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Priming of Visual and Functional Knowledge on a Semantic Classification Task

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Several lines of evidence suggest that semantic memory may be organized according to domain-specific attributes (e.g., visual or functional). Repetition priming both within and across these semantic knowledge domains was measured in 4 experiments to determine whether retrieval of one attribute can occur independently of retrieval of other attributes. The authors found a strong same-attribute priming advantage that persisted even when the classification task differed between study and test. Also evident was a small but consistent cross-attribute priming effect. Cross-attribute priming was not affected by changes in the modality of the test item, suggesting that the effect reflects the repetition of conceptual, and not perceptual, processes. On the basis of these results, the authors suggest that conceptual priming reflects the recapitulation of both domain-specific and nonspecific semantic processing.

Implicit memory is a general term to describe any changes in behavior that do not depend on the conscious recollection of the experience that resulted in those changes. Although the term has been applied to phenomenon ranging from classical conditioning to skill learning, the most common laboratory measurement of implicit memory comes from indirect tests of memory performance collectively termed repetition priming tests. *Repetition priming* is defined as any improvement in speed or accuracy following repeated exposure to a stimulus.

Long-Term Conceptual Priming

Repetition priming increases as a function of the extent to which the mental processes engaged during the initial encounter with a stimulus are recapitulated during a subsequent encounter with the same stimulus; this effect has been termed transfer appropriate processing (Roediger, Weldon, & Challis, 1989). When these processes require a conceptual or semantic analysis of the stimulus meaning, as opposed to an analysis of the form of the stimulus, the priming is described as conceptually driven, or conceptual.

In conceptual priming tasks, priming increases as a function of the degree of conceptual analysis required during the initial exposure to the stimulus. For example, in the category exemplar generation task, participants are presented a list of words containing some uncommon exemplars of categories (e.g., MANGO). Participants may be asked to make a surface judgment about the word (e.g., Is there an A in the word?) or a more semantic judgment about the word (e.g., Is the word a concrete or an abstract concept?). Later, participants are asked to generate exemplars of a category (e.g., FRUITS), and priming is measured as an increase in the probability of providing an exemplar that was previously encountered. More priming occurs following semantic judgments than surface judgments on conceptual priming tasks (e.g., Srinivas & Roediger, 1990).

The manipulation of level of processing, as in the aforementioned example, is thought to affect the amount of conceptual or semantic processing during the initial encounter with the stimuli in the study phase of an experiment. Like explicit memory tests, which are also affected by levels of processing manipulations (Craik & Lockhart, 1972; Craik & Tulving, 1975), conceptual priming tests require conceptual processing of the stimulus. According to transfer-appropriate processing, more priming occurs following a semantic encoding task than following a nonsemantic encoding task because there is more overlap between the processes invoked at study and at test. In contrast, manipulations during study that do not affect the degree of semantic processing (e.g., encoding modality) have no effect on the magnitude of conceptual priming (Srinivas & Roediger, 1990).

Domains of Semantic Knowledge

Discussions of conceptual processing with regard to implicit memory typically treat semantic memory as a unitary entity, describing a single type of information. Likewise, most models of word representation describe a single semantic system that represents the meaning of a word. Research in several diverse areas, from development to dysphasia, suggests that semantic representations may be

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usefully divided into subtypes of knowledge, depending on the type of attributes that knowledge describes.

A semantic description of an object can include both information based on physical properties of an object such as color or shape (visual attributes) and information based on abstract properties that are not physically defined such as function (functional attributes). For example, one's knowledge of an apple includes both visual characteristics, such as the facts that it is red and round, and functional characteristics, such as the facts that you can eat it or that you pick it from a tree. Visual attributes are acquired earlier than functional attributes (Nelson, 1974) and predominate the overextension of word use (Gentner, 1978). Visual attributes are essential for successful categorization of objects at the basic level, as opposed to superordinate levels (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976).

In adults, who use both visual and functional attributes to define and understand objects, differences persist between these two types of semantic information. These differences, reflected in subtle behavioral measurements in healthy adults, may be critical to understanding the language impairments of patients with focal brain damage resulting in category-specific knowledge deficits. Although differences between visual and functional attributes might in part reflect the different acquisition histories of these two types of features (Schreuder, Flores d'Arcais, & Glazenborg, 1984), there may also be differences related to (a) the modality from which information for each of these features originates (Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984); (b) the statistical relationships both within semantic features (intercorrelations) and between semantic features and phonological or orthographic representations (informativeness; Devlin, Gonnerman, Anderson, & Seidenberg, 1998); and (c) neuroanatomical organization of the features, which may reflect any or all of the distinctions mentioned above.

These two components of semantic knowledge—visual and functional—have been empirically differentiated using a semantic priming paradigm. Semantic priming measures the facilitation of the recognition of a word by an immediately preceding related word. Remarkably, a facilitation effect was observed between two words that share visual features but no functional features (e.g., BALL—CHERRY); additionally, it has been demonstrated that under some conditions (e.g., word naming task) the magnitude of visual priming exceeded that of functional priming (e.g., BANANA—CHERRY) indicating that visual information may be available earlier in processing than abstract or functional information (Flores d'Arcais, Schreuder, & Glazenborg, 1985; Schreuder et al., 1984).

Neuropsychological studies also demonstrate a functional dissociation between visual and functional knowledge. Reports of patients with selective impairments of semantic knowledge suggest that semantic information can be dissociated into categories roughly corresponding to living things and nonliving things (Farah, McMullen, & Meyer, 1991; Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984). For example, Warrington and Shallice (1984) described four patients with damage to bilateral temporolimbic structures following herpes simplex encephalitis who showed selective impairments for living things across a variety of visual and verbal tasks; Warrington and McCarthy (1983, 1987) described two patients who, as a result of vascular lesions in left, frontoparietal cortex, showed selective impairments for nonliving things. These deficits do not seem to be due to stimulus variables such as the visual complexity of the picture but rather reflect true category-specific impairments of semantic knowledge (Sartori & Job, 1988).

The interpretation of these findings as evidence for a taxonomic organization of semantic memory has been challenged by Warrington and colleagues, who suggested that the organization of semantic memory is domain-specific (Warrington & Shallice, 1984). To the extent that living things tend to be distinguished by visual attributes and nonliving things by functional attributes, these category-specific impairments may reflect the differential weighting of visual and motor information in the representation of knowledge about living and nonliving things. This sensory-functional hypothesis explains exceptions to the living–nonliving distinction that have been observed in these patients; for example, a patient with a selective impairment of living things was also impaired on categories of nonliving things that are defined largely in terms of visual characteristics (e.g., gemstones and fabrics; Warrington & Shallice, 1984). Farah and McClelland (1991) demonstrated that a model of semantic knowledge with only modality-specific components can account for selective impairments in knowledge of living and nonliving things.

