CHARACTERISTICS OF LONG-LASTING REPETITION PRIMING

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Facilitated performance in the identification of stimuli has been demonstrated due to prior exposure to the stimuli. Repetition priming can occur in the absence of explicit memory for the stimuli. Experiments explored the degree to which facilitation in visual object identification is due to perceptual or conceptual processing changes. Our results suggest that facilitation in picture naming is due to perceptual changes, but that these changes are not in low-level sensory processing. Additional experiments explored the generality of priming within and across modalities. We found priming in auditory and tactile modalities and that priming transferred between vision and touch. We have also explored the limiting conditions for the occurence of repetition priming. Are there situations in which exposure to stimuli does not induce priming? Our results suggest that priming only occurs when stimuli are processed in the context of performing a task. Finally, we have tested the duration of repetition priming. We have found that a single exposure to pictures at study can lead to facilitated test performance nearly a year later. The combined results provide a repetition priming that is sensitive to the study task demands and that can influence performance long after the original exposure.

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Characteristics of Long-Lasting Repetition Priming

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Introduction

Since the time of the fateful surgery that left patient H.M. densely amnesic (Scoville & Milner, 1957) there has been tremendous interest in different forms of memory and how they are mediated in the brain. Brain areas such as those removed in H.M.'s surgery are known to mediate explicit or declarative memory. Forms of nondeclarative or implicit memory seem not to be mediated by brain structures that are necessary for the formation of new long-term declarative or explicit memories (e.g., medial temporal lobe or diencephalon; Squire, 1992a). Among the forms of nondeclarative or implicit memory is repetition priming. Repetition priming is demonstrated in facilitated performance in processing stimuli based upon a prior exposure to those stimuli. Generally subjects exhibit facilitated identification of stimuli due to having processed them previously.

Beginning with demonstrations of preserved motor skill learning in H.M. (e.g., Corkin, 1968) there have been many demonstrations of memories that are dissociable from explicit memory. Repetition priming has been shown to be intact in amnesic patients (e.g., Graf, Squire, & Mandler, 1984) and to be statistically dissociable from explicit memory in normal subjects (e.g., Mitchell & Brown, 1988; Tulving, Schacter, & Stark, 1982). Repetition priming is particularly interesting as a form of implicit memory because it can be demonstrated following a single study exposure to stimuli unlike forms such as skill learning or conditioning.

It has also been shown that repetition priming can be long-lasting. Many forms of priming can be detected after delays of 24 hours or more e.g., Cave & Squire, 1992; Jacoby, 1983; Jacoby & Dallas, 1981; McAndrews, Glisky & Schacter, 1987; Mitchell & Brown, 1988; Mitchell, Brown, & Murphy, 1990; Moscovitch, Winocur & McLachlan, 1986; Musen & Treisman, 1990; Seamon, Brody & Kauff, 1983b; Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tardif & Craik, 1989). Using the picture naming paradigm Mitchell and Brown (1988) demonstrated that naming pictures on a study occasion could facilitate naming of those same pictures in comparison to new pictures following a 6 week delay in normal subjects. Cave and Squire (1992) used the same method to demonstrate that priming could be both long-lasting and of normal magnitude in amnesic patients who had severely impaired explicit memory (see Figure 1). The reported project also includes an experiment to test much longer delays between study and test in the picture naming paradigm in normal subjects (see Experiment 13).

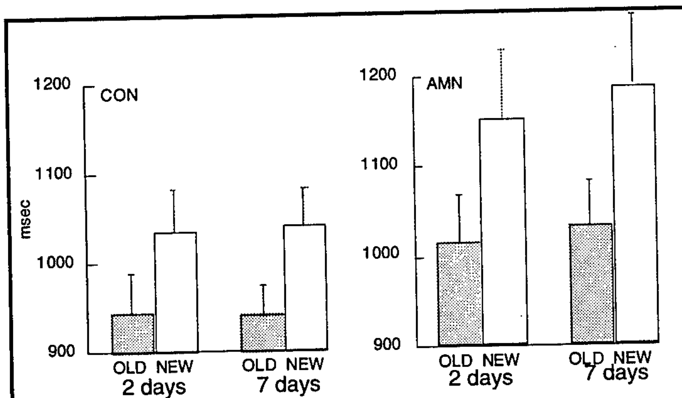

Figure 1. Times to name pictures repeated from study (old) and new pictures with delays of 2 days and 7 days between study and test. CON = normal control subjects. AMN = amnesic patients. Adapted from Cave & Squire, 1992.

The picture naming methodology provides a simple, ecologically valid test of priming that can be demonstrated on the basis of a single study exposure, that is dissociable from explicit memory, and that can show long-lasting effects. The project described herein makes heavy use of this paradigm and analogous methods. Performance on tests that allow subjects to make rapid decisions and that are easy and direct (e.g., naming, tachistoscopic identification) have been shown to be uncorrelated with explicit memory performance whereas tests that allowed controlled strategies (e.g., word fragment completion) were correlated with explicit performance (Perruchet & Baveux, 1989).

Many questions remain about the nature of repetition priming, several of which were addressed in this project. The degree to which repetition priming represents facilitated perceptual or conceptual processing is important for understanding the possible locus of priming within the brain. A related question of the perceptual specificity of repetition priming will also be important for determining the mechanisms mediating priming. The generality of priming in different modalities and across modalities is important for understanding whether priming reflects mechanisms specialized to modalities or general-purpose facilitatory mechanisms. The conditions under which priming occurs is important for understanding whether it is a by-product of other processing or whether it may play a functional role. Finally, how long the facilitation from a single stimulus exposure can last is important for determining the potential impact of priming on human abilities to detect stimuli in similar settings over time. Each of these issues has been addressed. The motivation, methods, and results of experiments will be described in separate sections to follow.

Because a large number of experiments will be described, the results will be discussed qualitatively. The author or appropriate publications can be consulted for detailed results. Likewise, the details of method will not be provided here. In all cases experimental stimuli were placed into matched groups and groups of stimuli were rotated through all conditions to assure that stimuli appeared in every condition equally often. Experiments were conducted using Macintosh computers and most used PsyScope experimental software (Cohen, MacWhinney, Flatt, & Provost, 1993).

Is Repetition Priming a Perceptual Phenomenon?

Many forms of repetition priming, including picture naming are considered to represent facilitation in the perceptual processing of the stimuli. However, this assumption had not been carefully tested. Several experiments to address the perceptual nature of priming in the picture naming paradigm grew out of the preliminary studies reported in the original proposal. The experiments described here have been submitted for publication and received an encouraging review. A final control condition is currently being completed.

Using pictures we have addressed the question, how important is the physical similarity between study and test pictures in eliciting priming? For instance, Biederman and Cooper (1991a, b; 1992) and Cave and Squire (1992) tested the degree to which exact physical repetition of a stimulus affected priming. Among their conditions were priming tests using identical pictures at study and test and pictures that were different examples of objects eliciting the same name at study and test (e.g., a beagle and a retriever, both of which would be named, "dog"). This condition tested for perceptual specificity in picture naming in that there was no modality change and no conceptual change in stimuli between study and test. Naming for the different pictures (exemplar changes) was primed but less so than for pictures that were physically identical to ones seen during the study session. Biederman and Cooper (1991a) and Cave and Squire (1992) suggested that enhanced facilitation for identical pictures at study and test was due to a "visual" perceptual facilitation and that facilitation for exemplar changes was due to some more abstract mechanism -- in the words of Biederman & Cooper, a "nonvisual" mechanism. Others using different priming paradigms have also reported reduced facilitation for conditions involving the use of two different same-name examples (e.g., Bartram, 1974, 1976; Jacoby, Baker & Brooks, 1989). These results leave open the possibilities that the "nonvisual" priming mechanism could be 1) facilitation in processing conceptual information, or 2) facilitation in verbal response selection or execution.

However, one need not propose a "nonvisual" source of facilitation when exemplar changes are primed. Cave & Squire (1992) also pointed out that facilitation in a exemplar change condition could be due to visual similarity between study and test items. If facilitation were due to visual similarity, then priming could be based on perceptual processing alone. Pictures that will elicit the same basic level name almost always are visually similar (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976).

Based on findings that pictures eliciting the same name usually look quite similar one might conclude that repetition priming in picture naming depends upon the repetition of visually similar stimuli from study to test and is therefore due to some modification in the perceptual processing of the stimuli that manifests itself less when perceptual characteristics are changed. Priming in the picture naming paradigm that is sensitive to abstract, but perceptually based characteristics of stimuli (e.g., a "generic" object model of the kind suggested by Marr, 1982, Lowe, 1985, or Biederman, 1987), could accommodate both the suggestion that repetition priming is based on perceptual facilitation as well as results from conditions in which exemplar changes in stimuli between study and test are presented.

In three experiments (Cave, in preparation) we demonstrated the perceptual nature of picture naming facilitation. In the first we showed that items repeated from study with a mode change (words at test and pictures at study) were not facilitated in naming in comparison to new words. Likewise pictures shown at study after having been studied as words were not facilitated in identification. In a second experiment we tested for the presence of conceptual facilitation from the study by asking for associates to stimuli shown at test (i.e. if shown a picture or word "tree" an appropriate response might be "bird). If study produces long-lasting conceptual facilitation then producing an associated item (that shares no perceptual similarity with the presented stimulus) at test should be facilitated. Test facilitation was only found when pictures were used at both study and at test but not when pictures were used at study and words were used at test. These results suggest that the facilitation in naming an associate was due to facilitated perceptual processing of the stimulus not to facilitated access to associated concepts. In the third experiment we tested priming for identical pictures repeated at test and exemplar change pictures repeated at test. In addition we tested these conditions at several delays. If different mechanisms mediate priming in identical vs. exemplar change conditions one might expect differential rates of decay in these two conditions. Identical patterns of relation between these conditions were seen across delays ranging from 3 min to 1 wk between study and test. The results taken together support the interpretation that a study task involving picture naming produces long-lasting modifications in the perceptual processing of the stimuli.

How Perceptually Specific is Repetition Priming?

The experiments just described along with others in the literature strongly suggest that repetition priming in object identification is a perceptually-based phenomenon. Recently, however, studies using pictorial stimuli in identification paradigms have demonstrated a number of instances of a lack of perceptual specificity. Some within-modality perceptual changes do not have the effect on priming that one might expect if repetition priming is dependent on facilitation of perceptual processing based upon repetition of the precise physical attributes of stimuli. For instance, size, location, or left/right reflection changes in pictorial stimuli between study and test have little if any effect on priming (Biederman & Cooper, 1991b; Biederman & Cooper, 1992; Cave & Squire, 1992; Cooper, Schacter, Ballesteros, & Moore, 1992). Changes in the shading of objects from study to test have only marginal effects on priming (Cave & Squire, 1992). These findings seem inconsistent with a priming mechanism that is based on facilitation of low-level perceptual processing.

However, there are ways to accommodate such failures to demonstrate perceptual specificity within a framework that suggests that repetition priming is a largely perceptual phenomenon. The manipulations that have failed to affect visual priming do not impact on basic level object identification. When tasks involve identification (as in naming tasks;

Biederman & Cooper, 1991a,b, 1992; Cave & Squire, 1992) or shape evaluation (as in object possibility judgments [i.e., whether a figure as depicted could exist as a 3-dimensional object]; Schacter Cooper & Delaney, 1990), physical attributes of objects such as size, location, or mirror reflection are more or less irrelevant to the task. An object will elicit the same name or judgment independent of size, location, and so on. The focus of such tasks is object shape.

