computed.

Our general research strategy uses the experimental paradigm introduced by Schacter et al. (1990a) as a tool for exploring the nature of the information embodied in structural description representations, which are hypothesized to mediate object decision priming, and episodic representations, which are thought to support recognition, of unfamiliar, three-dimensional objects. One simplified view of the nature of structural descriptions might hold that only information concerning relations among component units is preserved in the underlying mental representations. In this view, it follows that aspects of visual information irrelevant to the coding of such global relations among components should not be represented in or accessible from structural descriptions of objects. If, by hypothesis, structural description representations of this kind support priming on the object decision task, then variation in information concerning properties such as object size or overall reflectance, which do not contribute to the representation of global structure, should not influence performance on the object decision task. Variation in other forms of information that might serve to enhance or reveal certain relations while obscuring others (e.g., occlusion of intersections, depicted three-dimensional orientation) could contribute to the representation of global structure and consequently affect object decision performance.

The experiments to be reported were designed to examine whether certain forms of information are preserved in structural or episodic representations of objects by asking whether study-to-test changes in those types of information affect object decision performance compared with explicit recognition performance. The logic of our experimental approach is as follows: To the extent that study-to-test changes eliminate or significantly reduce the magnitude of obtained priming or recognition effects, we can conclude that the representational system accessed by the relevant memory task *does preserve* the type of information being changed. However, if obtained priming or recognition effects persist despite study-to-test changes in certain forms of information about objects, we can conclude that the representational system being accessed by the relevant memory test *is not sensitive* to the type of information undergoing change. In Experiment 1, the effects of introducing study-to-test changes in object size on implicit and explicit tests of memory are assessed. Experiment 2 examines the effects of overall reflection on both object decision and recognition tasks.

Experiment 1

Retinal size is a characteristic property of an object that is useful for recognition. In particular, differences in the absolute sizes of objects viewed at the same distance might function as an important source of information for discriminating among them. However, there is little reason to expect on logical grounds that size should be a property encoded in the structural description of an object. Indeed, if a structural description represents only global relations among the components of an object, then invariance over changing retinal size should enhance the generality of such representations. One source of evidence consistent with these logical considerations comes from studies of the neuroanatomical basis of visual object processing (for a review and discussion, see Plaut & Farah, 1990). Both behavioral evidence from monkeys with localized lesions (e.g., Ungerleider, Ganz, & Pribram, 1969) and electrophysiological evidence from the response properties of single cells (e.g., Desimone, Albright, Gross, & Bruce, 1984; Perrett, Rolls, & Caan, 1982; Perrett et al., 1985; Rolls & Baylis, 1986; Sato, Kawamura, & Iwai, 1980; Schwartz, Desimone, Albright, & Gross, 1983) indicate that regions of the inferior temporal cortex play a central role in the size-invariant representation of the structure or shape of visual objects.

Accordingly, we reasoned that size would most likely *not* be represented in the structural description of an unfamiliar three-dimensional object. Thus, we predicted that priming on the possible–impossible object decision task should be relatively unaffected by study-to-test variations in size. In contrast, we expected explicit recognition to suffer as a result of the size manipulation. This is because size seems to be a characteristic property that could enhance the distinctiveness of an object's representation in memory; hence, it is likely to be a useful form of information for the episodic system to encode. Consistent with this idea, research by other investigators (e.g., Jolicoeur, 1987; Jolicoeur & Besner, 1987) provides an empirical basis for predicting that study-to-test changes in the size of target objects should impair recognition performance.

Method

Subjects. The 96 subjects were undergraduate students at Columbia University who participated in the experiment for either course credit or payment of $5.00. Subjects were randomly assigned to the experimental conditions described next.

Stimuli. The experimental materials were line drawings of 40 unfamiliar three-dimensional objects similar to those displayed in Figure 1. Twenty of the objects were possible in that they depicted structures that could exist in the three-dimensional world. Twenty of the objects were impossible in that they contained edge and surface ambiguities resulting in structures that could not physically exist as three-dimensional objects. Eighteen of the 20 possible objects were taken from the set of materials described and used in the experiments reported by Schacter et al. (1990a). The remaining 2 possible objects were drawn from the set used by Schacter, Cooper, & Delaney et al. (1991). (This substitution was necessary because 2 of the 20 objects originally used by Schacter et al., 1990a, contained curved contours; curves are difficult to render on the computer graphics system used to display the stimuli in the present experiment.) All 20 of the impossible objects were taken from the materials used by Schacter, Cooper, Delaney, et al. (1991). It should be noted that all stimuli had previously met the following criteria for inclusion in the experimental set (described more fully in Schacter et al., 1990a; Schacter, Cooper, Delaney et al., 1991): (a) Average intersubject agreement as to the objects' possibility or impossibility was 95% or greater in a pilot study using unlimited exposure durations, and (b) baseline performance from an independent group of subjects for determining whether each object was possible or impossible when displayed for 100 ms was on average approximately 65%.

An additional baseline study was done to aid in selecting the object sizes for the present experiment and to ensure that absolute size was not systematically related to subjects' abilities to determine in the absence of prior study, whether briefly exposed drawings depicted possible or impossible objects. Twenty students viewed balanced 10-item subsets of the 40 selected target objects (along with 10 practice objects, 5 possible objects, and 5 impossible objects) at each of four sizes: 7.7, 11.5, 15.4, and 19.2 degrees of visual angle, at a viewing distance of approximately 50 cm. These sizes represent ratios of 1:1, 1:1.5, 1:2, and 1:2.5, moving from the smallest to the largest object set. The objects were displayed individually on the monitor of a Silicon Graphics Personal IRIS computer, and they appeared as white line drawings on a dark background. Each 100-ms exposure of an object was preceded by an illuminated fixation cross in the center of the screen. Subjects were instructed to press the leftmost button on a mouse if they judged an object to be possible and the rightmost button if they judged an object to be impossible. Baseline accuracy on this object decision task ranged from 60% to 80%, and performance was not systematically related to stimulus size. Consequently, the most extreme size ratio of 1:2.5, corresponding to 7.7 (small) and 19.2 (large) degrees of visual angle, was selected for use in Experiment