The goal of the current study was to use the transfer-appropriate processing framework to investigate the hypothesis that subtypes of semantic knowledge, namely visual and functional attributes, might have independently accessible conceptual representations. In other words, in order to study how much overlap there is between the retrieval of visual and functional knowledge, we can indirectly measure the degree to which retrieval of one attribute recapitulates the earlier retrieval of a different attribute by measuring the degree of repetition priming.

Semantic Classification Priming

In the present experiments, a semantic classification task was used both at study and at test to measure conceptual implicit memory. The task requires participants to make a classification of each item according to some semantic attribute. Like other conceptual priming tasks, the semantic classification task requires the participant to access conceptual knowledge about the stimulus. However, the task differs from other conceptual priming tasks in that the same stimulus is presented both at study and at test. The repetition of the stimulus form is a characteristic of most data-driven priming tasks.[1] Despite this repetition, Vriezen, Moscovitch,

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[1] Throughout this article, the term *data-driven* is used to describe processes relating to the physical form of the stimulus, which has also been called perceptual processing or perceptual priming in the literature (e.g., Woltz, 1996). The term *visual* is used to describe conceptual knowledge about the appearance of the referent of the stimulus, such as an object's shape.

and Bellos (1995) argued that the semantic classification task is insensitive to manipulations of stimulus form (e.g., picture or word representation) that typically affect data-driven priming tasks.

On classification tasks, changes in the nature of the probe question at study do not necessarily result in a reduction in priming at test. The lexical decision task is a word classification task that is considered primarily data-driven due to the effects on priming of stimulus-form manipulations at study (Scarborough, Gerard, & Cortese, 1979). Comparable magnitudes of priming were reported using the lexical decision task regardless of whether, at study, participants made the identical lexical classification, made a natural–manmade classification, or simply read the words aloud (Vriezen et al., 1995). This insensitivity to this type of study manipulation is typical of data-driven priming tasks. However, a similar result was also reported using a category classification task (e.g., "Is this an animal?" and "Is this concrete or abstract?"), which would appear to be a more conceptual priming task (Vaidya, Gabrieli, Keane, Monti, Gutiérrez-Rivas, & Zarella, 1997). Again, no priming differences were found between participants who made the identical classification at study and those who made a surface-level classification (e.g., "Is the word in uppercase?") at study. Therefore, priming is not necessarily reduced when the probe question changes between study and test. This suggests that classification priming is not simply the result of repeatedly answering the same question.

According to transfer-appropriate processing theories of priming, the lack of an effect of these study phase manipulations suggests that the processes required to classify a word at test are equally invoked under quite different study conditions; that is, the same processes may be tapped under quite different circumstances. For example, merely seeing a word might be sufficient to facilitate subsequent classification of that word. These results suggest a single lexical or semantic system that can be primed by any prior exposure to a word.

On the other hand, Vriezen et al. (1995) found no priming on a semantic classification task when the classification (size or manmade) changed between the initial and repeated processing of the word. Increased priming within a semantic domain relative to across a semantic domain suggests that there is not a single conceptual system but rather domain-specific knowledge representations. The present series of experiments elaborates on the effects of changing knowledge domain on subsequent classification, focusing on two domains that have been suggested to be neurologically dissociable: visual and functional knowledge.

In Experiments 1 and 2, the effect of changing semantic domains reported by Vriezen et al. (1995) was replicated by use of probe questions that either required visual knowledge or functional knowledge about the object. In Experiment 3, response-specific priming was studied by varying the specific probe question used within a domain of semantic knowledge. In Experiment 4, study modality was manipulated, to address the nature of the priming under conditions in which the probe question changes.

Experiment 1

In Experiment 1, repetition priming on a semantic classification test was measured using two types of probe questions. For some items, participants had to decide whether the object was round, a decision that demands retrieval of visual knowledge about the appearance of the object. For other items, participants had to decide whether the object was edible, a decision that demands retrieval of functional knowledge about the use of the object. During the test phase, the same two probe questions were used, keeping the question constant for half of the items (same-attribute) and switching the question for half of the items (cross-attribute).

If priming on the semantic classification task reflects processing within a unitary semantic system, or if it is the result of repeated reactivation of a lexical entry, there should be no difference between same-attribute and cross-attribute priming. If, however, it is possible to separately access one domain of semantic knowledge without automatically activating the entire semantic representation of the object, priming should be greater in the same-attribute condition than in the cross-attribute condition.

Method

Participants. Thirty-six undergraduates from Stanford University participated in the experiment for credit in an introductory psychology class. Participants were tested individually.

Materials. Common nouns were selected in four groups, based on attributes of their referents: (a) round and edible (e.g., APPLE), (b) round and inedible (e.g., DIAL); (c) nonround and edible (e.g., CARROT); and (d) nonround and inedible (e.g., JACKET). Norms were obtained from an independent group of 25 participants to verify the classification of each word. Elimination of words with classification agreement lower than 95% resulted in a set of 72 words, with 18 words in each of the four groups (see Appendix).

In the study phase, 48 words were presented, and participants made either a visual classification (i.e., "Is it round?") or a functional classification (i.e., "Is it edible?") for each word. Visual and functional questions were asked about equal numbers of items from each group and were counterbalanced across participants. The presentation order was pseudorandomized, so that no more than four consecutive classifications were made to the same probe question.

In the test phase, all 72 words were presented. Again, participants made either a visual classification (i.e., "Is it round?") or a functional classification (i.e., "Is it edible?") for each word. The same probe question asked at study was asked for 24 words (same-attribute; 12 visual–visual and 12 functional–functional), the different probe question was asked for 24 words (cross-attribute; 12 visual–functional and 12 functional–visual), and the remaining 24 words (12 visual and 12 functional) were unstudied, to serve as a baseline for comparison. These conditions were counterbalanced between participants, so across six counterbalancing orders, each word appeared in each of the three priming conditions (same-attribute, cross-attribute, or baseline) and in each of the two classification conditions (visual or functional). The presentation order was pseudorandomized as in the study phase.

Procedure. Stimuli were presented in lowercase letters on a Macintosh IIci computer using PsychLab experimental software (Montreal Neurological Institute, Montreal, Quebec, Canada) to display the stimuli and collect the reaction times. On each trial the probe question (i.e., "round" or "edible") appeared on the computer monitor. After a 500-ms delay, the target item was displayed below the probe question until a response was made. Participants indicated a response to either probe question by pressing a key labeled "Y" for yes or "N" for no. The dominant hand was always used to indicate a "yes" response. The study and test phases were separated by approximately 3 min.