Therefore, we suggest that repetition priming is perceptually sensitive, but in a way that reflects the demands of the task in which stimuli are evaluated. In other words, priming involving picture identification or shape evaluation may generally be sensitive only to relatively high-level perceptual characteristics that are important for establishing object identity -- e.g., shape. Priming is sensitive to changes in stimulus shape such as relatively radical changes in 3-dimensional orientation (Biederman & Gerhardstein, 1993; Srinivas, 1993) or changes in the exemplar picture used at study and test (Biederman & Cooper, 1991b, 1992; Cave & Squire, 1992). These changes that involve a different view of an object with a different retinal projection or an entirely different object (albeit eliciting the same name) do diminish priming, but do not abolish it. That priming is greater when the identical stimulus is used at study and test than in the case of exemplar substitution is taken as evidence that to some extent priming is occurring due to the repetition of visual qualities (e.g., Biederman & Cooper, 1991a; Cave & Squire, 1992).

Perhaps repetition priming involving basic level identification or shape evaluation tasks reflects the operation of stimulus processing mechanisms that are specifically "tuned" to processing stimulus characteristics that are intrinsic to visual object identity (e.g., shape, proportion, and spatial configurations of shape components). There has been considerable discussion of this possibility in the literature. For instance the "cognitive neuroscience" approach to implicit/explicit memory espoused by Schacter (1992a,b) suggests that priming in the visual modality is mediated in a perceptual representation system that is sensitive to physical attributes involved in the development of a structural description. Such a representation does not incorporate stimulus size, or position, but is a basic description of component shapes and spatial relations among them (Schacter, 1992a; Schacter, et al., 1990). Biederman & Cooper (1991a,b, 1992) have also adopted the position that priming reflects the operation of object identification mechanisms that operate independent of stimulus characteristics such as size, or position but with sensitivity to stimulus shape. They argued that object naming is an ideal task to allow assessment of the aspects of object identification reliant upon shape analysis without the influence of other forms of information (e.g., size, position, etc.) that are not related to basic object identification but that do enter episodic memory. Stimulus characteristics that affect priming are considered important characteristics for stimulus identification. For instance, using a priming paradigm Biederman & Cooper (1991a) concluded that facilitation in picture identification was related not to the repetition of image features or the object model, but to an intermediate representation roughly corresponding to the configuration of the object's parts.

The insensitivity of priming to variations in size, reflection, or location is consistent with priming being mediated in brain areas that are sensitive to stimulus shape but that equate across stimulus position and size. Neurons in inferotemporal cortex (IT) seem to act in just this way (see Plaut & Farah, 1990 for a review). Inferotemporal cortex is the "end stage" of processing in the "what" visual system (Ungerleider & Mishkin, 1982) that is essential for object recognition. Lesions to this area produce extreme deficits in object discrimination. The neurons in IT have very large receptive fields that always include the fovea and therefore this area is ideal for object processing independent of location. This mapping of priming onto high levels of object processing suggests that priming is not a low-level sensory facilitation phenomenon, but a reflection of higher level object processing.

If priming in picture naming is a reflection of object identification processing then it would seem immune to manipulations of physical attributes of stimuli that are not critical to object identification. Basic level object identification is highly dependent upon analysis of an object's shape (e.g., Biederman & Ju, 1988; Rosch, et al., 1976) and priming is affected by manipulations in stimulus shape. Other attributes of objects such as position and size are not critical to identification and do not affect priming, but what of other physical attributes such as color or surface texture? Although an object is that object independent of size, we do not equate so readily across variations in color or texture. On the other hand, for most objects color or texture are not critical for determining the object's basic identity. We hypothesized that to the extent that priming is elicited in a paradigm requiring basic level identification among easily discriminable stimuli one would not expect effects of color or texture on repetition priming. We hypothesized, however, that manipulations of color or texture would be detectable by explicit memory. Generally speaking manipulations of size, reflection, and location although not affecting priming have affected explicit memory (Biederman & Cooper, 1991b, 1992; Cooper, et al., 1992). Explicit memory may be tuned to encode different stimulus qualities in order to provide information about specific events that occurred at specific times rather than developing a generic object model.

Experiments 1-4 explored the perceptual specificity of repetition priming. Experiments 1 and 2 were published (Cave, Bost, & Cobb, 1996). Details of these experiments can be found there.

Experiment 1

Experiment 1A tested for effects of color changes on naming -- an implicit memory measure. In Experiments 1B and 1C, subjects were tested for their ability to explicitly remember the colors of objects and whether color changes would influence their old/new memory judgments, respectively.

Experiment 1A

Twenty-four subjects named colored line-drawings at a study session followed 1 hour later by a test session in which the study stimuli were repeated along with new pictures. At test half of the repeated stimuli remained the same color as at study and half were in different colors. The new stimuli appeared in all 4 possible colors.

The variable of interest was the naming times for pictures appearing at test. These times are shown in Figure 2. These results demonstrate that manipulations of stimulus color do not affect priming in picture naming.

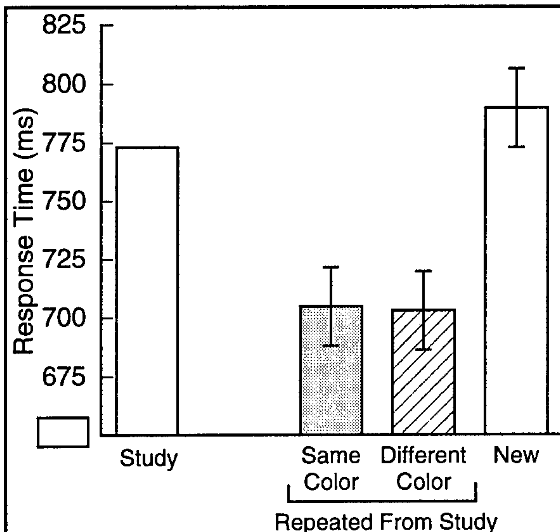

Figure 2. Times to name pictures repeated in same or different color vs. new pictures.

Experiment 1B

Twenty-four subjects were tested for their ability to explicitly detect color manipulations at test. They were exposed to the same study stimuli as in Experiment 1A. At test the same stimuli were repeated and there were no new stimuli. Subjects were asked to discriminate between objects that remained in the same color as at study and those that changed in color. This was an incidental explicit memory test. Subjects were able to detect these stimulus changes at above chance levels despite the fact that these same manipulations had not affected implicit memory in Experiment 1A.

Experiment 1C

Forty-eight subjects were tested for their ability to recognize the stimuli that were repeated from study vs. those that were new. Although subjects were not told of color manipulations we were interested in whether color changes would impact on old/new recognition ability. Twenty-four subjects were tested after a 1 hour delay and 24 subjects were tested after a 48 hour delay. Of interest was the number of recognition hits among the old stimuli for those that stayed the same color from study to test vs. those that changed in color from study to test. After a 1 hour delay the hits were very high and did not differ between the two conditions. After a 48 hour delay overall performance declined and a small but reliable difference showing more hits for same color than different color was detected.

The three experiments together showed that implicit memory was not affected by color manipulations, but that such manipulations could affect explicit memory and could be consciously detected by subjects. The explicit effects were detected despite incidental learning conditions that made these discriminations very difficult.

In order to rule out the possibility that the picture naming paradigm is simply insensitive to perceptual manipulations an additional experiment involving both color and exemplar changes was conducted.

Thirty-two subjects were tested. The study phase consisted of picture naming. At test study pictures were repeated under identical conditions as at study or with color, exemplar, or both color and exemplar changes. As shown in Figure 3 color manipulations again did not affect picture naming but exemplar changes did. There was no additive effect of both color and exemplar manipulations. These results show that the picture naming paradigm is sensitive to perceptual manipulations.

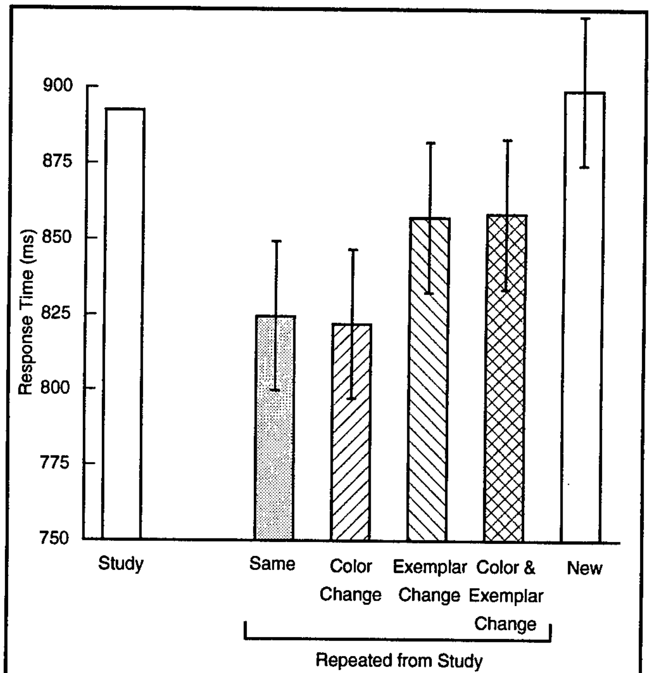

Figure 3.

Experiment 2

Experiment 2 was analogous to Experiment 1 testing for effects of fill pattern on priming rather than color. Results also closely matched those of Experiment 1.

Experiment 2A

Sixteen subjects were tested after a 1 hour delay and 32 subjects were tested with a 48 hour delay. Pictures named at study were filled with one of two patterns. At test the study pictures were repeated filled with the same pattern or the opposite pattern. New stimuli at test were presented in both patterns. As shown in Figure 4 the manipulations of fill pattern had no effect on test naming times.

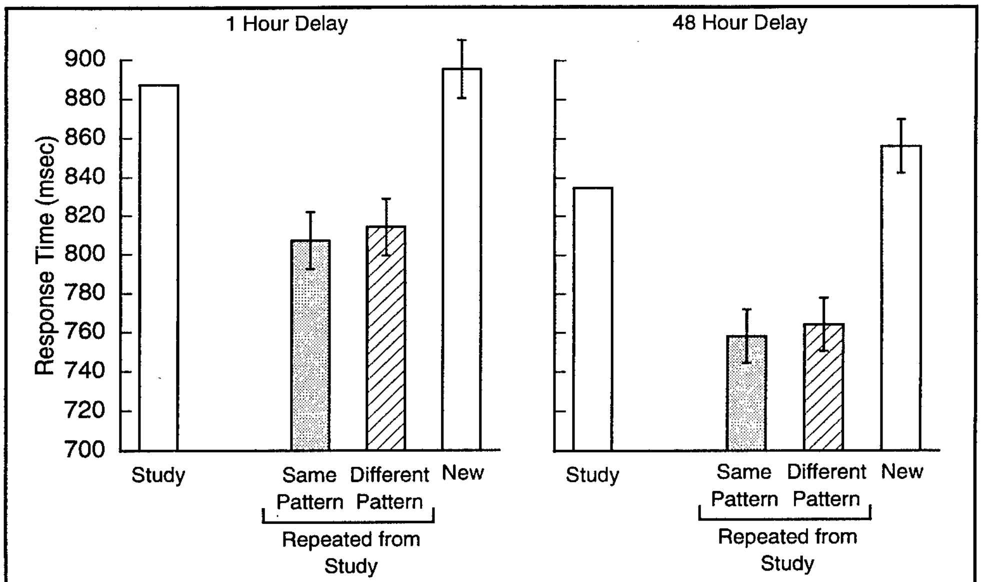

Figure 4. Times to name stimuli manipulated in fill pattern between study and test.

Experiment 2B

Twenty-four subjects were tested with a 1 hour delay and 24 were tested with a 48 hour delay. These subjects performed picture naming at study and at test the study pictures were repeated with the instruction to detect whether the picture contained the same fill pattern as at study or not. The subjects tested with a 1 hour delay were slightly, but reliably above chance in this incidental memory task, but after a 48 hour delay, subjects were not able to discriminate whether the patterns were the same as at study.

Experiment 2C

Twenty-four subjects were tested with a 1 hour delay and 24 were tested with a 48 hour delay. These subjects performed picture naming at study and at test were asked to perform old/new recognition on the stimuli. As in Experiment 1C it was of interest to test whether hits for old pictures were affected by whether the fill pattern was the same as at study. In neither delay condition was there any affect of fill pattern on recognizing the old stimuli.