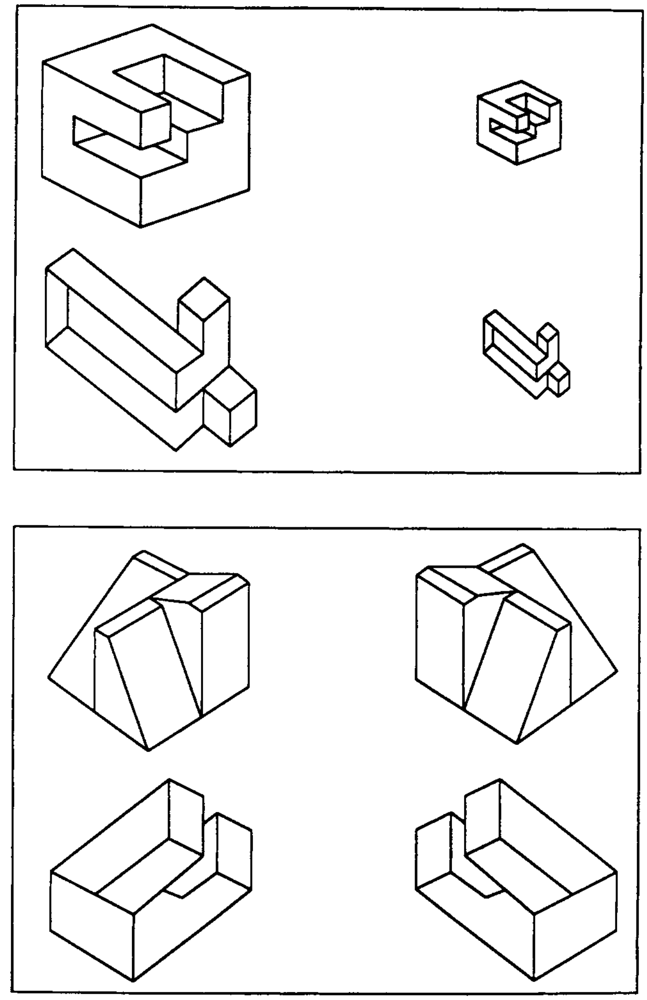

Figure 1. Examples of target objects used in Experiments 1 and 2. (The upper two rows depict a possible [top] and an impossible [bottom] object shown in both small [right] and large [left] sizes. The lower two rows depict a possible [top] and an impossible [bottom] object shown in both reflected [right] and standard [left] versions. See text for further explanation.)

1 to maximize sensitivity to effects of this variable. Within each size category, the 40 target objects were normalized for approximate size by scaling them to fit within a circular reference frame (cf. Schacter, Cooper, Delaney et al., 1991, Experiment 4). Thus, the visual angle specification for each of the stimulus sizes refers to the diameter of this reference frame (i.e., degrees subtended both horizontally and vertically). The top half of Figure 1 displays a possible object and an impossible object in two sizes, the ratio of which corresponds to that between the large and the small sizes used in the present experiment.

Design. The design of the main experiment was a 2 (small vs. large encoded sizes) × 2 (small vs. large tested sizes) × 2 (object decision vs. recognition tasks) × 2 (possible vs. impossible object types) × 2 (studied vs. nonstudied objects) mixed factorial. The first three factors—studied object size, tested object size, and type of memory task—were between-subjects variables. The last two factors—object type and item type—were manipulated within subjects. In addition, the 20 possible and 20 impossible target objects were randomly divided into two subsets, A and B, each containing 10 possible objects and 10 impossible objects. The two subsets were rotated through all experimental conditions, resulting in a completely counterbalanced design in which each subset appeared equally often as studied and nonstudied objects in each cell of the main design.

Procedure. The 96 subjects were tested individually under incidental memory conditions. That is, subjects were initially told that the experiment concerned the perception of objects; they were not informed of the subsequent object decision or recognition task until shortly before it began. Only the structural encoding task used by Schacter et al. (1990a, Experiments 1 and 2) and Schacter, Cooper, Delaney, et al. (1991) was used in all experimental conditions. Subjects were told that a series of line drawings would be presented and that they were to indicate for each whether the depicted object appeared to be facing primarily to the left or to the right. Subjects were instructed to use the entire 5-s exposure period to view each object carefully and make a considered left–right judgment. No mention was made of the possibility or impossibility of the objects at this point in the experiment. Five practice items were then presented, followed by presentation in a random order of 10 possible objects and 10 impossible objects. In this study phase, each object was presented centered on the screen for 5 s. Subjects were instructed to press the rightmost mouse button if the object appeared to be facing to the right and the leftmost mouse button if the object appeared to be facing to the left. After initial presentation of the study list, each of the 20 objects was presented again in a different random order.[1] Half of the subjects studied objects defined as small (7.7 degrees), and the other half of the subjects studied objects defined as large (19.2 degrees).

Immediately after presentation of the study list and completion of the left–right judgments, subjects proceeded to the test phase of the experiment. Half of the subjects participated in the object decision task, and the other half participated in the recognition task.[2] Within each test task, half of the subjects from each (small vs. large) encoding group viewed the test objects (half previously studied and half nonstudied) in the same size as presented during study; the other half of the subjects viewed the test objects in a size (small or large) changed from that presented during the left–right encoding task.

For the subjects who participated in the object decision task, instructions explained the difference between structurally possible and impossible objects and included some examples of both. Instructions emphasized the importance of looking at the fixation cross just before stimulus presentation as well as the brief 100-ms duration of the test objects. Subjects were requested to press the rightmost button of the mouse if they judged an object to be possible and the leftmost button if they determined that the object was impossible. Trials were self-paced; each trial began when the subject depressed the middle mouse button. The object decision task began with presentation of 10 practice trials: 5 displayed possible objects and 5 showed impossible objects. Immediately after practice, the 40 test objects were displayed individually. Twenty of the test trials consisted of possible structures and 20 consisted of impossible structures. Within each possible or impossible drawing type, half of the objects were structures that had been viewed previously during the encoding phase and half had not been seen before.

Subjects who participated in the surprise yes–no recognition task were informed that they would be presented with a series of objects, some of which had been shown during the previous left–right task and some of which were new. Subjects were told to indicate that an object had been presented before by pressing the rightmost button on the mouse and to indicate that an object had not been shown previously by pressing the leftmost button. Instructions emphasized that the yes–no judgments were to be based solely on the shape of the test objects. Ten practice trials, 5 consisting of previously displayed practice items and 5 showing new items, were presented, followed by the 40 test trials. Half of these trials contained possible objects and half contained impossible objects. Within each object type, half of the drawings had been shown during the study phase and half had never been shown before. For each subject, the recognition trials were presented in a random order, and each object was displayed for a maximum of 5 s, disappearing when the subject made the yes–no response.