Results

Median response times to each condition were computed for each participant, after excluding trials with incorrect responses. Mean median response times and mean error rates for each condition are given in Table 1.

Median response times and error rates were each analyzed in a repeated measures analysis of variance (ANOVA) of prime condition (same-attribute, cross-attribute, baseline), probe question (visual, functional), and response (yes, no). All effects were evaluated using a significance level of .05. As there were no interactions with response, all analyses reported are collapsed across response types. Functional classifications were made more quickly and more accurately than visual classifications; there was a main effect of probe question on response time, $F(1, 35) = 85.52$, $MSE = 5{,}448$, and on error rate $F(1, 35) = 13.29$, $MSE = 0.77$. There was also a main effect of priming on response time, $F(2, 70) = 23.86$, $MSE = 3{,}898$, and on error rate, $F(2, 70) = 7.15$, $MSE = 0.34$. Prime condition and probe question did not interact. Item analyses (collapsing over participants) yielded the same pattern of results as the subject analyses; there was a main effect of probe question on response time, $F(1, 71) = 52.06$, $MSE = 18{,}928$ and on error rate $F(1, 71) = 9.94$, $MSE = 0.47$, and a main effect of priming on response time $F(2, 142) = 16.07$, $MSE = 9{,}542$ and on error rate $F(2, 142) = 6.46$, $MSE = 0.28$.

Pairwise comparisons, using a Bonferroni-corrected alpha rate of .017, were used to analyze the priming effect. For both visual and functional questions, same-attribute classifications were made more quickly than either different-attribute or baseline classifications, but different-attribute and baseline classifications did not differ. None of the pairwise comparisons for error rate reached statistical significance. The absence of a significant cross-attribute priming effect was not simply due to insufficient power; the probability of failing to detect a cross-attribute priming effect that was half the magnitude of the same-attribute priming effect was low ($\beta < .10$).

Discussion

Priming on a semantic classification task was reduced when the type of semantic information probed was changed between study and test. Cross-attribute priming did not reach statistical significance, although for both visual and functional questions, a trend toward a reduction in response time in the cross-attribute condition relative to the baseline condition ($M = 24$ ms) was observed. However, there was also a suggestion of a speed–accuracy tradeoff for the cross-attribute condition. The same-attribute priming advantage replicates the finding of Vriezen et al. (1995) that changing probe questions on a semantic classification task reduces priming, and extends their results to the domains of visual and functional knowledge.

Experiment 2

The previous experiment examined two specific attributes: being round and being edible. The goal of the present experiment was to extend the results of the previous experiment to more general visual and functional attributes. Pairs of words were presented, and the task was either to decide if their referents had the same shape (visual question) or to decide if they had the same function (functional question).

Method

Participants. Thirty-six undergraduates from Stanford University participated in the experiment for credit in an introductory psychology class. Participants were tested individually.

Materials. Pairs of common nouns were selected in four groups, based on attributes of their referents: (a) same shape, same function (e.g., APPLE—PEACH); (b) same shape, different function (e.g., TIRE—DOUGHNUT); (c) different shape, same function (e.g., PIPE—CIGAR); and (d) different shape, different function (e.g., KEY—CART). Norms were obtained from an independent group of 25 participants to verify the classification of each pair. Elimination of pairs with classification agreement lower

Table 1

Experiment 1: Mean Median Response Times (in Milliseconds), Priming Effects (PE; Difference From Baseline Latency), and Error Rates (%) for Visual and Functional Classification Tasks

	Test question											
	Visual						Functional					
	Latency		PE		Errors		Latency		PE		Errors	
Test condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Baseline	791	25	—		6	1	683	18	—		1	1
Same-attribute	699	19	92	16	4	1	634	18	82	14	1	1
Cross-attribute	767	23	24	13	8	1	660	20	23	13	4	1

Note. $n = 36$.

than 95% resulted in a set of 72 word pairs, with 18 pairs in each of the four groups (see Appendix).

The structure and counterbalancing of the stimuli sets was the same as in Experiment 1. In the study phase, 48 pairs were presented, and participants made either a visual classification (i.e., "Do they have the same shape?") or a functional classification (i.e., "Do they have the same function?") for each pair of words. Visual and functional questions were asked about equal numbers of items from each group and were counterbalanced across subjects. The presentation order was pseudorandomized, so that no more than four consecutive classifications were made to the same probe question.

In the test phase, all 72 pairs were presented. Again, participants made either a visual classification (i.e., "Do they have the same shape?") or a functional classification (i.e., "Do they have the same function?") for each pair of words. The same probe question asked at study was asked for 24 pairs (same-attribute), the different probe question was asked for 24 pairs (cross-attribute), and the remaining 24 pairs were unstudied, to serve as a baseline for comparison. These conditions were counterbalanced between participants, so across six counterbalancing orders, each pair appeared in each of the three priming conditions (same-attribute, cross-attribute, or baseline) and in each of the two classification conditions (visual or functional). The presentation order was pseudorandomized as in the study phase.

Procedure. The procedure was identical to that of Experiment 1.

Results

Median response times to each condition were computed for each participant, after excluding trials with incorrect responses. Mean median response times and mean error rates for each condition are given in Table 2.

Median response times and error rates were each analyzed in a repeated measures ANOVA of condition (same-attribute, cross-attribute, baseline), probe question (visual, functional), and response (yes, no). All effects were evaluated using a significance level of .05. As there were no interactions with response, all analyses reported are collapsed across response types. Functional classifications were made more quickly and more accurately than visual classifications; there was a main effect of probe question on response time, $F(1, 35) = 12.22$, $MSE = 51{,}095$, and on error rate, $F(1, 35) = 22.08$, $MSE = 0.81$. There was also a main effect of priming on response time, $F(2, 70) = 34.30$, $MSE = 78{,}993$, although the priming effect on error rate did not quite reach statistical significance. Prime condition and probe question did not interact. Item analyses yielded the same pattern of results as the subject analyses; there was a main effect of probe question on response time, $F(1, 70) = 7.93$, $MSE = 153{,}097$, and on error rate, $F(1, 71) = 8.79$, $MSE = 0.98$, and a main effect of priming on response time, $F(2, 140) = 19.33$, $MSE = 245{,}139$. (A median response time could not be computed for one item because of a high error rate in one condition.)