As in Experiment 1 the results showed that implicit memory was not sensitive to manipulations of fill pattern whereas explicit memory could be shown to be sensitive to fill pattern. The explicit effects were small, but the discrimination was incidental and very subtle.

That priming can be independent of color and pattern provides additional demonstrations that repetition priming can be insensitive to the same stimulus characteristics as basic object identification. In general, easily discriminable objects are equally identifiable independent of size (within the limits of acuity), location, and surface qualities. The current results combined with previous insensitivities in visual repetition priming suggest that priming in an identification paradigm is not extremely perceptually specific. Color and pattern are processed of course and are even recognized later to a degree, but priming is not a reflection of modifications in early stages of perceptual processing. Instead priming seems sensitive to the stimulus properties that are most relevant for the task at hand. When subjects are asked to identify easily discriminable stimuli the focus is on the physical attributes that define object shape. If the shape of the objects was more difficult to extract (e.g., edges were obscured) perhaps additional physical attributes would be expected to influence performance. For instance, this may have been the case when changing the shading of objects produced a marginal effect on priming reported by Cave & Squire (1992). That repetition priming is not extremely perceptually specific makes it all the more interesting because it suggests more strongly that it is a valuable tool to aid our understanding of higher levels of object identification.

Experiment 3

Another kind of perceptual specificity is sensitivity of priming to viewpoint. Viewpoint effects on object identification have also become a central theme in testing basic object identification models. Repetition priming has recently been used as an indicator of basic perceptual processes under the assumption that basic perceptual processes are obligatorily engaged at study and therefore priming reflects the operation of those basic processes. One potential difficulty with using priming as an indicator of general object processing is that priming may not be the passive by-product of perceptual processing that the logic of testing object identification models assumes. Priming may be modulated by the demands of the *particular* tasks in which stimuli are presented and upon the nature of the stimulus set. For instance, an alternative interpretation of the absence of effects of color, size, direction of face, and location on priming may be that non-shape attributes are not critical for the solution of the experimental task in which the pictures appeared. Hence, these results should not be immediately interpreted as indicating that these attributes do not play a role in object identification. These attributes might be important in other perceptual tasks and might influence priming in other tasks (see Experiment 11). For instance, in object identification when discriminations among shapes become more demanding (i.e., the stimulus sets are visually similar), stimulus characteristics such as color can influence identification (e.g., Davidoff & Ostergaard, 1988; Ostergaard & Davidoff, 1985; Price & Humphreys, 1989). In other words, priming may reflect particular, task-specific processing demands rather than general object processing demands. Recent evidence also suggests that perceptually-based priming may not be an obligatory outcome of perceiving stimuli (Bost & Cave, in preparation; Schacter, Cooper, Delaney, Peterson & Tharan, 1991). This will be discussed in more detail in relation to Experiment 12.

If priming does not provide an unambiguous view of the attributes that affect object identification and if it does not occur whenever objects are perceived, then it is not necessarily a good indicator of mechanisms of perceptual processing (e.g., shape processing) that are engaged on every stimulus encounter. Therefore influences on priming may indicate more about the particular conditions prevailing in the priming task than they do about identification generally.

Experiment 3 tested the effects of rotation in depth on identification of familiar objects in a repetition priming paradigm. There were 128 subjects tested in study and test sessions 1 hour apart. At study and test the viewing orientation of objects was systematically manipulated. The task at both study and test was to identify common objects at the basic level. Naming latencies at study provide a baseline for whether viewpoint affects identification of familiar objects. The assumption is that study identification latencies reflect general object identification processing. There has been no prior experimental exposure and subjects have no expectations that should affect their identification performance.

At test stimulus objects were presented in the same study orientations or rotated by 90° or 180° in depth. Naming latencies for repeated objects were compared with times to name new pictures in all orientations. Primed identification latencies at test indicate how the study exposure affects test identification. If priming reflects facilitation of general object identification, then performance at test should differ from study only in being generally faster. There should be no systematic effects of changes in view.

Naming times at study demonstrated that unprimed identification of familiar objects is viewpoint invariant (when excluding canonical and unusual views, i.e., there were no significant effects of viewpoint). However, identification in an experimental setting at test preceded by a study exposure to a particular view of a stimulus is sensitive to viewpoint (see Figure 5). This dissociation between unprimed and primed identification suggests that priming may partially represent a *particular* stimulus encounter. In this sense, priming may not be a good indicator of processes commonly engaged in the identification of well-learned objects.

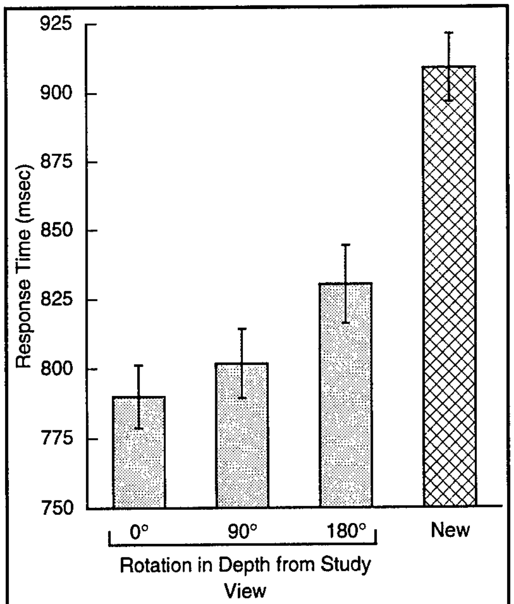

Figure 5. Times to name objects repeated from study manipulated in depth orientation vs. new objects in all possible orientations.

Prior viewing of objects does prime all later views of those objects (what one would predict if priming merely reflects the same processes engaged at study). However, the effect of viewpoint changes from study on test naming latency suggests that priming is not an ideal measure of general object identification processes. Simple assumptions that the mechanisms of repetition priming and general object identification are the same or similar may not be well founded. It is likely that we do not yet know enough about how priming itself works to use it as a tool to test models of object identification.

The current results showing viewpoint invariance in unprimed naming and some viewpoint sensitivity in primed naming suggest that priming may reflect processing that has been modified specifically by the study stimulus encounter.

Experiment 4

Experiment 4 was intended as an additional measure of the degree to which picture naming is a perceptual implicit test or has a conceptual component. The performance of patients with early Alzheimer's Disease (AD) can provide evidence about the perceptual/conceptual nature of implicit tests. Keane, Gabrieli, Fennema, Growdon, & Corkin (1991) have performed experiments suggesting that patients with early AD have impaired priming based on access to stimulus meanings, but good perceptual priming. These authors also suggest that conceptually mediated priming may be dependent upon brain areas damaged in AD (frontal, temporal, and parietal cortices) whereas perceptual priming is dependent upon primary sensory cortices that are relatively spared in AD. Recent findings suggest that picture naming priming is intact in early AD patients and dissociable from poor performance in stem completion (perhaps a more conceptually mediated form of priming) as well as explicit recognition (Gabrieli, Francis, Grosse, & Wilson, 1991), but these results did not directly address perceptual and conceptual aspects of priming within picture naming or the duration of priming in AD.

We proposed to conduct a standard picture naming experiment in AD patients to determine whether they showed normal picture naming priming (reflecting a perceptual nature to the task) or impaired priming (reflecting a conceptual component). We were unable to conduct this experiment due to difficulties in subject recruitment. Although there is a clinic serving a large number of AD patients at Vanderbilt we were never able to gain satisfactory access to these patients. Many contacts were made to facilitate this testing and before the proposal was submitted assurances were given that we would be able to test these patients. We did test a number of subjects with suspected AD through other facilities.

Unfortunately these patients were not well characterized and in general proved to be too demented for successful testing. We were not able to demonstrate priming in these patients nor were we able to document their mental or physical status. Because of the practical constraints on testing appropriate subjects this experiment was eventually abandoned.

How general is the occurrence of Priming Across Modalities?

Experiments 5-7 tested the generality of repetition priming within and across sensory modalities. If repetition priming is a general phenomenon related to identification in multiple sensory modalities, then speculation that priming is mediated within the perceptual processing systems is supported.

Experiment 5

Schacter, Church and their colleagues (Church & Schacter, 1994; Schacter & Church, 1992; Schacter, Church, & Bolton, 1995; Schacter, Church, & Treadwell, 1994) have recently reported repetition priming in the auditory modality using word stimuli. We were interested in replicating their results and extending them to basic identification of nonverbal material in the auditory modality. They reported that auditory word priming is largely a perceptual phenomenon (Schacter & Church, 1992) that is generally intact in amnesic patients (Schacter, et al., 1994). Experiment 5 tested for repetition priming in the auditory modality that is analogous to priming for visual object identification. In direct comparison with visual object identification we developed non-verbal auditory stimuli. These consisted of 72, 5s digitized segments of real-world stimulus sounds ranging from jackhammer to laughter.

Twenty-four subjects were tested. As in picture identification tasks they were asked to identify 36 sounds in an initial study session. To test for long-lasting facilitation in sound identification as has been found in visual identification, the delay between the study and test sessions was 4 weeks. At test both sound identification and explicit old/new recognition tests were given in counterbalanced order.

Median response times to identify sounds showed significant priming for having heard the sounds before despite a 4 week delay. Sounds repeated from study were identified in an average of 1582 ms whereas new sounds were identified in an average of 1796 ms. The data from the recognition tests were of primary interest in order to test whether sound identification priming is independent of recognition for the old sounds. Mitchell and Brown (1988) demonstrated equivalent naming times in picture identification for pictures in each recognition category. Naming times for sounds were also analyzed contingent on their recognition status. These results are shown in Figure 6.

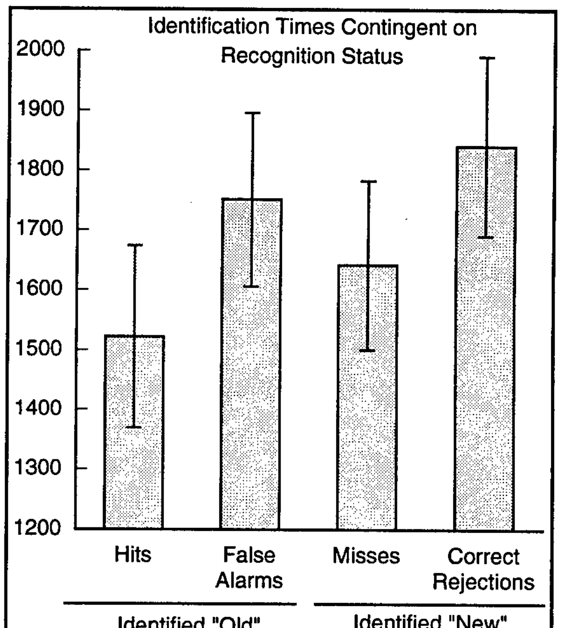

Figure 6.

Although the times to name sounds contingent on their recognition status were not equivalent, the fact that misses were identified more quickly than correct rejections demonstrates that conscious recollection of the stimuli is not necessary for demonstrating facilitated test responses. The fastest identification of sounds that were explicitly recognized does demonstrate that conscious recognition may also contribute to facilitated test performance in this paradigm. Sound identification is relatively slow and not as well practiced as visual object identification. As suggested previously, implicit tests that are independent of explicit memory are most likely to involve rapid and direct decisions such as visual object identification. Despite some influence of explicit memory in sound identification, which might also be exacerbated by the presentation of sounds over time, this experiment demonstrates the generality of repetition priming for environmental stimuli presented in the auditory modality.

Experiment 6

Experiment 6 tested the extent to which priming might be demonstrated for stimuli in the auditory modality that could not be named. The experiment was closely modeled on one by Johnson, Kim, & Risse, 1985) in which they exposed Korsakoff patients to melodies and tested for changes in affective preference for melodies based on the prior exposure. Others have demonstrated that mere exposure to stimuli can change affective response to those stimuli (e.g., Kunst-Wilson & Zajonc, 1980; Seamon, Brody & Kauff, 1983a,b).