At the completion of testing, all subjects were told the purpose of the experiment, and they were provided with a written description of the objectives and background of the program of research.

Results

The results of performance on the object decision task and the recognition task were analyzed and are described separately.

Object decision. Table 1 presents the central results for performance on the object decision task, expressed as proportion correct on the possible–impossible judgment, as a function of the main experimental variables: size of encoded item, size of tested item, possible–impossible object type, and studied–nonstudied test item status.

Several important features of these data should be noted. First, for possible objects presented in the same size at encoding and test (conditions SS and LL), there is substantial facilitation of object decision performance on studied items compared with nonstudied items. This is the usual priming effect (cf. Schacter et al., 1990a; Schacter, Cooper, Delaney, et al., 1991; Schacter, Cooper, Tharan, & Rubens, 1991) attributable to structural encoding. The data from the present experiment indicate that the magnitude of priming is not affected by the absolute (small or large) size of the studied and tested objects (.12 and .10, respectively). Second, when possible objects are studied and tested in different sizes (conditions SL and LS), priming of object decision judgments continues to be observed. Again, the magnitude of the effect does not depend strongly on the absolute sizes of the encoded and tested objects, and the amount of facilitation is even slightly greater when size relations at study and test are changed than when they remain the same (for condition SL,

[1] In both Experiments 1 and 2, the convention was adopted to have subjects view each object in the study list twice. Although this procedure differs from that of our previous experiments (e.g., Schacter et al., 1990a), in which the study list was only presented once, it is unlikely to have influenced the results in any meaningful manner. Schacter, Cooper, Delaney et al. (1991) reported that even four exposures of the studied objects resulted in no additional priming over levels obtained with a single study exposure; multiple study presentations did, however, produce an overall increase in the level of recognition performance.

[2] In fact, both groups of subjects participated in both memory tasks but in different orders (i.e., for one group, object decision followed by recognition, and for the other, recognition followed by object decision). However, performance on the second test task was not analyzed for either group of subjects because second-task performance in the present experiment does not illuminate any substantive issues. In the case of object decision followed by recognition, the recognition test is simply a list discrimination task. In the case of recognition followed by object decision, the study-to-test object transformations have already been viewed during the recognition phase. Hence, the object decision task cannot provide an uncontaminated measure of priming of responses to transformed test stimuli.

Table 1
Object Decision Performance: Experiment 1

	Encoding to test relation					
	Same size			Changed size		
Item type	SS	LL	*M*	SL	LS	*M*
	Possible objects					
Studied	.78	.75	.77	.77	.78	.77
Nonstudied	.66	.65	.65	.58	.63	.61
M	.72	.70		.68	.70	
	Impossible objects					
Studied	.58	.73	.66	.73	.66	.70
Nonstudied	.66	.81	.73	.78	.68	.73
M	.62	.77		.75	.67	

Note. SS = studied in small size and tested in small size; LL = studied in large size and tested in large size; SL = studied in small size and tested in large size; LS = studied in large size and tested in small size. Studied = proportion of studied items called "old." Nonstudied = proportion of nonstudied items called "old."

magnitude of priming = .19; for LS, priming = .15). Third, there is no evidence of facilitation of object decision performance on impossible objects in any of the experimental conditions.

Statistical analyses confirm this description of the central results. Two analyses of variance (ANOVAs) were performed on the object decision data: In one, encoded size (small vs. large) and tested size (small vs. large) were treated as separate factors; the other was collapsed over these factors, thus producing a single between-subjects factor of size (same vs. changed from study to test) as well as the within-subject factors of object type (possible vs. impossible) and item type (studied vs. nonstudied). Because the outcomes of these ANOVAs are entirely consistent, only the second ANOVA is reported. The main effect of (studied vs. nonstudied) item type was significant, $F(1, 44) = 4.75$, $p < .035$, $MS_e = .018$, as was the interaction between (studied vs. nonstudied) item type and (possible vs. impossible) object type, $F(1, 44) = 26.20$, $p < .0001$, $MS_e = 0.17$. Importantly, the main effect of (same vs. changed) size did not approach statistical significance, $F(1, 44) < 1$, nor did this factor enter into any significant interactions (all $Fs < 1$).[3]

It is worth noting that the data in Table 1 indicate the presence of negative priming for impossible objects or the tendency to respond more correctly to nonstudied items than to studied items. The presence of such negative priming raises the question of response bias in these data; in particular, the possibility that priming observed for possible objects may reflect nothing more than a generalized tendency to respond "possible" to any object, possible or impossible, viewed at the time of initial encoding (for extensive discussion of this point, see Schacter et al., 1990a; Schacter, Cooper, Delaney, et al., 1991). Evidence against this possibility is provided by the significant main effect of studied versus nonstudied objects, which indicates that the overall *accuracy* of object decision performance was increased by the study exposure.

To evaluate further the response bias issue, we conducted an analysis of the strength of association between the variables of object type (possible–impossible) and responses (possible–impossible) by computing the Yule Q statistic, a special case of the gamma correlation for analyzing association in 2 × 2 contingency tables (see Goodman & Kruskal, 1954; Hayman & Tulving, 1989; Nelson, 1984, 1990). Following the procedure recommended by Nelson (1984, 1990) and Reynolds (1977), 2 × 2 contingency tables defined by the orthogonal combination of object type and responses were created for each subject, and Q values were computed separately for studied and nonstudied items. The thrust of this analysis is to indicate the strength of association (range = +1 to −1) between subjects' responses and the actual (possible–impossible) type of object for each of the experimental conditions. To the extent that priming results from an increase in the accuracy of object decision performance as a consequence of study rather than from a general bias to respond "possible" to all studied items, the Q (or stimulus–response association) value for studied items should be higher than the Q value for nonstudied items. For the present data, the Q value for studied objects was .65; for nonstudied objects, $Q = .54$; and these Q values are significantly different, $t(47) = 2.003$, $p < .048$.