Pairwise comparisons, using a Bonferroni-corrected alpha rate of .017, were used to analyze the priming effect. For both visual and functional questions, same-attribute classifications were made more quickly than different-attribute classifications, and different-attribute classifications were made more quickly than baseline classifications. None of the pairwise comparisons for error rate reached statistical significance.

Discussion

As in the previous experiment, priming on a semantic classification task was reduced when the probe question changed between study and test. In the present experiment, however, cross-attribute classifications were made significantly faster than baseline classifications. In Experiment 1, there was an insignificant trend toward a cross-attribute priming effect, which was difficult to interpret due to indications of a speed–accuracy tradeoff. No such trade-off is reflected in the error data of the present experiment. Thus it appears that there is not only a same-attribute priming advantage but also a cross-attribute priming effect.

The advantage of same-attribute priming suggests that there may be separate semantic representations of visual and functional knowledge. However, some of the advantage of same-attribute priming may be explained by the identical question and response at study and test. In other words, the same-attribute priming advantage could reflect priming of the specific decision and response that is repeated at study and test, and not of the semantic attribute per se. Response-specific priming has not been found on other classification tasks (e.g., lexical decision, abstract–concrete classification) as discussed earlier (Vriezen et al., 1995, Vaidya et al., 1997). However, response-specific priming has not been

Table 2

Experiment 2: Mean Median Response Times (in Milliseconds), Priming Effects (PE; Difference From Baseline Latency), and Error Rates (%) for Visual and Functional Classification Tasks

	Test question											
	Visual						Functional					
	Latency		PE		Errors		Latency		PE		Errors	
Test condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Baseline	1880	104	—		11	1	1694	80	—		6	1
Same-attribute	1425	64	455	67	9	1	1378	62	316	59	3	1
Cross-attribute	1603	81	277	69	10	2	1512	84	182	59	7	1

Note. $n = 36$.

eliminated as an explanation of same-attribute priming advantage on the semantic classification task. Experiment 3 addresses response-specific priming.

Cross-attribute priming could reflect either conceptually driven or data-driven processes. One possibility is that there is some more general word representation, one that does not require specificity in the nature of the semantic knowledge being accessed for a facilitative effect of repeated stimuli. A second possibility is that the cross-attribute priming effect represents a nonconceptual priming effect. As discussed earlier, the semantic verification task differs from other conceptual priming tasks in that the form of the stimulus is identical at study and test. This stimulus redundancy could result in a data-driven priming effect caused by a savings in the amount of time needed to perceptually decode the stimulus.

Vriezen et al. (1995) argued that there is not a data-driven component to semantic classification priming, because a stimulus form manipulation did not cause a significant reduction in priming. When participants classified pictures at study and words at test, the priming effect was 29 ms, compared with an 80-ms priming effect in the comparable word-to-word condition of a previous experiment. Although the statistical interaction apparently did not reach significance with 20 participants, the 64% reduction in priming is suggestive of a data-driven component to the semantic classification task. Although Vriezen et al. concluded that the 29-ms picture–word priming effect indicated that "repetition of semantic processes at study and test is sufficient to produce priming on this classification task" (1995, p. 939), their data do not exclude the possibility that a data-driven component may contribute to the cross-attribute priming effect observed in the present experiments. Experiment 4 addresses the data-driven component of cross-attribute priming.

Experiment 3

The advantage of same-attribute priming suggests separate representations of visual and functional semantic knowledge. However, the same-attribute priming advantage could also reflect a response-specific priming effect, because the same decision and response is made at study and test. In other words, the same-attribute priming advantage could reflect merely the repetition of a specific classification, decision, and response and not the repetition of the domain-specific conceptual knowledge. This experiment addressed this possibility.

The test phase was identical to Experiment 2; participants had to decide if a pair of words had either the same shape or the same function. In the study phase, single words were presented (only one word from each pair), and participants had to classify the object as curved or straight, based on the shape of most of the edges of the object. In the same-attribute condition, participants had to make repeated classifications based on the shape of the object; however, the decision and response were not identical between study and test. If the same-attribute priming advantage represents simply an effect of response-specific priming, that advantage should be eliminated in this experiment.

Method

Participants. Fifty undergraduates from Stanford University or the University of Pennsylvania participated in the experiment for credit in an introductory psychology class. Participants were tested individually.

Materials. The 72 word pairs used in the test phase were identical to those of Experiment 2. In the study phase, 48 single words were presented, one word from each pair from Experiment 2. For each item, participants classified the word as either curved or straight, based on the shape of the majority of the edges of the object. In the test phase, for the 48 primed pairs (i.e., pairs in which one of the two words was presented in the study phase), visual classifications were made for 24 pairs (same-attribute), and functional classifications were made for 24 pairs (cross-attribute). The remaining 24 items served as a baseline, 12 visual and 12 functional. These conditions were counterbalanced between participants, so across four counterbalancing orders, each pair appeared in each of the two priming conditions (primed or baseline) and in each of the two classification conditions (visual or functional).

Note that unlike previous experiments, the design was not fully crossed; only visual questions were asked in the study phase, so in the test phase, items in the same-attribute condition were always visual classifications and items in the cross-attribute condition were always functional classifications. As an additional consequence of this design, same-attribute and cross-attribute conditions had different baselines, measured by the visual baseline items and the functional baseline items respectively.

Procedure. The procedure was identical to that of Experiment 2, with the exception of the classification task change in the study phase. In the study phase, participants indicated a response by pressing either a key labeled with a straight line or with a curved line, to indicate whether the majority of the edges were straight or curved, respectively. The dominant hand was used to press the key labeled "curved" in the study phase and "yes" in the test phase. There was no correlation between the response to a given item in the study phase (straight or curved), and the response to that item in the test phase (yes or no) for either same-attribute or cross-attribute conditions.

Results

Median response times to each condition were computed for each participant, after excluding trials with incorrect responses. Mean median response times and mean error rates for each condition are given in Table 3. (Note that, as explained above, the same-attribute items were always visual classifications at test and the cross-attribute items were always functional classifications at test, and that same-attribute and cross-attribute items had separate baselines, as reflected in the table.)