Two experiments were conducted. We began with a pilot study to determine whether shifts in rated liking for previously heard melodies could be obtained. Testing for changes in preference using a rating scale to evaluate individual stimuli had not been done previously. Previous tests used forced choice preference for stimulus pairs at test.

Twenty-four subjects were tested in each of 4 conditions -- affective ratings tests with 1 hr or 48 hr delays or recognition tests with 1 hr or 48 hr delays. Ten second clips from traditional Japanese songs were digitized. At study subjects were exposed to half of the melodies and were asked to judge whether each was a Japanese melody or not. At test they listened to all 60 melodies rating each for liking or judging whether each was one heard in the previous session or not.

Subjects showed significantly higher affective ratings for melodies they had heard previously in the study session than for new melodies. Higher ratings for repeated melodies were shown at both 1 hr and 48 hr delays. We had hoped that because the melodies were novel and could not be named, subjects would not demonstrate above-chance recognition for them. However, this was not the case. Although recognition performance was low, it was above chance at both 1 hr and 48 hour delays. Percent hits minus false alarms was 18% after a 1 hr delay and 41% after a 48 hr delay. The high recognition following a 48 hour delay was surprising and perhaps represents some kind of sleeper effect.

Because we could not demonstrate chance recognition for the melodies we conducted an additional experiment in which we tested both affective ratings and recognition for the same stimuli in the same subjects. In this way we could test for independence between the implicit and explicit measures. Forty-eight subjects were tested using the same study procedure. The test was conducted 48 hours later. The order of the affective ratings task and the recognition test was counterbalanced between subjects. In this experiment the effect on affective ratings of having heard some of the melodies previously was only marginal. Because the implicit effect was diminished despite a large N the test of independence does not seem warranted. We are still assessing this outcome. The failure to replicate the previously robust findings of affective changes due to prior exposure is surprising. Perhaps these findings can be attributed to the use of an affective rating scale rather than the more common forced choice preference procedure. This, however, does not account for our robust findings in the pilot experiment. In addition, if a forced choice paradigm is required to detect affective changes one might question the degree to which the effect requires a direct comparison between an old and new stimulus. This comparison is very similar to an explicit recognition test. If affective measures are truly implicit they should be detectable when individual stimuli are assessed by some continuous measure. This issue will merit further study.

Experiment 7

Analogous to the previous experiments, Experiment 7 was conducted to determine whether priming could be demonstrated in the tactile modality. The results of these experiments have been submitted for publication (Cave, 1996).

Experiment 7A

Experiment 7 tested speed of identification for familiar, 3D objects allowing a test of the generalizability of tactile priming in the domain of processing of everyday objects. Using 3D objects also allows subjects to use information beyond 2D shape such as volume, texture, and hardness that are central components of tactile experience and identification (Klatzky, Lederman, & Metzger, 1985). Identification of real objects by touch can be rapid and accurate (Klatzky, et al., 1985). In addition, we tested whether facilitation in tactile identification is independent of explicit memory for the study stimuli. Within subjects the same stimuli were tested for facilitation in identification as well as explicit recognition so that identification performance could be analyzed contingent on recognition status.

Forty-eight subjects identified a set of familiar objects by touch in a study session. Following a 4-week delay, a subset of those stimuli were presented again along with new stimuli for a tactile identification test in which speed of identification was the dependent measure. There was also a yes/no recognition test that used visual presentation of the names of objects. The long delay between study and test was used to test whether priming in the tactile modality could be long-lasting and to test recognition when it would be off ceiling.

Stimuli that were repeated from the study task were identified significantly more quickly than new objects. This is the basic priming effect. In addition we considered whether facilitation in identification was independent of recognition memory for the old items. Test identification latencies were analyzed contingent on recognition status. There were main effects of whether the object was old or new and whether the object was classified as old or new in the recognition test. These findings suggest that facilitation in naming in the tactile modality is both implicit and explicit. This is similar to the results from the sound identification study discussed earlier. These findings are not surprising given that tactile identification is not rapid and well-practiced as is visual object identification. Therefore, despite no instruction to engage in explicit recognition for the identification task, recollection of having felt objects previously may aid in identification. The fact, however, that objects that were misses in the recognition test were identified more quickly than objects that were correct rejections also demonstrates that facilitation can occur without conscious recollection. These results demonstrate the importance of testing for independence between implicit and explicit memory in new modalities despite using a test analogous to others that have shown independence.

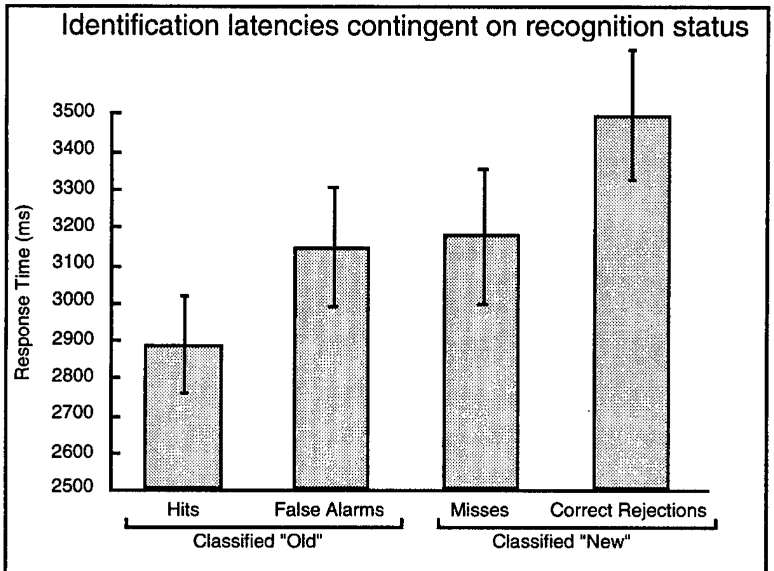

Figure 7.

Experiment 7B

A second experiment explored the possibility of transfer between visual and tactile identification. Modality specificity has been considered a defining characteristic of repetition priming and a primary piece of evidence to suggest that repetition priming is substantially based upon the modification of perceptual processes. Modality specificity, however, may also be a function of the particular modalities tested. Recently, Easton, Srinivas, & Greene (in press) showed that cross-modal priming in word stem completion could be very substantial. The modalities tested were vision and touch. The hypothesis was that visual and tactile words could both be presented geometrically. In other words geometric representations of words might be shared between modalities or based on an amodal spatial representation. The current experiment is built upon the same logic and tested for cross-modal priming using familiar 3D objects rather than words.

Findings that priming is not obligatorily sensitive to all stimulus attributes and is perhaps not a simple by-product of perceiving stimuli suggest that repetition priming is based upon higher-level, "functional" representations of stimuli. In other words, perhaps priming is perceptually based but is sensitive to the qualities of stimuli that are critical for the solution of the perceptual task being performed on the stimuli. Only the attributes critical to task performance affect priming whereas other attributes do not affect priming. For instance, basic-level object identification is sensitive to object shape (i.e., exemplar) and relatively insensitive to attributes such as size or color. The same pattern is seen in effects on priming. If priming can be based upon higher-level representations, then cross-modal perceptual priming should occur when the modalities share high-level representational qualities.

In the current experiment twenty-four subjects were presented with familiar, 3D stimuli in one modality at study -- either vision or touch -- with no mention of the other modality. This was done to assure that they did not strategically try to form a representation that would be amodal or multimodal. At test identification was tested in both the visual and tactile modalities with trials randomly intermixed. Half of the repeated stimuli were presented in the study modality and half were presented in the unstudied modality. Half of the new stimuli were presented in the visual modality and half were presented for tactile identification.

Unlike in most previous tests of cross-modal priming in which there was substantially reduced or absent priming (e.g., Blaxton, 1989; Jacoby & Dallas, 1981; Kirsner & Smith, 1974; Weldon, 1991), robust priming was shown between the visual and tactile modalities replicating and extending the recent findings of Easton, et al. (in press). Significant priming occurred both when the study and test were in the same modality and when they differed in modality. See Figure 8. This is an important finding given that one of the hallmark features of repetition priming has been modality specificity. Little or no priming following a shift in modality has been used as an important indicator of the perceptual nature of repetition

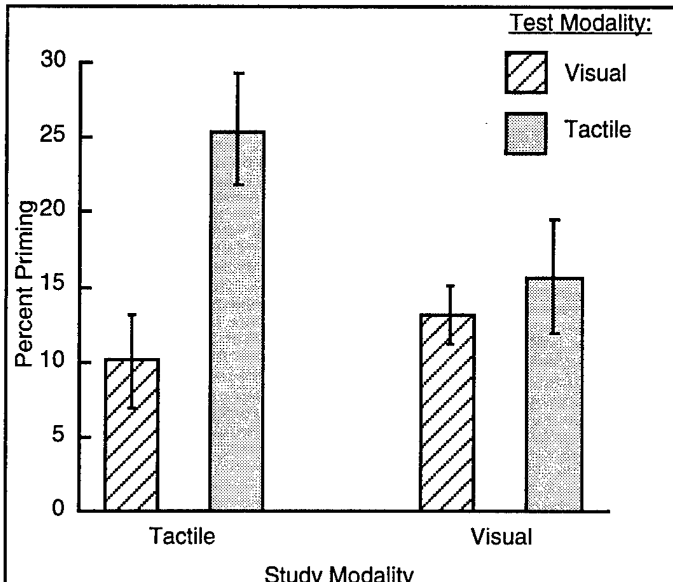

Figure 8. Amount of priming using identification of new stimuli within the same modality at test as a baseline.

priming. The current results and those of Easton, et al., however, do not undermine the interpretation that repetition priming is dependent upon the perceptual qualities of stimuli, but may place more emphasis upon the nature of higher-order representations rather than low-level sensory attributes.

It has been suggested previously that priming in the visual modality is mediated in the ventral visual stream (the "what" system, Ungerleider & Mishkin, 1982; e.g. Biederman & Cooper, 1992; Cave, Bost, & Cobb, 1996; Schacter, 1992). Visual priming may be related to the formation or use of a relatively high level representation as might be processed in inferotemporal cortex (IT). This area seems primarily a visual area that would not support cross-modal priming. However, there are other brain areas that might be more likely to support cross-modal visual-tactile representations. One such possibility would be the dorsal "visual" stream. Recently, it has been suggested that this processing stream is representing information relevant to visuo-motor coordination as opposed to visual object location (e.g., Goodale & Milner, 1992; Goodale, 1993). In other words, Goodale and Milner have suggested that the two visual processing streams (Ungerleider & Mishkin, 1982) be considered "what" and "how" streams instead of "what" and "where." Evidence suggests that parietal areas are processing information about object sizes, shapes and orientations to allow for the computation of appropriate grasping movements and visually-guided reaching. Damage to the dorsal stream appears to disrupt not only location information, but grasping and orientation of movements in ways appropriate to the objects to be manipulated. This computation of movement (in particular, hand and arm movements that allow appropriate handling of objects) in coordination with vision suggests a close alliance between vision and touch and perhaps the use of a single visuo-spatial representation. Both temporal and parietal areas may be involved in shape analysis but for different purposes that may be under strategic control (DeYoe & Van Essen, 1988). Basic object identification may be computed in the ventral stream whereas action-oriented representations may be computed in the dorsal stream. Although it is speculative at this time, cross-modal priming may be mediated via representations in the dorsal stream. The two processing streams also project to areas in the superior temporal sulcus which might also be a possible locus for mediating cross-modal priming (Goodale & Milner, 1992).

Are there Laterality Effects in Priming?