Recognition memory. Table 2 displays the central results for recognition, expressed in terms of hits, false alarms, and a corrected recognition measure of hits minus false alarms, as a function of the main experimental variables. These data differ quite clearly from the object decision data with respect to the effect of the size manipulation on accuracy of performance. Most important, changing the size of test objects from that initially viewed during encoding (conditions SL and LS) produced substantial impairment of recognition performance compared with conditions in which the study-to-test size relation was preserved (SS and LL). As the mean recognition scores in Table 2 illustrate, this outcome was obtained for both possible and impossible objects, and it is apparent in both the hit rate and hits minus false alarms measures of performance. As in the results for the object decision task, however, the absolute sizes of encoded and tested objects have little influence on accuracy of remembering previously studied items (i.e., hit rates in condition SS vs. LL and condition SL vs. LS); rather, the *relation* between studied and tested object sizes determines the level of this measure of recognition.[4]

ANOVAs performed on the hit rates and on the hits minus false alarms corrected recognition measure yielded virtually identical outcomes as did ANOVAs with encoded size (small

[3] ANOVAs reported for both experiments were based on data from individual subjects rather than from individual items. However, analyses computed over items confirmed the same central results as those obtained in the subject-based analyses.

[4] Although not reliable at a statistical level, inspection of the recognition results in Table 2 suggests that, for possible objects and for the hits–false alarms measure only, the bulk of the difference between recognition performance for same versus changed-size stimuli is accounted for by the difference between the LL condition and all of the others. This is attributable to the unusually high false-alarm rate in the SS condition; comparison of hit rates indicates that performance in both same size conditions is substantially superior to performance in both changed size conditions (.78 and .88 for SS and LL, .68 and .66 for SL and LS).

Table 2
Recognition Performance: Experiment 1

	Encoding to test relation					
	Same size			Changed size		
Item type	SS	LL	*M*	SL	LS	*M*
	Possible objects					
Studied	.78	.88	.83	.68	.66	.67
Nonstudied	.31	.13	.22	.23	.15	.19
Hits–false alarms	.47	.76	.61	.46	.51	.48
	Impossible objects					
Studied	.78	.82	.80	.66	.69	.68
Nonstudied	.26	.24	.25	.23	.26	.25
Hits–false alarms	.52	.58	.55	.43	.43	.43

Note. SS = studied in small size and tested in small size; LL = studied in large size and tested in large size; SL = studied in small size and tested in large size; LS = studied in large size and tested in small size. Studied = proportion of studied items called "old" (hit rate); Nonstudied = proportion of nonstudied items called "old" (false alarm rate).

vs. large) and tested size (small vs. large) treated as separate factors and with a single between-subjects factor of size (same vs. changed from study to test). Thus, we report only the results of the hits minus false alarms ANOVA with size (same vs. changed) as the between-subjects factor. The only effect in this analysis to achieve statistical significance was the main effect of (same vs. changed) size, $F(1, 44) = 6.45$, $p < .01$, $MS_e = .062$.

Discussion

Several features of the results of Experiment 1 merit special attention. Some replicate theoretically important findings from earlier work; others provide new evidence concerning the representation and retrieval of information about three-dimensional objects. First, significant priming of object decision performance was obtained for possible objects under conditions of structural (left–right) encoding. The analyses reported previously here indicate that this facilitation is not attributable solely to a bias to respond "possible" to previously studied items. Thus, we have replicated one of the central findings of the earlier studies of Schacter et al. (1990a, 1990b) and have provided yet another demonstration of implicit memory for unfamiliar three-dimensional objects with no preexisting representation in memory. Second, no priming of object decision judgments was exhibited for impossible objects under any of the experimental conditions. This replicates the results of Schacter et al. (1991a) and provides additional evidence for the notion that object decision priming, when obtained, is supported by a mental representation of the global structure and relations among components of an object. That is, priming is not observed for impossible objects because of an inability to represent impossibility at the level of global structure; rather, the computation of impossibility relies on the detection of local edge and surface inconsistencies. This conclusion corresponds well with Hochberg's (1968) finding of the difficulty that subjects experience in integrating successive views of impossible objects into global structures. Third, we have demonstrated a marked dissociation between performance on implicit (object decision) and explicit (recognition) tests of memory. The presence of this dissociation is consistent with the idea that separable memory systems mediate the two types of judgments (cf. Schacter, 1990; Tulving & Schacter, 1990).

The *nature* of the observed dissociation constitutes our most important experimental finding. It goes beyond our previous results by providing evidence concerning whether a particular kind of information about visual objects (namely, size) is preserved in structural description or episodic representations of those objects. Specifically, the variable of size relation between studied and tested objects failed to produce an effect on performance on the object decision task, but it produced a marked effect on the level of explicit recognition memory. The lefthand section of Figure 2 provides a graphic summary of the differential effects of the study-to-test size relation variable on performance on the implicit (object decision, top panel) and the explicit (recognition, bottom panel) memory tasks. The generally high level and invariance of priming on the object decision task, for both same and changed size relations, provide compelling evidence that the structural description representations that support facilitation of implicit memory for unfamiliar three-dimensional objects do not incorporate information concerning retinal size. The representational system underlying recognition, however, does appear sensitive to size in that changing the relationship between studied and tested object sizes produces a sharp decline in recognition performance.

One potential objection to our previous conclusions concerning differences in the sensitivity of structural description and episodic representations to information about object size centers around the ability of our experimental procedure to detect differences attributable to manipulation of the size variable. That is, might the conclusion that size information is not incorporated in structural description representations rest on an inappropriate acceptance of the null hypothesis (i.e., no differences in magnitude of priming on the object decision task resulting from study-to-test changes in object size) in a situation with inadequate power to detect differences? A number of considerations legislate against this possibility. First, our argument that structural descriptions of objects fail to incorporate size information requires that priming be obtained in both same and changed size conditions. Note that this requirement demands a *positive* result, namely, facilitation of object decision performance in both cases, rather than relying on acceptance of an absent or negative effect. Second, even under the stringent criterion of equivalent magnitudes of priming in same and changed size conditions, the results of Experiment 1 fare extremely well. In addition to the statistical analyses reported previously, inspection of Figure 2 indicates (nonsignificantly) *more* facilitation of object decision performance with study-to-test variation in object size than in the same size condition. Third, and most important, although Experiment 1 *did not* reveal a difference in magnitude of *priming* resulting from size variation, it *did* demonstrate a statistically reliable decrement in *recognition* attributable to manipulation of this same variable. Thus, we feel confident that our experimental situation is capable of

