Varieties of priming

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Recent data from brain-damaged and normal subjects converge to suggest several characteristics of repetition priming: firstly, it is sensitive to the physical and structural properties of input; secondly, it is unaffected by semantic processing at encoding; thirdly, it is frequently preserved in amnesic patients with impaired explicit memory; fourthly, it depends upon perceptual representations processed and stored by modality-specific cortical memory systems; and, finally, it is subject to constraints particular to the task employed and the type of information that is primed.

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Introduction

Human memory is often studied by exposing subjects to target items, such as words or pictures, and later asking them to explicitly recall or recognize the targets. In recent years, however, it has also been shown that exposure to target items has a persisting effect on later task performance when subjects are asked to identify perceptually degraded versions of the targets, without conscious or intentional recollection of their prior exposure. This persisting effect, known as direct or repetition priming, is an implicit, or non-conscious, form of memory [1–4]. Repetition priming can last over intervals of minutes, hours, and even weeks, which distinguishes it from other types of priming, such as indirect or semantic priming, that persist for only a few seconds [5].

A number of early studies revealed that amnesic patients, who have severe problems remembering recent experiences as a consequence of damage to limbic and/or diencephalic brain structures, nevertheless exhibit normal repetition priming effects [1,6]. This observation provides compelling evidence that repetition priming and explicit remembering depend on fundamentally different underlying processes. Several streams of data converge to suggest that many repetition priming effects depend on a perceptual representation system that handles information about the physical form and structure, but not the meanings or associative properties, of words and objects [2,7,8]. In this article, we discuss recent work that supports and extends these conclusions by suggesting that different types of repetition priming tap into distinct, cortically based memory subsystems that are separate from the limbic structures supporting explicit memory.

Repetition priming for visual word forms

Most repetition priming research has involved visual presentation and testing of words. Past studies have delineated some basic characteristics of visual word priming, foremost among them are a sensitivity to physical and structural features of studied material, and an insensitivity to conceptual or semantic elaboration of studied material (see [1,7,9•] for reviews). For the most part, recent research has focused on a variety of variables whose effects on word priming help place limits on the generality of these two principal characteristics.

Some researchers have examined the effects of stimulus repetition and of retention intervals on priming. For example, Grant and Logan [10] found that priming on a lexical decision test, in which people decide whether letter strings constitute correctly spelt words, increases as a power function (i.e. increases exponentially) of the number of repeated presentations distributed evenly across time intervals of minutes to hours. They found that this effect lasts for up to two months. On the other hand, Moscovitch and Bentin [11] found that when subjects' explicit memory is reduced to chance levels by increasing the retention interval to 24 hours, lexical-decision priming may also be non-significant. Challis and Sidhu [12] found that massed repetitions of words enhanced explicit recall, but did not affect priming on a test that involved completing fragments of words. Roediger *et al.* [13] found that priming effects on tests of word-stem and word-fragment completion were undiminished after a 48 hour retention interval. Overall, these studies suggest that the effects of stimulus repetition and of the retention

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interval on the magnitude of priming may be specific to particular tasks.

Confirming and extending prior findings concerning the perceptual specificity of priming, Roediger *et al.* [13] found more priming on word-stem and word-fragment completion tasks following study of words rather than following study of corresponding pictures. The relatively small amount of cross-form priming (i.e. priming from pictures to words) that does occur may be eliminated by reducing the subject's opportunity for labeling the pictures or by reducing the time they get to complete word fragments [14].

Although the perceptual specificity of priming is impressive, there is reason to believe that nonperceptual processes may play some role in repetition priming under certain task conditions. Weldon [15] manipulated the amount of response time allowed for completion of word fragments after subjects studied pictures, spoken words, or printed words. She found that priming was reduced by study-to-test changes in surface features, but also reported that the magnitude of this effect diminished as more time was allowed for word-fragment completion. It seems that the perceptual processes supporting priming are activated quickly, whereas nonperceptual processes become active more slowly.

Other forms of repetition priming seem to be driven primarily by conceptual processes. Challis *et al.* [16] had subjects complete word fragments or answer general knowledge questions that were primed by prior visual or auditory presentation of one-word answers. Priming on a word-fragment completion test, which has a large perceptual component, was substantially reduced by study-to-test shifts in modality. However, priming on the general knowledge test, which is probably driven primarily by amodal conceptual information, was unaffected by changes in presentation modality. These observations point to important differences between perceptual and conceptual repetition priming, and other evidence suggests that conceptual priming may be affected by damage to neural structures different from those that support perceptual priming ([17]; also see below).