Experiment 8

There are results that suggest that priming for different kinds of stimuli may be lateralized differently (e.g., Marsolek, Kosslyn & Squire, 1992; Squire, Ojemann, Miezin, Petersen, Videen, & Raichle, 1992). Marsolek et al., (1992) reported that when perceptually identical word stimuli were presented at study and test that priming was facilitated by presentation to the right hemisphere and they suggested that this type of priming involving exact visual repetition should be short-lived. Priming for stimuli that changed in typeface between study and test did not differ according to the hemisphere of presentation. The natural extension of the Marsolek et al. interpretation is that in the picture naming paradigm one would expect that priming would be greater for presentations of identical stimuli to the right hemisphere. There should be no difference between the two hemispheres (or perhaps a left hemisphere advantage) for stimulus presentations that do not represent perceptually identical stimuli (i.e., exemplar changes). In addition, one might expect that the advantage for presentation of identical stimuli to the right hemisphere would dissipate within a relatively short time (<2 hours).

To test these predictions a picture evaluation task was devised that would not involve picture naming in order that there would not be a left hemisphere advantage for a naming task. Objects were constructed such that part arrangements were violated producing objects that were not "real." For instance, a temple from a pair of glasses might extend from the nosepiece rather than the side of the lens producing a violation of the usual spatial relations between object parts. Using 80 such pictures that could appear in both real and unreal renditions as well as in two different exemplars we tested for whether the left hemisphere would be less sensitive to exemplar changes in making real/unreal judgments than the right hemisphere. Thirty-two right-handed males were tested with a 1 hour delay between the study and test. Stimuli were studied in free view and the task was a real/unreal judgment. At test stimuli were lateralized using a standard divided visual field procedure. Again, the task was a real/unreal judgment. Some stimuli remained the same as at test, others were a different exemplar than at study. There were also new real and unreal objects at test.

The results showed no effects of hemisphere, or of type of stimulus (same as study or a different exemplar). Real objects were responded to more quickly than unreal objects. There was no evidence of priming (facilitated responses for old objects) in any condition. When only responses to real stimuli were analyzed there was still no priming. Because we were unable to detect priming using this paradigm we were not able to test the predictions concerning laterality of priming.

Repetition priming is generally a quite robust phenomenon therefore it is surprising in an experiment with a relatively large N to fail to detect priming. This may be an interesting finding in itself. Perhaps a real/unreal judgment is so easily made that a perceptual record is not made of stimuli that appear in such a task. The possibility that the mere presentation and perception of stimuli may not elicit facilitated processing of the same stimuli in the future is interesting and relates to the results of Experiment 12 that considers the possibility that not all perceptual experiences induce priming.

How does Priming Occur for Novel Stimuli?

Experiment 9

When this project was begun our model for repetition priming was that it could reflect the modification of relatively low-level perceptual processes. Despite the notion that priming might be based on the processing of low-level object properties, there were certain stimuli that had failed to elicit priming. For instance, Schacter, Cooper & Delaney (1990, 1991) used a task in which subjects decided whether figures represented "possible" physical relationships or "impossible" physical configurations. In this task impossible figures did not show priming. The suggestion was made that priming depended upon the development of a stable 3-D representation in a "structural description system." It would be difficult if not impossible for subjects to create such a representation for the impossible figures. In an extensive follow-up of the original result (Schacter, et al., 1991) these authors demonstrated that in the object decision task impossible figures did not prime despite repeated exposure (up to 4 exposures), an additional encoding task, and equating stimulus sizes. The conclusion that priming in the object decision task requires the development of a structural representation of objects seems well-founded. However, perhaps failures to find priming with these stimuli is related to the nature of the task in which priming was sought. In other words, if the task demands the evaluation of an object model then priming will be sensitive to the object properties of stimuli. If a task that did not depend upon the evaluation of an object model were used, perhaps priming could be demonstrated on the basis of more elemental stimulus properties in impossible figures.

We conducted several experiments to test whether priming could be elicited for impossible figures using several different tasks. Our initial attempts centered around the use of an affective response to stimuli. Others have demonstrated priming effects on affective responses to stimuli (e.g., Johnson, et al., 1985; Seamon et al, 1983a,b). Perhaps in comparison with other impossible figures, previously seen impossible figures would be judged differently in an affective assessment task. This task requires nothing more than basic perceptual processing and in particular makes no demands for the formation of a 3-D structural description. In addition, we tested the effects of superimposing impossible figures with line drawings of common objects to test for differential disruption of the processing of the common objects depending upon prior presentation of the impossible figures.

In brief, despite several experiments using different variations of study and test tasks we have not reliably detected priming for the processing of impossible figures. We tested 72 subjects with a study task using possible and impossible novel figures judging whether each faced left or right. This is a task used in several experiments by Schacter, Cooper, and their colleagues. One third of the subjects were tested at each delay -- immediate, 1 hour, and 48 hours. At test they rated their liking for each stimulus (an equal number of repeated and new as well as possible and impossible figures). Although subjects generally liked possible figures better than impossible, there was no indication that old impossible figures were liked better than new figures. In another experiment we used the same task at study and test to maximize the processing overlap between the study and test. In this case subjects performed the possibility judgment used by Schacter and colleagues at both study and test. Stimuli were shown for 2s at study and 100ms at test. There was no indication of priming (i.e., a greater number of old stimuli than new judged correctly) in any condition. Next we tested 12 subjects with a left/right facing judgment at study and forced choice preference for figures at test. Each test pair contained an old and a new figure. There were no preferences for old figures above chance.

Using a different methodology we also superimposed possible and impossible novel figures on Snodgrass & Vanderwart (1980) line drawings of common objects for test stimuli. We then measured subjects' ability to segment the line drawing from the superimposed figures based upon whether they had prior study of the superimposed figures. In one case the Snodgrass and Vanderwart pictures were fragmented. Following a study of novel figures we tested the level of fragmentation at which the Snodgrass and Vanderwart figures could be identified. Identification at greater levels of fragmentation for pictures superimposed with studied figures would be a measure of priming. This method did not reveal any effects of having studied possible or impossible superimposing figures. Another similar method superimposed novel figures with intact Snodgrass and Vanderwart stimuli and tested the naming speed for the common objects. Subjects judged the novel figures at study for whether they faced left or right. At test possible and impossible figures were superimposed on line drawings of common objects. Although superimposing an impossible figure on the line drawing allowed faster naming of the common object there was no effect of having studied the impossible figures previously. Several other variations on these experiments were conducted and although there were some effects of prior study of possible figures, we did not reliably obtain priming for impossible figures.

These results taken together suggest that a failure to obtain priming for impossible figures is a real and robust finding independent of the test task used to assess priming. Unlike our original hypothesis that priming could be detected on the basis of processing low-level visual features, we have found no evidence for this. Despite mixed findings in the literature (e.g., Seamon, Williams, Crowley, & Kim, 1995), priming may be limited to situations in which a relatively high-level representation of a stimulus can be formed. This is consistent with the findings discussed earlier in relation to effects of color and pattern on priming. Only stimulus attributes that are relevant for the formation of a high-level object representation affect priming. Other low-level sensory attributes do not generally affect priming.

Experiment 10

The goal of Experiment 10 was to learn more about the limits of modifiability in the mechanisms responsible for priming. One might consider priming as some modification (perhaps conceived as modification of weights in a network) in a system such as the "word form system" (Petersen, Fox, Posner, Mintun, & Raichle, 1989) or a "perceptual representation system" (Schacter, 1990). Modifications in the "word form system" would seem to account for nonword priming as this system is activated by words and orthographically acceptable nonwords, but not by consonant strings or "false fonts" (stimuli that look like they could be letters but are not; Petersen, Fox, Snyder, & Raichle, 1990).

Under what circumstances might one elicit priming using "false fonts" (characters that look like they could be letters, but are not) and what brain system would mediate such priming? Judging from results of PET studies in which false fonts do not activate the word form system one might assume that subjects would not initially demonstrate priming for false font stimuli. A group of 16 pilot subjects were tested initially to determine whether priming could be demonstrated for false fonts without any specific training. A "false font" alphabet was constructed in which 14 letters were represented by novel stimuli. Using these stimuli a set of 4 and 5 letter "words" was created (groups of the false fonts such that their corresponding letters formed words). A corresponding set of nonwords were created by changing one "letter" in each word. Word sets were matched for frequency. In the pilot, subjects were exposed once to a randomly mixed set of 20 false font "words" and 20 "non-words" for 5s each with a corresponding label of word or nonword. The subjects were not given any training on correspondences between the false font characters and the English alphabet equivalents. At test they received a lexical decision test containing the stimuli from study along with an equal number of new false font words and nonwords. Not surprisingly, these subjects did not show reliable facilitation in their decisions for whether studied stimuli were words or non-words in comparison to new stimuli. In other words, a single exposure to the stimuli did not facilitate their categorization performance.

A second group of 24 subjects performed a similar study and test task except that these tasks were preceded by a learning phase for the alphabetic equivalents of the false font symbols. The training consisted of 3 presentations of the false font stimuli paired with their English alphabet counterpart for 3s each. Following these presentations subjects were given each false font character to be matched with the corresponding letter with feedback until the set was completed without error 3 times in succession. Following this training these subjects performed a lexical decision task on 20 false font words and 20 nonwords. The test following a 30 minute delay then consisted of a lexical decision task containing the studied words and nonwords along with an equal number of nonstudied false font words and nonwords. Although this task is slow and difficult, subjects did demonstrate significant priming for having studied stimuli previously. This effect was seen for both words and nonwords (see Figure 9).

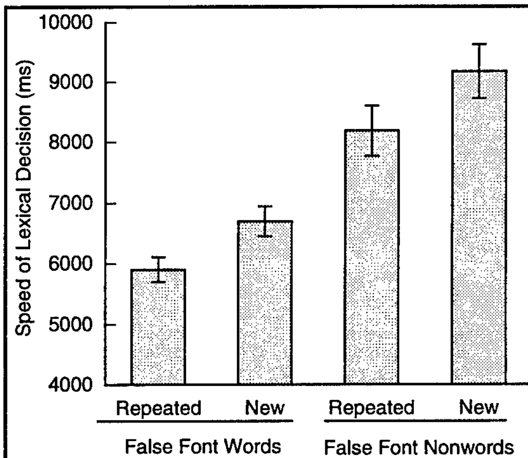

Figure 9.

These results are perhaps not surprising as they mirror common results in the priming literature. However, these manipulations have not been reported with novel stimuli. Given previous findings that "false font" characters do not activate word form areas in the brain (Petersen, et al., 1990), it would be of interest to determine where in the brain the priming effect is mediated in subjects who demonstrate priming for these stimuli following relatively brief training and study sessions. In other words, these findings provide fertile ground for pre- and post-learning scanning for brain activity. One would presume that no activity would be found in previously reported word form areas for false font stimuli. It would then be of interest to put these subjects through a training session and then scan for activity to determine where priming is mediated for false font stimuli that are learned within an experiment. Would the word form area be activated (or reduced in activation due to prior study) or would facilitation be mediated elsewhere, e.g., in object processing areas (despite the word/non-word decision)?

Experiment 11

Experiment 11 was originally designed to test hypotheses about the operation of repetition priming as modifications in a neural network. We were planning to test the duration of priming for common and unusual examples of stimuli. Because the results of Experiment 13 and others in our lab demonstrated the extreme longevity of visual priming effects, this experiment did not seem feasible. Instead, we have begun testing predictions that arose from our work in Experiments 1 and 2. These experiments demonstrated that the stimulus attributes of color and fill pattern did not affect repetition priming in a standard object identification paradigm. Our interpretation of these results was that priming, rather than being absolutely sensitive or insensitive to stimulus attributes, would be sensitive to the stimulus attributes that were relevant for task performance. In the case of basic level object identification this would be shape. Shape manipulations in the form of exemplar changes between study and test do reduce priming.

A prediction that arises from such an interpretation is that if the task in which stimuli appear is modified to place emphasis upon other stimulus attributes rather than shape that those attributes could be shown to affect priming. Because shape is such a salient attribute on which to classify familiar objects it becomes difficult to develop a large stimulus set on which to test the sensitivity of priming to non-shape features. Rather than using familiar objects, we developed a large set of artificial stimuli consisting of the combinations of 8 distinct but non-nameable shapes, 8 colors, 8 fill patterns, and 4 sizes.