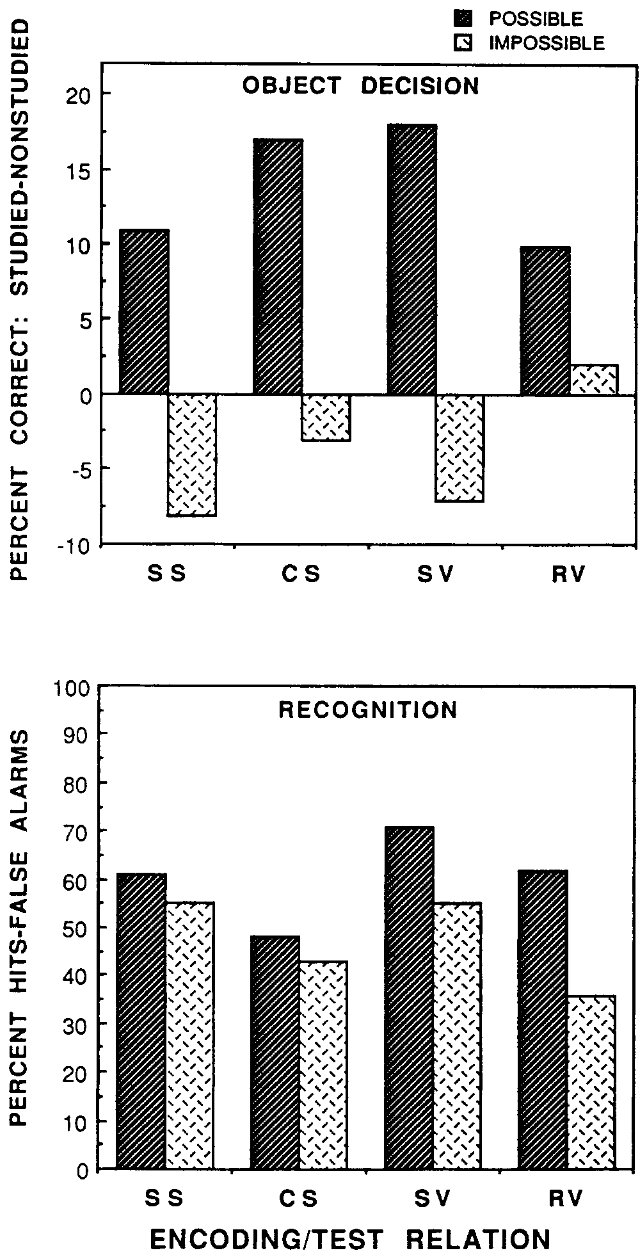

Figure 2. Summary of results from Experiments 1 and 2. (The upper panel displays priming on the object decision task, expressed as percentage correct on studied items minus nonstudied items, as a function of object type [possible vs. impossible] and relationship between studied and tested objects. SS = same size; CS = changed size; SV = standard version; RV = reflected version. The lower panel displays recognition, expressed as percentage of hits minus false alarms, as a function of the same variables. See text for further explanation.)

producing and detecting performance differences, when those differences are there to be detected.

In summary, the results shown in Figure 2 and our interpretations of them make good sense on logical grounds. Furthermore, they correspond nicely to the findings of other investigators using experimental materials and tasks quite different from our own. Specifically, Biederman and Cooper (in press-b) reported an invariance of priming effects over changes in object size. Their paradigm used a repetition priming procedure, pictures of familiar objects as stimuli, and latency for object naming as the principal and most sensitive dependent measure. The consistency of these investigators' results with those of the present Experiment 1, which used an implicit memory task arguably closer to the level of perceptual or visual representation than the name-identification task of Biederman and Cooper (in press-b), lends strong support to the claim that the structural description representations underlying priming do not incorporate information concerning object size.

The recognition results displayed in Table 2 and Figure 2 (bottom left) can also be related to the findings of other researchers. Jolicoeur (1987) documented an impairment in recognition memory for drawings of unfamiliar objects under conditions of study-to-test size variation; in a recognition version of their object-naming experiment, Biederman and Cooper (in press-b) found that size change caused a deterioration in both speed and accuracy of recognition. Similarly, the general finding in the literature on same–different matching of objects differing in size (e.g., Bundesen & Larsen, 1975; Bundesen, Larsen, & Farrell, 1981; Jolicoeur & Besner, 1987; Larsen & Bundesen, 1978) is that time to make the comparison increases with increasing size discrepancy (for conflicting results, see, e.g., Kubovy & Podgorny, 1981). This body of evidence, then, corresponds well with our finding of recognition impairment after a transformation in the size of unfamiliar three-dimensional objects.

A final result of interest from Experiment 1 concerns the difference in the perception of impossible objects in the implicit and the explicit memory tasks. As noted already, we failed to obtain object decision priming for impossible objects owing, we have argued (Schacter, Cooper, Delaney et al., 1991), to computational constraints on the construction of structural descriptions of such objects, but we did observe robust priming for possible objects. In the explicit recognition situation, however, the variable of size transformation had parallel effects on possible and impossible objects; possible objects yielded overall higher levels of recognition. This finding reinforces our claim of a dissociation between the representational systems underlying performance on implicit and explicit memory tasks. That is, the variable of size change as well as the variable of object type affect these indexes of memory differentially. Apparently, the system supporting recognition is capable of constructing some sort of mental representation of an impossible object (perhaps a piecemeal set of features; cf. Hochberg, 1968), and this representation is coded with respect to size.

Experiment 2

Another salient property of an object is its overall parity or left–right orientation in three-dimensional space. Experiment 2 explored the effects of manipulating this property on both object decision judgments and explicit recognition. As with the feature of size, there are logical and empirical grounds for suspecting that left–right orientation is not coded in the structural description representation of an object. If structural descriptions embody only information about global relations among components of objects, then such relations will remain invariant despite a transformation of overall reflection about the vertical axis. Research examining the discrimination abilities of monkeys with inferior temporal cortex lesions (e.g., Cowey & Gross, 1970; Gross, 1973; 1978; Gross, Lewis, & Plaisier, 1975) indicates that performance on mirror-image discriminations with visual patterns is not impaired following lesioning. Thus, inferior temporal cortex is implicated as a neural locus for the representation of information about object structure independent of size and mirror-image reflection. On the basis of these logical considerations and suggestive experimental reports, we reasoned that facilitation of object decision performance should be observed despite study-to-test changes in the left–right orientation of our unfamiliar three-dimensional objects. If left–right orientation, like size, serves as a property that enhances the distinctiveness of an object's episodic representation in memory, then we should expect the study-to-test transformation of overall reflection to produce impairment of explicit recognition performance.