Median response times and error rates were each analyzed in a repeated measures ANOVA of probe question (visual, functional), prime status (studied, baseline), and response (yes, no). All effects were evaluated using a significance level of .05. As there were no interactions with response, all analyses reported are collapsed across response types. Functional classifications were made more quickly and more accurately than visual classifications; there was a main effect

Table 3
Experiment 3: Mean Median Response Times (in Milliseconds), Priming Effects (PE; Difference From Baseline Latency), and Error Rates (%) for Visual and Functional Classification Tasks

	Test question							
	Visual (Same-attribute)				Functional (Cross-attribute)			
	Latency		Error rate		Latency		Error rate	
Test condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Baseline	1422	56	7	1	1139	48	3	1
Studied	1222	47	11	1	1106	38	5	1
PE	200	47	—		32	28	—	

Note. $n = 50$.

of probe question on response time, $F(1, 49) = 47.75$, $MSE = 41{,}491$, and on error rate, $F(1, 49) = 42.36$, $MSE = 1.76$. Studied items were classified more quickly, but less accurately, than baseline items, with a main effect of prime status on response time, $F(1, 49) = 18.39$, $MSE = 36{,}702$, and on error rate, $F(1, 49) = 17.34$, $MSE = 1.67$. The interaction between prime status and probe type was significant for response time, $F(1, 49) = 9.00$, $MSE = 38{,}918$, but not for error rate. Item analyses yielded the same pattern of results as the subject analyses; there was a main effect of probe question on response time, $F(1, 71) = 39.23$, $MSE = 19{,}472$, and on error rate, $F(1, 71) = 22.67$, $MSE = 0.39$, a main effect of priming on response time, $F(1, 71) = 21.19$, $MSE = 14{,}821$, and on error rate, $F(1, 71) = 13.91$, $MSE = 0.21$; and an interaction of prime type and probe question on response time, $F(1, 71) = 29.80$, $MSE = 18{,}322$.

Studied items were classified faster (*M* difference = 200 ms) than baseline items for visual (same-attribute) classifications, $t(49) = 4.25$, but not for functional (cross-attribute) classifications (*M* difference = 32 ms), $p > .25$. Studied items were also classified incorrectly more often than baseline items for both visual classifications, $t(49) = 3.54$, and functional classifications, $t(49) = 3.17$. The absence of a significant cross-attribute priming effect was not simply due to insufficient power; the probability of failing to detect a cross-attribute priming effect that was half the magnitude of the same-attribute priming effect was low ($\beta < .10$).

The possibility of a speed–accuracy tradeoff was assessed by computing the difference in latency and accuracy between studied and baseline items for each participant. The correlations between the latency difference and the accuracy difference did not approach significance for either visual or functional classifications, $0 < r < .05$. Additionally, there was no correlation between error rate and response time at the item level, $0 < r < .15$. Furthermore, when a subset of participants were selected who had equal or fewer numbers of errors for studied than for baseline items, the pattern of response times was unchanged; in this group of 38 participants, the same-attribute priming effect ($M = 220$ ms) was greater than the cross-attribute priming effect ($M = 33$ ms), interaction $F(1, 37) = 7.43$, $MSE = 44{,}742$.

Discussion

As in the previous experiments, the magnitude of same-attribute priming was significantly greater than that of cross-attribute priming. The advantage of same-attribute priming over cross-attribute priming persisted despite changes in the classification task between study and test. Therefore, the same-attribute priming advantage does not appear to be entirely the result of the repetition of the decision or of the response (although the repetition of the exact motor movement cannot be eliminated as a factor in this study, as the mode of responding was the same). Instead, the same-attribute priming advantage suggests separate representations of visual and functional attributes.

The persistence of the same-attribute priming advantage indicates that response repetition was not the sole cause of the same-attribute priming advantage in the previous experiment. In order to evaluate whether response repetition was even a contributing factor, we compared the results from this experiment with the results from Experiment 2, in which response repetition could have influenced the otherwise identical test phase. (Because Experiment 3 probed exclusively visual knowledge in the study phase, only the conditions in Experiment 2 with a visual probe at study were included in this comparison.) The magnitude of priming in Experiment 2 was 455 ms (24% reduction) for the same-attribute condition and 182 ms (11% reduction) for the cross-attribute condition. The magnitude of priming in Experiment 3 was 200 ms (14% reduction) for the same-attribute condition and 33 ms (3% reduction) for the cross-attribute condition. Thus, although there was a decrease in the absolute magnitude of priming in the same-attribute condition in Experiment 3, relative to the magnitude of cross-attribute priming, the same-attribute priming advantage was comparable in the two experiments. In a statistical comparison of the same-attribute priming advantage, using experiment as a between-subjects factor, the difference in the priming magnitudes was not reliable, $t(84) = 1.07$, $p > .25$. This comparison between the results of Experiment 2 and Experiment 3 indicates that the contribution of response or decision repetition to the same-attribute priming effect observed in Experiment 2 was likely to have been fairly minimal at most.

The accuracy data in this experiment differ substantially from the pattern observed in the previous experiments. The highest error rate was for studied items in the same-attribute condition. Although this suggests a possible speed–accuracy tradeoff, correlational analyses across participants and items between the speed advantage and the accuracy disadvantage do not support such a tradeoff. Furthermore, in the subset of participants with equal or fewer errors in the primed compared with baseline conditions, the pattern and magnitude of priming was comparable. In other words, the majority of participants (38 of 50) showed a facilitation in response time without any decrement in accuracy.

As in the previous experiments, the magnitude of priming in the same-attribute condition was greater than in the cross-attribute condition. Although cross-attribute priming was not significant, as it was in Experiment 2, there was a trend toward a cross-attribute priming effect. Furthermore, when the data from this experiment were combined with the comparable data from Experiment 2 (i.e., visual question at study and functional question at test), there was a significant cross-attribute priming effect across the two experiments, $t(85) = 3.12$. In Experiment 4, we examined whether the cross-attribute priming effect is the result of the repetition of primarily data-driven or conceptually driven processing.

Experiment 4

In Experiment 2, cross-attribute classifications were made significantly faster than baseline classifications; in Experiments 1 and 3 there was a trend toward a cross-attribute priming effect. The variability in the magnitude of the cross-attribute priming effect across these three experiments may be in itself telling; the experiment that found the greatest cross-attribute priming effect (Experiment 2) was the one with the highest degree of stimulus overlap between study and test (i.e., two repeated words). This raises the possibility that the cross-attribute priming effect may be merely the result of some lower-level perceptual savings of repeated processing of the same stimulus, rather than reflecting something about lexical or semantic representations. Although Vriezen et al. (1995) argued that the semantic classification task is unaffected by stimulus-form manipulations, their data, specifically the 64% reduction in priming following a modality change, are not very persuasive. In the current experiment, the data-driven component of the semantic classification task was assessed.