We began by having 24 subjects perform a classification task with these stimuli. In a study phase subjects were asked to classify stimuli according to shape. Four of the 8 possible shapes were used. Shape was used as the classification task because the same task would have to be used at test otherwise stimuli would change classes between study and test. We were interested in testing the sensitivity of priming not to the primary classification attribute but to other attributes. The stimuli were chosen such that unbeknownst to the subjects the colors of the stimuli were perfectly correlated with the shapes at study. Size and fill pattern varied randomly with shape/color. At study subjects categorized each stimulus by pressing 1 of 4 keys on the computer keyboard corresponding to the shape of each stimulus. They classified the same 32 stimuli 3 times at study. After a 1 hour delay at test they performed the same shape classification task except some of the stimuli were identical to those at study, some had changed in color (the correlated characteristic) others changed in either size or pattern (the uncorrelated characteristics) and there were stimuli of a new shape that was to be classified using a new key. We compared classification times for the conditions of repeated stimuli with the classification of new stimuli and found no evidence for priming. Upon further consideration we determined that the new stimuli could be classified too easily because they were of a single shape whereas the old stimuli still had to be sorted into one of 4 classes. Therefore, a new baseline does not seem feasible in this experiment.

We next considered the classification times across the blocks of the study phase (which were continuous). Our hypothesis was that classification into the 4 shapes should steadily speed up across the study trials and a comparison of these study trials with the repeated stimuli in the test block would be of interest. A consideration of the study data showed that each repetition of the stimuli at study produced faster response times. When identical stimuli were repeated at test there was no difference between the test response times and the last repetition during study. When the characteristic correlated with the classification characteristic (i.e. color) was changed at test response times for classification were slower than the last repetition of the study phase. Although this difference did not reach significance we are encouraged that sensitivities to stimulus attributes other than shape (even when they are incidental to the task) can be demonstrated. We are currently replicating this experiment using more trials in each block. We are not using any new stimuli in the final block -- only manipulating the characteristics that accompany the classification attribute.

When Does Priming Occur?

Experiment 12 tested the limiting conditions for the occurrence of repetition priming. Does everything we perceive prime?

Experiment 12

Although priming has become a very frequent visitor to our journal pages, we have not tested many of the assumptions that have been adopted about its operation. How does a single exposure to stimuli change our performance on a later task involving those stimuli? Most formulations of priming suggest a strong role for the modification of the perceptual processing of the stimuli (Roediger, Weldon, Stadler, & Riegler, 1992; Schacter, 1992; Squire, 1992a; Srinivas, 1993). There has been considerable debate about the particulars of such formulations (e.g., whether different types of performance are mediated in different brain areas [e.g., Tulving & Schacter, 1990] or whether consideration of the match between study and test processing is more fruitful [e.g., Roediger & Blaxton, 1987]). Leaving this debate aside as well as priming that is conceptually based (e.g., category exemplar production; e.g., Cabeza, 1994; Hamann, 1990), there is substantial evidence that many instances of repetition priming have a strong perceptual component. This evidence includes relatively strong modality specificity in priming (e.g., Graf, Shimamura, & Squire, 1985; Roediger & Blaxton, 1987; but see Easton, et al., in press, and Cave, 1996) as well as other examples of perceptual specificity such as reductions of priming due to font changes (e.g., Graf & Ryan, 1990; Roediger & Blaxton, 1987) or pictorial exemplar changes (e.g., Bartram, 1976; Biederman & Cooper, 1991a, b; Cave, Bost, & Cobb, 1996). Following from early demonstrations of a strong perceptual component in repetition priming there has been an implicit assumption that an exposure to a stimulus *necessarily* modifies perceptual processing of that stimulus. For instance, priming studies of object identification assume that perceptually processing a stimulus at study modifies processing in a way that indicates the fundamental characteristics of object identification (e.g., Biederman & Cooper, 1991a, b).

This assumption that priming is a by-product of perception initially suggested that priming would display a high level of perceptual specificity. In other words that priming would be sensitive to virtually any change in the perceptual attributes of the stimulus between study and test. Not all findings, however, have been consistent in pointing to a perceptually specific mechanism of repetition priming. Effects of perceptual modifications on priming in verbal paradigms have been mixed (see Graf & Ryan, 1990, for a review). As discussed in relation to Experiments 1 and 2, repetition priming involving pictorial stimuli is unaffected by a broad range of perceptual manipulations such as changes in size, location, direction of face, color, and illumination (e.g., Biederman & Cooper, 1991a, b, 1992; Cave, Bost & Cobb, 1996; Cooper, et al., 1992, Srinivas, 1996a). These invariances are not consistent with a framework that suggests that priming is a by-product of low-level sensory processing. Some of these findings have been interpreted as evidence that object identification is not sensitive to certain stimulus attributes, and therefore priming is not affected by these attributes. However, we have not directly tested the assumption that priming is a fixed index of basic perceptual processes. Priming may not be an obligatory by-product of perception. Rather than being a fixed index of basic perceptual processes, priming may be an index of the processes required for task solution. In other words, priming may reflect the nature of the task in which stimuli appear and the utility of making processing modifications in the service of that task.

For instance, considering the findings regarding perceptual specificity, perhaps priming is sensitive to the stimulus attributes that are central to the performance of the task in which the stimuli appear. In the case of diverse pictorial stimuli occurring in an identification task, the stimulus attributes that are critical are those that differentiate the stimuli from one another -- generally shape. Manipulations of pictorial exemplar or rotation in depth can affect priming perhaps because they affect the ability to extract the basic shapes of objects (Biederman & Cooper, 1991a, b, 1992; Biederman & Gerhardstein, 1993; Cave, Bost & Cobb, 1996; Srinivas, 1993). The size or color of an isolated picture of a car adds little to one's ability to identify it as a car rather than a desk and therefore does not affect priming. In the context of basic level identification this interpretation differs little from an interpretation that priming reflects fixed attributes of object identification. However, if priming is sensitive to task demands, then the sensitivity of priming to stimulus attributes would change according to the importance of those attributes for the solution of the study task. In other words, perhaps the sensitivity of priming to certain stimulus characteristics is not fixed, but instead is variable. Recently, Srinivas (1996b) has shown that picture priming can be sensitive to size in the context of study and test tasks that required size judgment. Previous insensitivities were in the context of basic level object identification. Presumably, the task demand in Srinivas' study made sensitivity to size in perceptual processing useful in the context of task performance. Likewise, the results discussed in Experiment 11 suggest that sensitivity to stimulus color can be demonstrated in a task for which color may be useful for task solution. A similar interpretation can be applied to tasks involving words. To the extent that the study task does not require specific perceptual analysis of the stimuli, these qualities will not influence priming. Our lifetime experience with words discounts the perceptual aspects in favor of the conceptual aspect. Perceptual specificity is generally seen for word attributes that help in the solution of a task (e.g., Graf & Ryan, 1990).

If the requirements of study task solution can modulate the sensitivity of priming to stimulus attributes, a logical extension of such a framework is that study task requirements can modulate the *occurrence* of priming. In other words, priming need not occur at all for stimuli for which there is no utility in modifying their processing. Most real-world tasks require that one carefully process only some of many stimuli. We constantly perceive objects and words, yet our processing goals do not require specific focus on most of those items. Under specific laboratory circumstances (and perhaps many real-world settings) one might detect priming only for certain objects and not others. The notion that there might be bounds on when priming occurs has not been thoroughly tested. Yet the bounds on priming (if they exist) are definitional for what priming is. Does perceiving a stimulus produce a lasting modification in perceptual processing of that stimulus that is a fixed indicator of basic perception? Or can a stimulus be perceived and passed to other cognitive processes without modifying perceptual processing?

Of course, the fact that certain stimulus attributes seem not to affect priming does not mean that these attributes are not perceived. They are perceived, and they can affect explicit memory (e.g., Biederman & Cooper, 1991a, b; Cave, et al., 1996; Cooper, et al., 1992). The nature of explicit memory is such that important stimulus attributes are those that differentiate an *instance* of an item from other items or other instances of the same type item. Therefore, all stimulus attributes are processed, but different attributes affect later performance in priming tasks according to how those attributes aid in study task performance. The perceptual processing of a stimulus need not necessarily modify the later perception of that stimulus (resulting in perceptual priming), but the percept may nonetheless be passed to other processes including explicit memory.

Very few results address whether the occurrence of repetition priming depends on the task in which the stimuli are encountered. A few experiments conducted with words demonstrate that a study focus on individual words produces repetition priming, whereas study tasks that focus on extracting meaning from sentences result in substantially reduced or absent priming for the individual words (Levy & Kirsner, 1989; MacLeod, 1989; Oliphant, 1983). These findings may be interpreted as reflecting the nature of the task. Individual word presentation produces a focus on the attributes of those particular words, whereas sentence reading produces a focus on the meaning of the sentence, virtually disregarding the individual words.

We have conducted six experiments to test whether repetition priming for visual objects depends upon their relevance for the solution of a task at study. The first four of these experiments were conducted with a graduate student, Preston Bost (Bost & Cave, in preparation). They have been submitted and are currently under revision to be resubmitted within the next few weeks. The last two experiments were conducted with another graduate student, Jon Holbrook (Cave & Holbrook, 1996). They are currently under review.

In Experiments 12A-D, each study stimulus was not a single picture but an array of four pictures. If RP is dependent on task relevance, subjects should show priming for different subsets of the same stimulus set as study tasks demand focus on different stimuli. Study tasks were designed such that one, all, or none of the four pictures was relevant to the task. We suggest that only those pictures that are the focus of the study task will show facilitation in a later picture naming test. If a representation is formed automatically with perceptual processing, however, priming should occur for all pictures that subjects perceive.

We manipulated the task relevance of study pictures by conducting three experiments using four-picture study arrays. Subjects in each experiment saw the same arrays, but in each experiment study tasks demanded focus on different pictures. Would priming would be restricted to items that were the focus of the study task?

In Experiment 12A, study arrays contained a single task-relevant stimulus: a target, defined by its membership in a category, which the subject was to name. This task requires that subjects respond to one item, but involves perception of some irrelevant stimuli (nontargets). If priming is dependent on the focus of the study task, subjects should show facilitation for only the targets. If priming is an automatic consequence of perceptual processing, subjects should show facilitation for nontargets as well as targets.
Experiment 12B provided no study focus. Subjects fixated in the center of each array. Under these circumstances, no individual object is critical to the subjects' task; strict dependence on task relevance should therefore result in no facilitation for study pictures. If priming depends solely on perception, however, subjects should show facilitation for all study stimuli. Experiment 12C tested the prediction that subjects will prime for all stimuli in an array if they are all task relevant. Subjects covertly named every picture in each study array.

Experiment 12A

In Experiment 12A, each trial began with a broad category label (e.g., "transportation") and then a 4-picture array. Subjects were to name the one picture that matched the category label (e.g., "bicycle"). At test subjects were asked to name individual pictures as quickly as possible. These included targets from the study task, nontargets from the study task, and new pictures. Naming at test was facilitated only for targets of the study search and not for nontargets that were also perceived, but that were not relevant to the performance of the study task (see Figure 10 A).

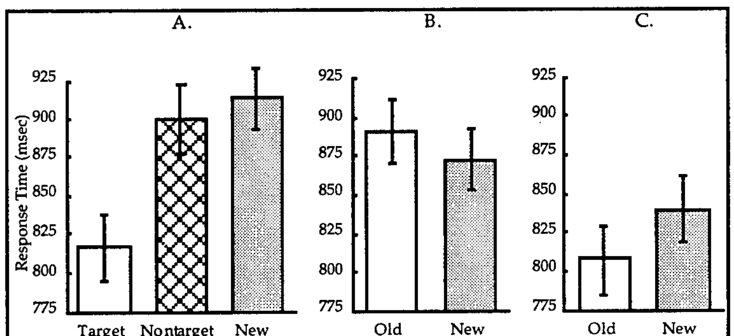

Figure 10. A. Naming times for pictures that were targets and nontargets in a category search at study vs. new pictures. B. Naming times for pictures fixated in a array at study vs. new pictures. C. Naming times for pictures in arrays covertly named at study vs. new pictures.