Method

Subjects. Sixty-four undergraduate students at Columbia University participated in the experiment for either course credit or payment of $5.00. Subjects were randomly assigned to the experimental conditions described next.

Stimuli. The stimulus set was composed of line drawings of 48 unfamiliar three-dimensional objects similar to those displayed in Figure 1. Twenty-four of the drawings depicted possible three-dimensional objects, and the other 24 represented impossible structures. The entire set of drawings contained all 40 of the objects used in Experiment 1. Eight objects—4 possible and 4 impossible—were added to increase the number of observations per cell of the experimental design to a level that would permit the stimulus transformation variable to be manipulated within rather than between subjects. The 4 additional possible objects were taken from the set used by Schacter, Cooper, Delaney et al. (1991), and the 4 additional impossible objects came from the set used by Schacter et al. (1990a). All 48 objects met the joint criteria for inclusion in the stimulus set described in Experiment 1.

During testing, the objects were displayed individually on the monitor of a Silicon Graphics Personal IRIS computer, and they appeared as white line drawings on a dark background. Objects were normalized for approximate size by scaling them to fit within a circular reference frame (cf. Schacter, Cooper, Delaney et al., 1991, Experiment 4). Angular subtension of the circular frame was 8 degrees at a viewing distance of approximately 50 cm. The bottom panel of Figure 1 shows a possible object and an impossible object from the stimulus set displayed in both standard and reflected versions.

Design. The design of the experiment was a 2 (standard vs. reflected test versions) × 2 (possible vs. impossible object types) × 2 (studied vs. nonstudied item types) × 2 (object decision vs. recognition memory tasks) mixed factorial. All factors except the last test task factor were within-subject variables. The 24 possible and 24 impossible objects were randomly assigned to one of two object groups. Each object group contained 12 possible and 12 impossible objects. Both object groups appeared equally often in the standard and the reflected versions and as studied and nonstudied items.

Procedure. The 64 subjects were tested individually under incidental memory conditions. The procedure was identical to that described for Experiment 1, except for the following key differences: In the present experiment, the overall left–right orientation of test objects was varied, rather than their sizes as in Experiment 1. Because stimulus transformation was a within-subject factor in the present experiment, all subjects in all experimental conditions studied objects displayed in the arbitrarily defined standard orientation. Half of the test objects were presented in the standard orientation, and half were presented as mirror images or reflected versions. Order of presentation of the test objects was random.

Results

As in Experiment 1, object decision data and recognition data were analyzed separately.

Object decision. Table 3 shows the central results for performance on the object decision task, expressed as proportion correct on the possible–impossible judgment, as a function of the main experimental variables. Note, first, that overall accuracy for possible objects is .13 higher for studied than for nonstudied items, indicating the presence of priming. For possible objects viewed in the standard orientation at both study and test, this priming effect is extremely large (.18). For possible objects presented as mirror images or reflected versions at the time of test, the magnitude of priming is decreased but remains substantial (.10). Second, there is essentially no evidence of priming for impossible objects regardless of the relationship between the versions presented for study and at test. When impossible objects are studied in the standard version and tested in the reflected orientation, accuracy is slightly (.02) higher for studied than for nonstudied items. For impossible objects displayed in the standard version at both study and test, some negative priming (−.07) is exhibited. Combined across possible and impossible objects, the overall priming effects in the standard (.06) and reflected (.06) orientations are identical.

ANOVA confirmed the pattern of results described previously. The main effect of (studied vs. nonstudied) item type was significant, $F(1, 31) = 9.57$, $p < .005$, $MS_e = .02$; the main effect of (possible vs. impossible) object type was significant, $F(1, 31) = 7.21$, $p < .02$, $MS_e = .05$; and the interaction of these two variables was statistically reliable, $F(1, 31) = 11.10$, $p < .002$, $MS_e = .04$. In addition, the three-way interaction of Item Type × Object Type × Version (standard

Table 3
Object Decision Performance: Experiment 2

Item type	Encoding to test relation: Standard	Reflected	*M*
	Possible objects		
Studied	.89	.82	.85
Nonstudied	.71	.72	.72
M	.80	.77	
	Impossible objects		
Studied	.70	.70	.70
Nonstudied	.77	.68	.72
M	.73	.69	

Note. Studied = proportion of studied items called "old"; Nonstudied = proportion of nonstudied items called "old."

vs. reflected) was significant, $F(1, 31) = 5.06$, $p < .04$, $MS_e = .03$. Importantly, the main effect of version (standard vs. reflected) did not achieve the level of significance, $F(1, 31) = 2.73$, $p > .11$, $MS_e = .03$, nor did this factor produce any significant two-way interactions with other factors (all Fs < 1).

As in Experiment 1, we assessed the potential contribution of a bias to respond "possible" to all studied objects, regardless of the actual possible or impossible type, to the priming results shown in Table 3. That a significant main effect of studied versus nonstudied items was observed indicates that the accuracy of object decision performance was facilitated by the study task. We also computed Yule's Q values—measures of strength of association between the variables of object type (possible–impossible) and subjects' responses (possible–impossible)—separately for studied and for nonstudied items. For the data displayed in Table 3, the Q for studied items (.78) and the Q for nonstudied items (.66) are significantly different, $t(31) = 3.13$, $p < .004$, providing further evidence that study of objects increased the accuracy of object decision performance rather than creating a bias to respond "possible" to previously viewed items.

Recognition memory. The principal results of the explicit recognition task are displayed in Table 4, expressed in terms of hits, false alarms, and a corrected recognition measure of hits minus false alarms, as a function of the main experimental variables. Note, in particular, that recognition is impaired, as assessed by each of the three performance measures, when reflected versions of the objects viewed at study are presented at the time of test compared with the level of recognition exhibited when both studied and tested objects are presented in the standard left–right orientation. Furthermore, although the recognition impairment is greater (on all measures) for impossible than for possible objects, the same general pattern is apparent for both object types.