The most studied manipulation of stimulus form in priming tasks is modality. Same-modality (e.g., auditory study and visual test) priming is consistently greater than cross-modality (e.g., visual study and visual test) priming on tests of word fragment completion (Srinivas & Roediger, 1990), word stem completion (Graf, Shimamura, & Squire, 1985), and lexical decision (Scarborough et al., 1979), all tasks that are considered primarily data-driven tasks. In fact, the existence of a modality effect is often used as a marker of a data-driven priming task. On the other hand, modality changes have no effect on conceptually driven tasks, such as category exemplar generation (Srinivas & Roediger, 1990; Vaidya et al., 1997), and the absence of modality effects is considered a hallmark of conceptual priming tasks.

In the present experiment, the procedure was identical to Experiment 2 with one critical difference: Half of the stimuli in the study phase were presented auditorily and half visually. In the same-modality condition, the results should replicate the previous experiments: Responses in the same-attribute condition should be faster than in the cross-attribute condition, which should be faster, although perhaps not significantly so, than the baseline condition. In the cross-modality condition, same-attribute priming should still have an advantage. If cross-attribute priming is eliminated, then the cross-attribute priming observed in the previous experiments was most likely the result of data-driven priming. If cross-attribute is unaffected by the modality shift, then the cross-attribute priming is unlikely to be a data-driven priming effect. This would suggest that there is some nonspecific semantic or lexical representation that underlies the cross-attribute conceptual priming effect.

Method

Participants. Thirty undergraduates from Stanford University received $5 for their participation in the experiment. Participants were tested individually.

Materials. The materials were identical to those used in Experiment 2. For auditory presentations of the stimuli, words were recorded by a male speaker and were played via the computer speakers. The duration of each auditory presentation ranged from 0.75 to 1.5 s. All conditions were counterbalanced between participants, so across 12 counterbalancing orders, each word appeared in each of the three priming conditions (same-attribute, cross-attribute, or baseline), in each of the two classification conditions (visual or functional), and in each of the two modality conditions (same-modality, cross-modality).

Procedure. During the study phase, half of the pairs were presented visually and half of the pairs were presented auditorily. At the beginning of each trial, participants were told whether the words in that trial would be presented visually or auditorily, using the cues "look" and "listen." This cue was followed by the probe word (i.e., "shape" or "function"), which remained on the screen until the participant responded. The presentation of the visual pairs was adjusted to resemble the auditory presentation as closely as possible; rather than using a simultaneous presentation of the two words (as in Experiment 2), words were presented sequentially for both auditory and visual study conditions. The procedure during the test phase was identical to that of Experiment 2, and all words were presented visually.

Results

Median response times to each condition were computed for each participant, after excluding trials with incorrect responses. Mean median response times and mean error rates for each condition are given in Table 4.

Median response times and error rates were each analyzed in a repeated measures ANOVA of condition (same-attribute, cross-attribute, baseline), study modality (same, different), and response (yes, no). As there were no interactions with response, all analyses reported are collapsed across response types. Because there were fewer items in each condition of this experiment (due to the addition of the modality factor), responses to visual and functional questions were not analyzed separately; on the basis of the previous experiments, which found no indication of interactions involving the probe question, collapsing over the two types of probe questions was justified. Both response times and accuracy varied as a function of condition, with a main effect on response times, $F(2, 58) = 21.32$, $MSE = 67{,}547$, and on error rate, $F(2, 58) = 8.44$, $MSE = 0.88$. There was no main effect of study modality. More important, there was no interaction between prime status and study modality on response time or error rate, $ps > .50$. Item analyses yielded the same pattern of results as the participant analyses, with a main effect of priming on response time, $F(2, 142) = 28.79$, $MSE = 21{,}391$, and on error rate, $F(2, 142) = 11.21$, $MSE = 0.22$, and no interaction between prime status and study modality.

Table 4
Experiment 4: Mean Median Response Times (in Milliseconds), Priming Effects (PE; Difference From Baseline Latency), and Error Rates (%) for Semantic Classifications in Same- and Cross-Modality Conditions

	Study modality											
	Visual (Same-modality)						Auditory (Cross-modality)					
	Latency		PE		Errors		Latency		PE		Errors	
Test condition	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Baseline	1661		—		10	2	1775		—		10	2
Same-attribute	1388	75	273	48	8	1	1430	97	345	61	7	1
Cross-attribute	1496	89	164	51	14	2	1584	92	190	74	13	2

Note. $n = 30$.

Pairwise comparisons, using a Bonferroni-corrected alpha rate of .017, were used to analyze the priming effect. Averaged across modalities, same-attribute classifications were made more quickly than different-attribute classifications, and different-attribute classifications were made more quickly than baseline classifications. As suggested by the failure to find an interaction between prime type and modality, this pattern was identical for same-modality and cross-modality items, with the exception that there was no difference between same-attribute classifications and different-attribute classifications in the same-modality condition ($p = .056$). Across modalities, accuracy was higher for same-attribute classifications than for cross-attribute classifications, $t(30) = 4.02$; no other pairwise differences were significant.

As is evident in Table 4, there was a difference between visual and auditory items in the baseline response latencies. To ensure that the absence of an interaction was not simply the result of arbitrary differences in the respective baselines of the two conditions, the ANOVA was repeated after pooling response times in the two baseline conditions ($M = 1{,}718$ ms). The resulting analysis of the priming effects (as compared with the common baseline) produced results identical to those reported above; namely, there was no interaction between the study modality and the type of priming, $p > .50$, and there was a significant cross-attribute priming effect for both same-modality and cross-modality items.

Discussion

The results of this experiment replicate the findings of Experiment 2. Priming on a semantic classification task was reduced when the probe question changed between study and test, although response times in the cross-attribute condition were significantly faster than baseline response times. Cross-attribute priming was observed when items were studied either in the same modality or in a different modality than at test.

If cross-attribute priming were merely the result of overlap between the physical stimulus at study and at test, then the magnitude of cross-attribute priming should have been substantially reduced when the modality changed between study and test. The failure to find any trend toward a reduction in cross-attribute priming in the cross-modality condition indicates that cross-attribute priming is not the result of a data-driven process. Rather, like other tests that fail to show any effect of modality shift on priming magnitude (e.g., category exemplar generation; Srinivas & Roediger, 1990), cross-attribute priming seems to reflect primarily conceptual processing.

General Discussion

The series of experiments reported in this article were designed to address whether long-term priming of conceptual knowledge is the result of the recapitulation of specific semantic knowledge (i.e., visual or functional knowledge) or, alternatively, whether it is the result of the recapitulation of nonspecific semantic or lexical information. Two effects emerged across all four experiments that shed light on this question. First, in each experiment there was a same-attribute priming advantage; that is, the magnitude of priming when the domain of knowledge retrieved about an object was repeated exceeded the magnitude of priming when the item repeated but the domain of knowledge was switched. Second, across all experiments there was a smaller cross-attribute priming effect. Each of these effects have implications for the nature of conceptual priming.