Experiment 12B

In Experiment 12B subjects focused on a fixation point during the display of the same 4-picture arrays at study. In this case, none of the study pictures primed in a later naming test despite the fact that the study arrays were exposed for 1400 ms. In this case, the study task (fixation) did not require focused analysis of any of the stimuli (see Figure 10 B).

Experiment 12C

In Experiment 12C subjects covertly named all four stimuli in each array at study. In this case all pictures were important to the performance of the task and all primed later at test (see Figure 10 C).

Using the same stimuli in all three experiments, the focus of performing the study task determined which of those stimuli were facilitated in a later naming task for individual pictures.

Experiment 12D

In Experiment 12D subjects performed the category search task at study and later performed an explicit memory test for study vs. new stimuli. These subjects were able to recognize nontargets from the study task at above chance levels despite the fact that these stimuli had not elicited priming. Likewise, half of the subjects in Experiment 12B participated in a yes/no recognition test for the stimuli that they saw in the fixation condition vs. new pictures. Testing priming and recognition for the same stimuli in the same subjects, there was no priming for studied stimuli, but recognition was above chance (despite a high false alarm rate). This group of experiments suggests that the occurrence of priming can be modulated by the nature of the study task. Stimuli that do not produce priming can still be perceived and can be recognized.

We have recently submitted results from 2 additional experiments (Cave & Holbrook, 1996) that demonstrated that stimuli can be perceived without eliciting priming. Our goal was to present stimuli such that they could be readily perceived, but not interpreted as being relevant to the performance of a task. Subjects were told that they were participating in a pupillary response experiment. The experiment would require monitoring their eyes and would begin with a calibration of the monitoring camera.

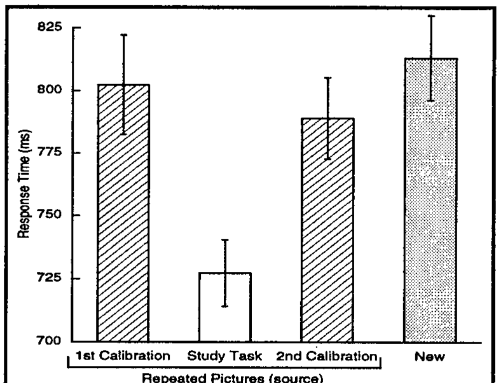

Figure 11. Naming times for pictures that had been previously shown in "camera calibration" phases did not demonstrate priming relative to times to name new pictures. Pictures that were named at study did demonstrate priming. See text for details.

Experiment 12E

In Experiment 12E pictures were individually presented in the "calibration" phase followed by a picture naming phase. After a 15 min delay there was a second calibration and a naming test that included pictures from all preceding phases as well as new pictures. The results of the naming test shown in Figure 11 demonstrate that subjects did not prime in the naming test for pictures displayed in the calibration phases. This is despite previous demonstrations that passive viewing of individual pictures can induce priming (Brown, Neblett, Jones, & Mitchell, 1991). Half of the subjects also answered whether they recognized pictures. Explicit recognition for pictures from the calibration phases was significantly above chance, despite the lack of priming.

Experiment 12F

In Experiment 12F the study pictures and calibration pictures were equated for exposure duration and the study pictures were covertly named rather than overtly named.

The results were similar except that there seemed to be some carry-over of the covert naming task into the second calibration that induced some priming in this condition.

These experiments provide evidence that priming may be modulated by task relevance by showing that participants demonstrate repetition priming for different sets of similar items depending on the task requirements. When the stimuli are relevant to study task performance, there is priming; when the stimuli are not relevant to study task performance, there is no priming at test. These findings fit well within a framework of task modulated priming, but they pose difficulties for the assumption that perceptual priming is a necessary consequence of perceptual processing.

The results also demonstrate that study conditions that do not produce priming may yet allow for explicit memory. A dissociation between explicit and implicit memory in the direction of demonstrating explicit without implicit memory has very rarely been shown in normal subjects. The only other such demonstrations were demonstrations that priming could be insensitive to stimulus attributes such as size or color that affected explicit memory (e.g., Cave, et al., 1996; Cooper, et al., 1992, Srinivas, 1996a). Again these results are consistent with the idea that perceiving stimuli need not necessarily modify perceptual processing, but only does so when the stimuli and particular attributes are important for the solution of a perceptual study task. Still, the perceptual information that does not affect implicit memory is processed and made available to different memory processes that solve different tasks and retain different information.

The question of whether the current results may have been predicted on the basis of transfer appropriate processing (TAP; e.g., Morris, Bransford, & Franks, 1977; Roediger, 1990; Roediger, Weldon & Challis, 1989) may remain. It is difficult to assess the degree to which TAP might predict these results because the issue of whether study processing *necessarily* produces some processing facilitation has not been addressed in this framework. Given the importance placed upon the study - test match one might reasonably assume that this framework assumes that study processing does modify processing. The demonstration of priming relies upon the use of an appropriate test to take advantage of that facilitation. Under this assumption, a failure to detect priming would be considered a failure to employ a priming test that was sensitive to the processing modifications. An alternative explanation is simply that not all processing induces priming. Priming in this conception is sensitive to the processing demands of the situation, not merely an outcome of having performed some processing.

How Long does Repetition Priming Last?

Experiment 13

Experiment 13 tested the duration of repetition priming in the picture naming paradigm with a single study exposure. The results of this experiment are in press in *Psychological Science* (Cave, in press).

Picture naming offers a method that in both normal and amnesic patients produces long-lasting priming effects based on one stimulus exposure independent of explicit memory (Cave & Squire, 1992; Mitchell & Brown, 1988). The task is easy and therefore not susceptible to strategic influences and no mention is made of repeating stimuli. In the longest test of picture naming facilitation previously published, Mitchell & Brown (1988) demonstrated priming after delays of up to 6 weeks. Just how long might an initial exposure in a picture naming task affect later naming? Fully characterizing RP, including its possible duration, will provide data that must be accounted for in theories of implicit memory. For instance, relatively long-lasting priming effects helped dispel the idea that priming could be mediated by sustained activation from the initial exposure.

Subjects named pictures in session 1 (each picture was shown only once) and returned for a second naming session after delays ranging from 6 to 48 weeks. Recognition memory for a separate group of pictures was also assessed in the second session.

As shown in Figure 12, priming can last a very long time following a single, brief study exposure. Priming does appear to diminish slowly over long delays but is surprisingly long-lasting -- at least 48 weeks. Recognition performance is low but above chance across these long delays. (See Figure 13.) Perhaps this is not surprising as recognition is a test of long-term memory. However, it has often been suggested that implicit memory is more long-lasting than is explicit. For instance, Mitchell & Brown (1988) showed a sharp decline in recognition memory across 1-6 week delays with steady naming facilitation over the same delays. This was one criterion for claiming independence between explicit and implicit performance. The shortest delay in the current experiment was the same as Mitchell & Brown's longest delay. Despite some differences in design, the results in the two six week delays are quite similar. They reported 9% priming and just over 20% hits - FA (from their Figure 1) compared to the current 7.3% priming and 20% hits - FA. Therefore it seems reasonable to consider the present results as extending those of Mitchell and Brown (1988).

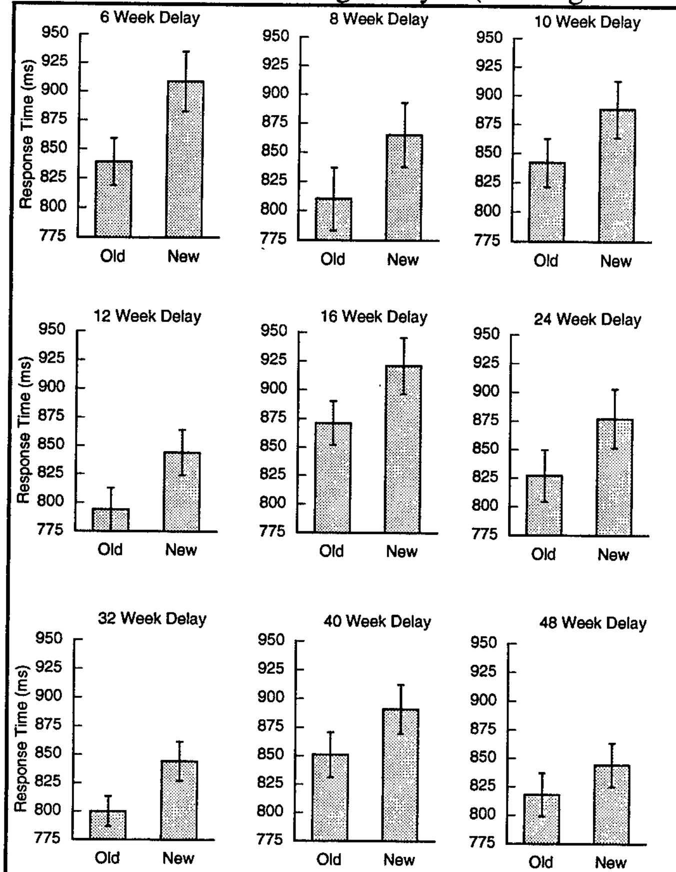

Figure 12.

Despite prior evidence that recognition declines rapidly over short delays the patterns of priming and recognition seem similar at long delays. Evidence that amnesic patients show normal priming in this paradigm (Cave & Squire, 1992) and that naming times in normal subjects are not influenced by whether stimuli are recognized or not (Mitchell & Brown, 1988) suggests that performance on the two tests are not both mediated by explicit memory. Perhaps instead, low levels of recognition memory are mediated by "automatic" (Jacoby, 1991) memory processes, familiarity (Mandler, 1980), or perceptual fluency (Johnston, Dark, & Jacoby, 1985) rather than conscious recollection (but see Haist, Shimamura, & Squire, 1992). Interestingly, recognition memory is very rarely at chance even after long delays (cf. Moscovitch & Bentin, 1993) or in amnesic patients. Recognition in the current experiment is similar to that shown by amnesic patients in the same paradigm (Cave & Squire, 1992).

One way to test the relation between implicit and explicit performance is to test whether implicit memory can be detected in the absence of explicit memory (or vice versa). Recently, Moscovitch and Bentin (1993) claimed that when explicit memory was very poor, priming in lexical decision was eliminated. The current experiment also offers an opportunity to consider priming when recognition memory is eliminated by forgetting. A group of 49 subjects were identified on the basis that their hits - FA were less than 10%. Their average recognition performance (5% hits - FA) did not differ from chance. Priming in these subjects was significantly above chance. These subjects with low recognition scores demonstrated marginally *more* naming facilitation than the remaining subjects with higher recognition scores (6.4% vs. 4.8% priming -- when priming was based on means this difference reached significance).

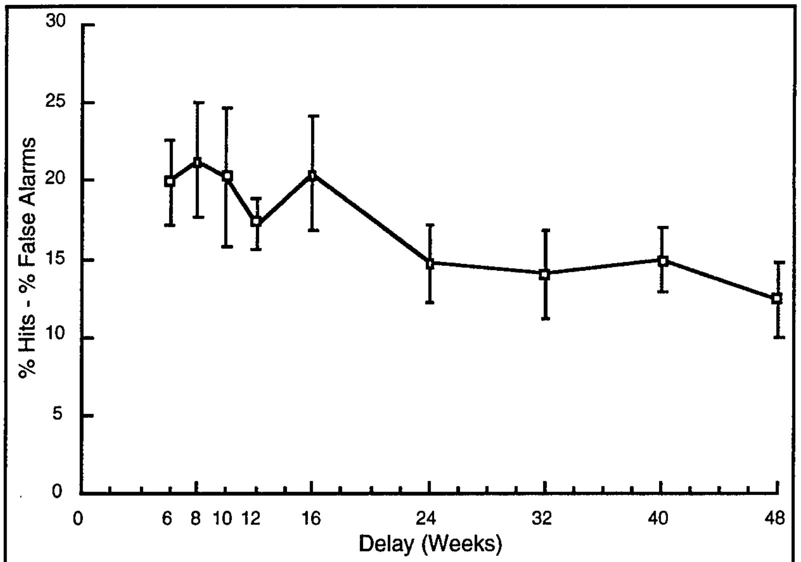

Figure 13. Yes/no recognition performance.