Two ANOVAs were conducted using hit rates and hits minus false alarms as the dependent variables. The two ANOVAs yielded virtually identical outcomes, both substantiating the patterns described previously, so only the results of the second ANOVA are reported. The only two terms in the ANOVA to achieve statistical significance were the main effects of version (standard vs. reflected), $F(1, 24) = 10.67$, $p < .004$, $MS_e = .07$, and of object type (possible vs. impossible), $F(1, 24) = 40.65$, $p < .03$, $MS_e = .03$.

Table 4
Recognition Performance: Experiment 2

Item type	Encoding to test relation: Standard	Reflected	*M*
	Possible objects		
Studied	.83	.78	.80
Nonstudied	.12	.16	.14
Hits–false alarms	.71	.62	.66
	Impossible objects		
Studied	.77	.63	.70
Nonstudied	.22	.27	.25
Hits–false alarms	.55	.36	.45

Note. Studied = proportion of studied items called "old" (hit rate); Nonstudied = proportion of nonstudied items called "old" (false alarm rate).

Discussion

The results of Experiment 2, examining the effects of left–right reversal on object decision priming and explicit recognition, parallel quite nicely the study-to-test size variation findings from Experiment 1. Although not as clear-cut as the results of Experiment 1, all theoretically important outcomes of Experiment 2 are statistically reliable. The key findings can be summarized as follows: First, robust priming of object decision performance was obtained for possible but not for impossible objects. Second, priming for possible objects continued to be exhibited, although at a somewhat attenuated level, despite study-to-test variation in the left–right orientation of possible three-dimensional objects. Third, marked dissociations of the effects of the variables of object version (standard vs. reflected) and object type (possible vs. impossible) on priming and recognition were observed. The righthand sections of Figure 2 provide a convenient summary of these results. Note, in particular, that although priming is evident even for reflected versions of possible test objects (top panel), recognition performance (bottom panel) declines when study-to-test changes in left–right orientation are introduced. Furthermore, recognition impairment occurs for both possible and impossible test objects; the complementary facilitation of object decision performance is not obtained for impossible objects under any of the experimental conditions.

That the magnitude of priming for possible objects on the implicit memory task is decreased somewhat when studied and tested objects are mirror images, relative to conditions in which the objects are the same in version, may at first glance appear somewhat problematic for interpreting the results of Experiment 2. We think not for a number of reasons. First, an additional analysis (suggested by one of the reviewers) comparing the level of object decision performance on studied, possible, untransformed test objects (.89) with that obtained for corresponding reflected versions (.82) failed to find a significant difference, $t(31) = 1.54$, $p > .05$. This analysis thus confirms the finding of those reported previously, namely, that the amounts of facilitation on the object decision task obtained for possible test objects in standard and reflected versions are not distinguishable statistically. Second, as noted in the Results section, when level of priming is collapsed over possible and impossible objects, standard and reflected versions produce identical results. Third, the (.10) facilitation of object decision performance to reflected test objects indicates substantial priming well within the range that we have come to expect from earlier studies (cf. Schacter et al., 1990a, 1990b; Schacter, Cooper, Delaney et al., 1991; Schacter, Cooper, Tharan, & Rubens, 1991); this level of priming is being compared with an unusually large (.18) amount of priming yielded by the standard condition.

Thus, the pattern of results from Experiment 2 leads us to conclude that parity, or overall left–right orientation, like size, is not incorporated in the structural description representations of objects that mediate priming. However, the episodic system underlying explicit recognition does appear sensitive to the left–right orientation of these unfamiliar three-dimensional objects. In addition, we again find evidence, as in Experiment 1, that the episodic system is is able to generate and to access for purposes of retrieval representations of impossible objects. Our results for object decision performance correspond well to some aspects of the data recently reported by Biederman and Cooper (in press-a). Using stimulus materials and experimental procedures quite different from our own (described in the Discussion section of Experiment 1), these investigators found that repetition priming for naming briefly presented pictures of familiar objects is exhibited even when the test pictures are mirror images of those displayed in the initial presentation. The explicit recognition measure used by Biederman and Cooper (in press-a) involved memory for the left–right orientation of initially presented objects rather than "old–new" recognition as in our procedure. We expect that had these investigators included a recognition measure like the "yes–no" discrimination in the present Experiment 2, they would have found, as we have, an impairment in recognition of reversed versions of the test pictures.

General Discussion

The central results of our experiments have implications for several key theoretical issues in the areas of object representation and memory. We briefly discuss three issues.

Nature of Structural Description Representations

The results of Experiments 1 and 2 are entirely consistent with the idea, described in earlier articles (Schacter et al., 1990a, 1990b; Schacter, Cooper, Delaney, et al., 1991; Schacter, Cooper, Tharan, & Rubens, 1991), that priming on the object decision task is supported by a system that encodes the global, three-dimensional structure and relations among components of unfamiliar visual objects. Results of previous experiments indicate that this structural description system cannot compute globally consistent representations of impossible structures (Schacter, Cooper, Delaney et al., 1991), and the failure to observe priming of such objects in the present experiments confirms this idea. Furthermore, structural description representations appear to be constructed as a result of study tasks that require attention to global aspects of the organization of surfaces of objects (such as the left–right encoding task used in the present experiments) but not from tasks that require elaboration or the attribution of meaning to unfamiliar objects (Schacter et al., 1990a, Experiment 2). The present experiments add to our characterization of the properties of structural descriptions by demonstrating that such representations are abstract in the sense of being insensitive to or invariant over the size and the left–right orientation of objects.

We have speculated that regions of inferior temporal (IT) cortex might constitute the neuroanatomical locus of the structural description system that produces priming in our object decision task (Schacter, Cooper, Tharan, & Rubens, 1991). Evidence from behavioral studies of animals with lesions in IT and from neurophysiological studies of the response properties of single units in this area, described previously here and reviewed in Plaut and Farah (1990), is clearly consistent with this proposal. Cells in IT appear to be sensitive to global, stable properties of objects (such as shape) but not selectively responsive to object attributes that change with minor variation in conditions of viewing. These are just the properties that should prove useful for a representational system dedicated to coding invariants of perceptual structure like the structural description system that we have explored in the present experiments. (For further discussion of the relation between the structural description system and other, related presemantic subsystems of perceptual representation, see Schacter, 1990; Schacter et al., 1990a; Schacter, Cooper, Delaney et al., 1991; Schacter, Cooper, Tharan, & Rubens, 1991; Tulving & Schacter, 1990.)