Same-Attribute Priming Advantage

The consistent demonstration of a same-attribute priming advantage indicates, based on the logic of transfer-appropriate processing, that there is a recapitulation of some processes in the same-attribute conditions that does not occur in the cross-attribute condition. Because the physical form of the stimulus and the lexical information are identical in the same-attribute and cross-attribute conditions, data-driven processing and lexical retrieval can be ruled out as candidate mechanisms for the same-attribute priming advantage. Several other possibilities remain. In the same-attribute condition, not only is similar lexical and semantic information retrieved, but the decision and response are identical at study and test. However, in Experiment 3, this possibility was addressed by changing the decision and response in the same-attribute condition from one judgment about shape at study (i.e., straight or curved edges) to a different judgment about shape at test (i.e., same as or different from a second object). Despite this change, a same-attribute priming advantage remained. In fact, the magnitude of the same-attribute priming advantage was no less than in the three other experiments in which the decision and response were the same at study and test. Thus, it is unlikely that the same-attribute priming advantage is due to the recapitulation of processes specific to the decision or response.

We suggest, instead, that the same-attribute priming advantage is the result of the recapitulation of domain-specific semantic knowledge. If there was a unitary conceptual system, one would predict that any type of semantic retrieval, whether about the shape of an object or its function, would activate that conceptual system, and that the repetition of semantic retrieval about that object would result in a priming effect that would be comparable in same-attribute and cross-attribute conditions. This is not the pattern we observed. Rather, our data indicate that the retrieval of domain-specific information during the study phase is recapitulated at test in the same-attribute condition but not in the cross-attribute condition. It appears that accessing knowledge about one type of semantic information does not necessarily result in the access of the entire semantic description of the object. That is, it is possible to independently access one specific attribute of semantic knowledge. These findings, consistent with a wide variety of research (e.g., Gentner, 1978; Schreuder et al., 1984; Warrington & Shallice, 1984), suggest that semantic memory has functionally discrete representations of different attributes or domains of knowledge.

There is neuroimaging evidence that supports the idea that these domain-specific representations are functionally dissociable as well. Martin, Haxby, Lalonde, Wiggs, and Ungerleider (1995) used positron emission tomography (PET) to record cortical activity while participants generated related colors and actions of line drawings and found specific cortical areas activated when participants generated either colors or actions. Color generation resulted in increased activity in the mid-fusiform gyrus, bilaterally. Action generation resulted in increased activity in the left mid-temporal and left inferior frontal cortex, and in the right cerebellum. Likewise, using functional magnetic resonance imaging (fMRI), Thompson-Schill, D'Esposito, Aguirre, and Farah (in press) reported increased fusiform activity when answering questions about visual characteristics of objects relative to nonvisual characteristics. The results of these neuroimaging studies suggest that there are neuroanatomically distinct domain-specific representations that can be activated under different semantic retrieval conditions.

The attributes studied in the current investigation, namely, visual and functional characteristics, were chosen because of their parallels to previous behavioral (e.g., Schreuder et al., 1984), neuropsychological (e.g., Warrington & Shallice, 1984) and neuroimaging (e.g., Martin et al., 1995) studies. Furthermore, the results of the current study are consistent with the conclusions from these prior studies that visual and functional knowledge about objects have distinct representations that can be independently accessed. However, the current study does not provide any evidence as to the possible distinctions that might exist in semantic memory within visual or functional knowledge. For example, Martin et al. (1995) tentatively proposed a distinction between functional attributes associated with object use versus object motion based on the loci of increased blood flow in their neuroimaging study of action generation. Likewise, visual knowledge might include knowledge about color, shape, and size, among other visual characteristics. Additional research is necessary to determine whether a same-attribute priming advantage will be observed when there is a shift in knowledge within the attributes presently used (e.g., from color to shape).

This raises the possibility that any shift between study and test will result in a decrease in priming, reducing our conclusions to an illustration of the effect of a task switch on the resulting degree of transfer-appropriate processing (Roediger et al., 1989). It is important to reiterate that it is not the case that any change between study and test will reduce priming; as we observed in Experiment 3, very significant changes between the task performed at study and test do not reduce priming when the knowledge that is being retrieved is the same. Therefore, this procedure presents a viable method for determining the degree of overlap in the knowledge that is retrieved under two different conditions. In the current study, the overlap was high when two very different tasks tapped the same type of knowledge yet was low when two similar tasks tapped different types of knowledge.

Cross-Attribute Priming Effects

The second major finding in these experiments was evidence for a much smaller cross-attribute priming effect. In the cross-attribute condition, the retrieval of specific semantic knowledge is not repeated at study and test. Several processes are repeated, which are candidate mechanisms for this effect. For example, the low-level physical features of the stimulus are present at study and at test. To address the possibility that perceptual repetition could result in a data-driven cross-attribute priming effect, in Experiment 4 we eliminated this repetition by switching modalities between study and test and found no effect on the magnitude of the cross-attribute priming effect. In light of this finding, several possibilities remain.

First, several investigators have demonstrated that newly formed associations can be primed; that is, lexical decisions for a pair of words that were previously presented as a pair are faster than for words that were previously presented but paired with different words (McKoon & Ratcliff, 1979, but see Durgunoglu & Neely, 1987, for qualifications on the generality of the effect). Although there is evidence that priming of associations on a lexical decision task is data-driven (Goshen-Gottstein & Moscovitch, 1995a), when a semantic decision task was used, similar to that used in the present experiments, priming of new associations persisted despite modality changes between study and test (Goshen-Gottstein & Moscovitch, 1995b). This finding may have some relevance to the current study, with a few caveats. On the one hand, the greatest cross-attribute priming was observed in the present study (Experiments 2 and 4) when a pair of words was presented both at study and at test. Although there was a trend toward cross-attribute priming when only a single word was presented at study (Experiments 1 and 3), it may be very relevant that under these conditions reliable cross-attribute priming was not obtained. However, Goshen-Gottstein and Moscovitch (1995a) found conceptual priming only for new associations (e.g., QUEEN–LEMON) and not for preexisting associations (e.g., SHEEP–LAMB); they concluded that priming of preexisting associations is merely a data-driven phenomenon. In the current study, at least for the functionally similar words, there was a preexisting association, yet no differences were found between the magnitude of cross-attribute priming for functional versus visual pairs. If priming of preexisting associations is data-driven, as Goshen-Gottstein and Moscovitch (1995a) argued it is, and the cross-attribute priming observed in the present experiments is not, it seems unlikely that the cross-attribute priming effect we observed could be based simply on the priming of the association. However, there may be ways in which future studies could reconcile these findings, so it would be premature to rule this possibility out completely.