The current results suggest that even with chance explicit memory, robust priming can still be detected in normal subjects. These results imply that despite similar patterns of performance on implicit and explicit tasks, these performances are independent. This conclusion should be considered with some caution because in this experiment the measures were not conducted on the same stimuli (although the stimuli were matched).

Further evidence for independence is the lack of correlation between recognition and priming (N=202), r = -0.10. When Perruchet & Baveux (1989) tested correlations between explicit and implicit measures they concluded that implicit tasks that were direct and immediate (e.g., tachistoscopic identification) elicited performance uncorrelated with explicit memory while other tasks that allow controlled strategies (e.g., word fragment completion) were correlated with explicit memory. Picture naming, like other measures uncorrelated with explicit memory, is easy and direct. Attempting to recall whether an item is old or new might even be detrimental to naming speed. Therefore, the nature of the task in which "memory" is measured may largely determine whether conscious recollection is engaged in its solution. For instance, slow and effortful identification in the tactile and auditory modalities seemed to allow influence of explicit memory.

Effects of a simple, brief exposure of familiar stimuli can be detected after very long delays. These effects appear to be independent of explicit memory when assessed in a direct task that does not call upon conscious strategies. Proposed mechanisms of RP will need to account for these findings. For instance, it will be important to consider neural mechanisms that might mediate long-lasting priming (e.g., Park, Blaxton, Gabrieli, Figlozzi, & Theodore, 1994; Squire, et al., 1992) and whether such mechanisms might operate over the demonstrated delays.

General Discussion

The experiments conducted for this project taken together give us a more thorough understanding of repetition priming as a form of implicit or nondeclarative memory. In the paradigms often used there is good evidence that priming is mediated by modifications in the perceptual processing of the stimuli. This is consistent with previous notions that repetition priming reflects the processing of stimuli in areas of the brain that perceive stimuli rather than those known to be necessary for the formation of new explicit memories. In picture naming, a form of priming that is long-lasting and apparently independent of conscious recollection, the evidence suggests that priming is not related to the activation of conceptual information or to response facilitation. Priming that occurs in ways analogous to visual priming in the auditory and tactile modalities is strong evidence that priming is related to basic identification processes that occur within all modalities. Therefore, it may be related to general mechanisms that allow us to classify and learn classifications of stimuli.

With good information that priming is or at least can be perceptually mediated the interest turns to how that mediation occurs. Although priming is a function of modifications in perceptual processing, indications are that early ideas about the extreme perceptual specificity of repetition priming were probably incorrect as were ideas that repetition priming must be modality specific. Many examples of insensitivity to perceptual manipulations in repetition priming have now been reported. These include insensitivity to color or fill pattern manipulations. These insensitivities cannot be attributed to priming simply acting after constancy mechanisms that might account for lack of size or location effects for instance. In addition evidence is now accumulating that repetition priming can transfer robustly across modalities. Tests of priming between vision and touch have shown good transfer. Previous tests of modality specificity have been tests between the auditory and visual modalities. Audition and vision depend upon very different underlying representations to identify stimuli whereas vision and touch may both use spatial information to identify stimuli. An account of repetition priming that considers the requirements of the representations necessary for task solution offers a good explanation of patterns of both perceptual and modality specificity in repetition priming.

A comprehensive account of the sensitivity of repetition priming to exemplar manipulations but not other manipulations suggests that repetition priming is sensitive to the stimulus attributes that are critical for the solution of the task in which stimuli are encountered and insensitive to other attributes. In the case of identifying familiar objects, the salient attribute is shape (thus sensitivity to exemplar), but other attributes such as color or size are irrelevant to basic level identification. Likewise, a consideration of the task requirements of visual and tactual identification provides a good explanation for priming transfer between these two modalities and not between vision and audition. In other words, priming may not be simply a passive by-product of inflexible, low-level perceptual processing mechanisms but may instead reflect the task requirements of particular study situations.

The notion that priming is not absolutely sensitive to certain stimulus attributes places the interpretation of priming results in a slightly different light. Priming has been studied not only in its own right, but as a method to learn more about basic object identification processes. With this goal in mind an assumption is that priming reflects fixed perceptual processes. If, however, the sensitivity of priming is determined by the nature of the task surrounding the perception of stimuli, then this assumption may not be well-founded. The results of the test of orientation effects on repetition priming suggest that at study the identification of common objects is not orientation sensitive. However, studying a particular viewpoint confers sensitivity to that viewpoint. In other words, priming seems to be a measure of the effects of a *particular* study encounter not obligatory processes that occur on every stimulus encounter. The findings of insensitivity of priming to color manipulations may be used to show that object identification in general is not sensitive to color. In many cases this is true, but to suggest that priming is a indicator of fixed perceptual processes may be unwarranted. If the nature of the priming task requires sensitivity to stimulus attributes that are generally not important for task solution, sensitivity might be seen. Preliminary results of having subjects classify artificial stimuli suggest that they can be sensitive to color if task performance is aided by such a sensitivity. We will be pursuing this notion further.

A logical extension of the idea that priming is not obligatorily sensitive or insensitive to certain stimulus attributes is that it may not be obligatorily sensitive even to the *presence* of stimuli. In other words, perhaps priming can be "turned on and off" according to task demands. If priming occurs for every stimulus we perceive and if it is long-lasting (as the results of Experiment 13 suggest), then there needs to be either extreme context sensitivity for the expression of priming, which does not seem to be the case to the extent that it has been tested, or there needs to be a mechanism to "undo" priming and return responses to baseline. Given the long-lasting nature of priming, it is difficult to conceive that priming would not have been "undone" in that period if it works in this way. Instead, it might be useful to consider priming as a facilitation that is not a by-product of perceiving stimuli, but of the nature of the processing that is performed on those stimuli. If a stimulus is encountered in the context of a task that suggests future relevance for that stimulus, then processing of that stimulus is modified. If processing is "routine" then the costs of modifying perceptual processing may not be incurred and priming does not occur. In other words modifying the processing of stimuli is not without costs -- e.g., synaptic changes must occur. These modifications may not occur in trained perceivers when the perception of stimuli is occurring merely to allow us to navigate or to interact with objects. If, however, a specialized task, such as generally occurs in a laboratory, confers special status on objects in the solution of a task, then the processing of those stimuli may be modified. This task relevance need not be conferred by any conscious or strategic process, but is a form of a top-down influence that allows for a change in the way certain stimuli are processed.

Our results thusfar in assessing whether perception produces priming suggest strongly that subjects may perceive stimuli, but not demonstrate priming for those stimuli if they are perceived in a way that does not make them relevant to the solution of a task. For instance, if subjects are merely searching through groups of stimuli or if they simply watch stimuli they do not demonstrate later priming for those stimuli. Because the usual setting of an experiment generally makes all stimuli encountered in an experiment potentially relevant for later performance, priming is generally easy to elicit in the laboratory. In fact, it is difficult to develop situations that approximate settings in which stimuli are perceived with no particular goal in mind. When this is accomplished, priming seems not to occur when stimuli are not perceived to be relevant to the solution of a task. Priming that occurs in the service of task solution may be functionally important in making certain stimuli more readily processed than others.

This task modulation conception of repetition priming is generally consistent with the transfer appropriate processing approach (which states that test performance is maximized to the extent that study processes are repeated at test; e.g. Roediger, et al., 1989), but we believe it expands upon those ideas. We believe that the modification of stimulus processing is a function of the utility of making a modification and therefore is critically dependent upon the nature of the study conditions. Of course, a test that also requires similar processing (which has been modified by the study) is also critical to detect priming. We believe that the notion of task modulation enhances TAP by strengthening the reason why the test must match the study. The study task does not automatically result in modifications that can be detected at study, but only modifies processing for stimuli and stimulus attributes that are critical in the solution of the study task. The test need not match the study task exactly (in fact many priming paradigms do not use the same task at study and test), but the test must be sensitive to processing the same stimulus attributes that were modified at study. Critically, not all stimulus attributes are modified by a study task, and we believe that the perception of a stimulus does not necessarily modify the processing of that stimulus in any way that is later detectable in a priming test. Under this reasoning, priming occurs because there is utility in modifying the processing of certain information and not other information given certain circumstances. Priming that is perceptually based but that is not an obligatory by-product of perceiving stimuli allows for the flexible modification of stimulus processing and the possibility that perceptual information can be passed to other memory mechanisms without producing modifications that are detected by implicit tests.

If priming is modulated by task demands, then it should not be thought of as a phenomenon that is strictly sensitive or insensitive to certain manipulations but instead as sensitive to information that is important in the service of performing the task. Sensitivity would be expected to change with the requirements of the study task. For any given stimulus many representations are formed, and most likely the processing of many different aspects of a stimulus is modifiable. Which aspects of stimulus processing are modified and which are not may reflect the utility of such modifications in the later performance of the same task. Given that there are compelling results to localize repetition priming in IT, in parietal or superior temporal areas, probably in auditory processing areas, and so on, we perhaps should not be thinking in terms of localizing priming. Priming is a behavioral manifestation of modifications in neural mechanisms. Many representations are formed for any given stimulus and most likely the processing of many different aspects of a stimulus is modifiable. The variability in priming results may be accommodated by considering the combination of stimuli and the processing demands that surround those stimuli. Previous results with attention manipulations for example have shown that neural processing can be modified by task demands (e.g., Moran & Desimone, 1985). Likewise, we may think of priming as representing processing modifications in whatever processing areas that are forming representations critical for the task(s) at hand. In other words, priming may not occur in any particular brain area, but processing modifications may occur in any of many brain areas dependent upon the task demands. Such flexible processing facilitation would seem highly adaptive.

Although much of our focus has been on understanding the nature of repetition priming and whether it may reflect flexibly engaged processing modifications, a number of interesting findings regarding explicit memory have also arisen. In cases of perceptual specificity, attributes that do not affect implicit memory performance consistently affect explicit memory performance. Likewise, our tests of whether the occurrence of priming can be task modulated have resulted in explicit memory for stimuli that do not elicit implicit memory. These results highlight one of the initial interests in RP -- that it is dissociable from explicit memory. We suggest that this dissociation is largely based on the tasks that each type of memory performs. Implicit memory is sensitive to stimuli and attributes that allow the performance of tasks such as identification. These tasks are insensitive to qualities that signal a particular instance as opposed to general classification. Explicit memory, on the other hand, is sensitive to the stimulus qualities that signal a particular instance occurring in a particular setting.

If perceptual processes are modifiable on the basis of task demands, then stimulus attributes that are not central to task performance will not be modified and those attributes will not affect priming. However, those attributes may be processed and passed to other processes such as explicit memory -- leading to effects on explicit memory of stimulus attributes that did not affect implicit memory. Likewise, perhaps entire stimuli can be perceived, but the processes of perception are not modified if those stimuli are not playing a functional role in task performance. These stimuli would not demonstrate priming, but may well be recognized. Manipulations that have led to implicit memory without explicit memory have been abundant. A few demonstrations of explicit memory without implicit memory have occurred (e.g., Gabrieli, Fleischman, Keane, Reminger, & Morrell, 1995). The task modulation framework suggests that under certain conditions this dissociation may be common. The possibility that explicit and implicit memory may be doubly dissociable in normal subjects certainly merits more study.

Repetition priming appears to be a long-lasting phenomenon that may have functional significance reflecting the processing demands of a study task. Priming that is long-lasting, independent of explicit memory and sensitive to processing demands may form an important component of human sensitivity to repeated stimuli in ways that reflect the relevance of stimuli and their attributes in task solution.

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