An important question remaining for further research concerns what properties of the representation of objects the structural description system does incorporate as well as which properties, in addition to size and parity, structural descriptions are invariant with respect to. If we take seriously the proposal that IT is the locus of the structural description system supporting object decision priming, then several tentative predictions (some of which we are in the process of testing) can be advanced. Representations of objects in IT appear to be abstracted over the properties of size, location, and to some extent picture-plane orientation, although the evidence is conflicting (see Gross, 1978; Holmes & Gross, 1984; for a review, Plaut & Farah, 1990). Thus, we expect to observe priming on the object decision task despite study-to-test changes in these object properties. Some evidence suggests that IT neurons are selective to texture and depicted three-dimensional orientation of objects as well as to global shape (e.g., Desimone et al., 1984; Desimone, Schein, Moran, & Ungerleider, 1985; Perrett et al., 1985; Schwartz et al., 1983). We might expect that structural descriptions of objects represent these latter stimulus dimensions; hence, priming of object decision performance might not be exhibited after study-to-test transformations of such properties.

Nature of Episodic Representations of Objects

An issue of considerable importance concerns the nature of the representations of unfamiliar three-dimensional objects that underlie explicit recognition. Data from our present and previous experiments highlight a number of encoding, stimulus, and subject manipulations that produce marked effects on the level of explicit memory while having little or no effect on object decision priming. Encoding or study-task conditions that produce enhancement of recognition performance include multiple exposures to the study list (Schacter, Cooper, Delaney et al., 1991, Experiment 1), meaningful elaboration of the encoded objects (Schacter et al., 1990a, Experiments 2 and 3), and encoding the list twice under different study instructions (Schacter, Cooper, Delaney et al., 1991, Experiment 3). Stimulus manipulations that reduce the level of explicit recognition include the size and reflection transformations introduced in the present Experiments 1 and 2. In addition, we consistently observe that overall recognition of impossible objects is lower than of possible objects, although both types of objects are affected by the experimental manipulations cited previously here in similar ways. Finally, subject manipulations of organic amnesia (Schacter, Cooper, Tharan, & Rubens, 1991) and age (Schacter, Cooper, & Valdiserri, in press) impair recognition performance while sparing object decision priming.

These patterns of recognition performance have led us to conclude that explicit recognition of unfamiliar three-dimensional objects involves the episodic memory system (Tulving, 1972, 1983). That is, episodic memory relies crucially on access to information about the distinctive spatial, temporal, contextual, and semantic aspects of objects that differentiate them from each other. Accordingly, any of these sources of information that are part of the conditions under which objects are encoded can be expected to enhance distinctiveness and, hence, the accessibility of the representation of an object to episodic retrieval processes. Any of these sources of distinctive information that are transformed from study to test (e.g., object size and left–right orientation as in Experiments 1 and 2) can be expected to impair explicit recognition.

We view the information contained in structural descriptions of objects as just one of many sources of information used by the episodic system that underlies explicit recognition. A significant problem for future investigation concerns a clarification of the contribution of structural description representations to episodic recognition. At present, we can simply conclude, based on the data from Experiments 1 and 2, that size and left–right orientation are aspects of visual objects that are represented by the episodic system but not by the structural description system.

Nature of Underlying Memory Systems

We noted early in the article that much of the evidence demonstrating priming effects and dissociations between implicit and explicit tests of memory could be interpreted either as supporting the idea of multiple, separable underlying memory systems (e.g., Schacter, 1990; Schacter et al., 1990a; Schacter, Cooper, Delaney, et al., 1991; Schacter, Cooper, Tharan, & Rubens, 1991; Tulving & Schacter, 1990) or as being within the framework of transfer-appropriate processing (e.g., Roediger & Blaxton, 1987; Roediger et al., 1989). This latter approach views priming as the outcome of a reinstatement at the time of testing of the processing operations by which an item was initially encoded.

The data from Experiments 1 and 2, although not decisive, seem to us to be more compatible with a multiple-systems view than with the transfer-appropriate processing formulation. In particular, the finding that study-to-test changes in object size and left–right orientation produce robust priming of equal (Experiment 1) or substantial (Experiment 2) magnitude, when compared with conditions in which size and reflection relations remain constant from study to test, appears difficult to account for in a satisfying manner by the principle of transfer-appropriate processing. That is, if similarity in processing operations at encoding and test are responsible for the existence of priming, then we should expect that changes in stimulus properties from study to test would undermine the similarity of processing operations and thus produce conditions unfavorable for the occurrence of priming on the object decision task. Indeed, advocates of transfer-appropriate processing have offered just this kind of analysis to account for observed effects of study-to-test changes in various kinds of surface information on implicit tasks such as fragment completion and perceptual identification (e.g., Roediger et al., 1989).

It is, of course, possible to modify the transfer-appropriate processing account to accommodate our findings by claiming that size and left–right orientation are not initially encoded by the processing operations active at the time of study. However, this modification then faces the serious problem of explaining why size and reflection variations do produce substantial effects on explicit recognition performance; if extended even further, this account becomes indistinguishable from our proposal of separate representational systems for information concerning global object structure (the structural description system) and information concerning distinctive visual, semantic, and contextual properties of objects (the episodic system). In short, we view the results of the present Experiments 1 and 2—along with demonstrations of stochastic independence between performance on implicit and explicit tests of memory (e.g., Hayman & Tulving, 1989; Musen & Treisman, 1990; Schacter et al., 1990a) and demonstrations of spared implicit memory with impaired explicit memory in amnesic patients (e.g., Schacter, Cooper, Tharan, & Rubens, 1991)—as lending strong support to the multiple-systems formulation.

The results of Experiments 1 and 2 raise many questions in addition to those just addressed, and our interpretations leave many issues unresolved. In addition to further questions concerning forms of information represented in structural descriptions of objects, our results leave open the issue of what role, if any, structural description representations play in recognition and other high-level visual tasks (see Cooper, 1988, 1989, 1990, 1991, for discussions). Another important question concerns the possible relationship between the dissociable representational systems that we are examining and the distinguishable processing subsystems proposed by other investigators (e.g., Kosslyn, 1987). Still another matter of interest concerns the generality of the present findings to other sets of experimental materials and other tests of implicit and explicit memory. All of these questions and issues are foci of attention in our ongoing program of research.

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