Second, there may be a more general semantic or lexical representation that is accessed regardless of specific semantic knowledge that is being addressed. Woltz (1996) argued that conceptually driven priming on a semantic comparison task was not the result of mere lexical identification but rather required comparison of semantic meaning, favoring an interpretation in the present study of a nonspecific semantic representation. Whereas Woltz suggested that a trial-specific comparison was the basis for the conceptual priming effect, in our study priming was observed even when a comparison was not repeated at study and test (Experiment 3), indicating that repetition of semantic retrieval may underlie conceptually driven priming. This general semantic system may underlie the comparable priming effect seen across study manipulations on the nonspecific classification tasks (e.g., abstract–concrete) discussed earlier (Vaidya et al., 1997).

Several neuroimaging studies are consistent with the idea that there is a nonspecific semantic system. For example, Martin and colleagues (1995), in the experiment described above, also found that when activity during color and action generation was compared with baseline task performance (e.g., naming the object), both semantic tasks showed increased activation in the left inferior frontal gyrus (IFG). This is the same cortical area that has been linked to semantic processing on other nonspecific semantic tasks. Gabrieli and colleagues (1996; Demb et al., 1995) reported increased fMRI signal in similar cortical areas during semantic (deep) encoding of words, relative to a nonsemantic (surface) encoding task, regardless of the relative difficulty of the nonsemantic encoding task. Additionally, activation decreased in the left IFG during repeated semantic encoding relative to initial semantic encoding of the same words. These findings demonstrated the role of the left IFG in retrieval of semantic information. One theoretical account for the precise nature of this region is that the left IFG is involved in the process of selecting relevant semantic information, perhaps from other domain-specific semantic networks (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997).

Third, there may be domain-specific semantic representations that are somewhat interactive, such that retrieval of one domain of semantic knowledge will result in some facilitation during subsequent retrieval of other domains of semantic knowledge. Again, there is some neuroimaging data to support this argument. Predictions made by a model of semantic knowledge that is domain-specific but highly interactive (Farah & McClelland, 1991) were tested using fMRI by Thompson-Schill and colleagues (in press). In their study, cortical areas associated with visual knowledge retrieval were activated, as seen with fMRI, even during retrieval of nonvisual knowledge of objects that are distinguished largely by visual features (e.g., animals).

Although the precise mechanisms underlying the cross-attribute priming effect are not clear, the existence of such effects suggests that at some level semantic retrieval is not entirely domain-specific. Whether this is the result of a nonspecific semantic system or of interactions between domain-specific representations should be the subject of future studies using both behavioral techniques and neuroimaging methods. Additional research will be necessary not only to understand the mechanisms that underlie the cross-attribute priming effect, such as those proposed above, but also to explain what factors may have resulted in the considerable variability in the magnitudes of the cross-priming effect observed in the four experiments reported here. The experiments (2 and 4) with the largest cross-attribute priming effect have several things in common that may be relevant; for example, in both of those experiments general comparisons of shape were required at study and test, whereas Experiments 1 and 3 required more specific shape judgments (e.g., round or straight). The differences between the magnitudes of cross-attribute priming across these four experiments may prove to be just as informative as their convergence.

We have shown that the repetition of conceptual processing within a semantic domain results in greater repetition priming than across a semantic domain. Furthermore, we have shown that this same-attribute priming advantage is unlikely to be the result of response-specific facilitation. On the basis of these findings, we suggest that different domains of semantic knowledge can be independently accessed during different retrieval conditions, consistent with an organization of semantic memory into functionally discrete domain-specific systems. However, we have also demonstrated a smaller cross-attribute priming effect that does not seem to reflect mere data-driven facilitation based on word form. We suggest that the cross-attribute priming effect may reflect either processing in a nonspecific semantic system or interactions between domain-specific representations. Although still speculative, our results are consistent with neuropsychological and neuroimaging studies that find both domain-specific regions of cortex located close to the cortical regions that mediate the perception of those attributes and cortical areas related to nonspecific semantic retrieval. Taken together, these studies provide important insights into the nature of the representation and organization of semantic memory.

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Appendix

Stimuli for Experiments 1–4

Stimuli for Experiment 1

Round	Not round	Round	Not round
Edible	Edible	Inedible	Inedible
pea	banana	wreath	bench
tomato	breadstick	wheel	jacket
apple	carrot	ball	television
orange	zucchini	globe	bed
radish	lasagne	drum	canoe
pie	pickle	ring	sofa
hamburger	asparagus	marble	broom
peach	hotdog	moon	wallet
plum	toast	head	napkin
meatball	brownie	frisbee	oven
grape	butter	bowl	necktie
olive	bacon	saucer	shoebox
pizza	spaghetti	record	blanket
pancake	lobster	cymbal	knife
cookie	celery	fan	flag
lollipop	sandwich	doorknob	rake
onion	shrimp	button	book
cherry	taco	coin	comb

Stimuli for Experiments 2–4

Shape: Yes	Shape: Yes	Shape: No	Shape: No
Function: Yes	Function: No	Function: Yes	Function: No
desk–table	marble–grape	bell–gong	hat–towel
pencil–crayon	coin–button	jet–helicopter	ladle–knob
yarn–thread	banjo–racket	belt–suspenders	lampshade–baton
apple–peach	pen–asparagus	cassette–record	teapot–wheel
piano–organ	flag–sheet	pipe–cigar	canoe–comb
deck–patio	cigarette–chalk	clarinet–harmonica	funnel–guitar
blanket–quilt	lemon–football	snap–zipper	key–cart
crib–cage	pizza–plate	wallet–purse	antennae–igloo
bench–sofa	cymbal–frisbee	lighter–match	razor–iron
hammer–mallet	thimble–cup	telescope–binoculars	anchor–slingshot
apron–smock	tire–doughnut	globe–map	microphone–magazine
stable–barn	oar–spatula	lightbulb–candle	stamp–vase
coat–jacket	hose–rope	orange–banana	saucer–needle
bass–cello	fork–rake	scissors–knife	tray–mop
bed–cot	ball–plum	hourglass–clock	cake–scarf
club–bat	spoon–lollipop	saw–axe	envelope–wreath
bicycle–moped	television–box	broom–vacuum	sock–umbrella
muffin–cupcake	balloon–melon	bottle–bucket	phone–house

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