Increasingly, data concerning priming in brain-damaged populations, in addition to amnesic patients, are providing important evidence about underlying processes and systems. Schacter *et al.* [18] found normal levels of priming on a word identification test in a patient with a left temporo-occipital lesion, which produced a severe reading disorder, yet appeared to spare access to stored visual word forms. Carlesimo *et al.* [19••] provide complementary data from a reading-impaired patient with left-posterior cortical damage, who could not access the visual form of words. The patient exhibited no priming on tests of word identification and word-stem completion, yet showed normal priming on auditory tests. These data provide support for the view that visual word priming depends upon a visual word-form system that represents the perceptual form of words [7]. Converging evidence from neuropsychology and brain-imaging studies suggests that this system has a significant locus in extrastriate visual cortex [7,20]. An initial positron emission tomography study of word-stem completion indicated significant decreases in activation of right extrastriate cortex, but also indicated activation of the right hippocampus during priming [21]. There are, however, strong reasons to suspect that during the priming task these subjects engage in explicit retrieval (see [2] for discussion).

A recent study that examined word-stem completion priming under conditions in which explicit retrieval could be ruled out experimentally revealed significant decreases in right extrastriate cortex, but no activation of right hippocampus (D Schacter, M Albert, N Alpert, B Rafferty, S Rauch, unpublished data). Damage to some other cortical areas, such as the frontal lobes [22], appears to have little effect on perceptual repetition priming. Indeed, many sources of data indicate that areas of the frontal lobes subserve semantic priming, in contrast to posterior visual cortices that subserve repetition priming [23,24].

Experimental evidence also suggests that a word-form subsystem in each cerebral hemisphere may store different types of representations. Marsolek *et al.* [25•] found that changing the type-case of the words between study and test did not affect word-stem completion priming when word stems were presented to the left hemisphere at test, but had a large effect when word stems were presented to the right hemisphere at test. This sensitivity to type-case change suggests that the right-hemisphere subsystem may store form-specific perceptual representations of words. This subsystem may support priming on other tasks that are sensitive to surface features of words.

Although evidence of preserved priming in amnesic patients motivated early research in this area, the limbic structures damaged in amnesia may be necessary for certain kinds of visual word priming to occur — priming effects that require linkage or binding between different kinds of information. Kinoshita and Wayland [26•] found that normal control subjects, but not amnesic subjects, show more priming on a word-fragment completion test when the typefont of target words is the same at study and test than when it differs. These data suggest the possibility that limbic structures may occasionally participate in priming by binding together episodic information about a word form and its context-specific typefont (see [2] for discussion). Similarly, amnesics typically exhibit impaired priming for newly acquired associations that depend on binding together conceptual and perceptual information (e.g. [27,28]). Recent data show, however, that when study and test conditions focus primarily on the perceptual aspects of stimuli, amnesics can build up representations that support priming of new associations when the stimuli are presented repeatedly [29].

Repetition priming for visual objects

Priming of visual objects has only recently become the subject of systematic investigations, but it appears that object priming exhibits many characteristics that are similar to those of word priming. Furthermore, object priming appears to be supported by a distinct perceptual representation subsystem, a structural description system that preserves information about the three-dimensional structure and form of objects at a pre-semantic level [2,7].

Srinivas [30] has provided strong evidence that priming for pictures of familiar objects can be highly specific to surface contours and orientation in depth. Further aspects of repetition priming of familiar objects have been delineated by Murray *et al.* [31], who found that priming on a picture-naming task is reduced by changes in the picture–plane orientation of objects, and by Biederman and Cooper [32], who found that priming of picture naming was unaffected by changes in stimulus size.

Considerable interest centers around the issue of priming for novel objects, as the nature of such priming can reveal functional characteristics of the subsystems supporting priming that cannot be discovered with priming for familiar objects that have pre-existing representations. Schacter, Cooper and colleagues (e.g. [33]) have examined priming with an object-decision task in which subjects decide if briefly presented line-drawings represent structurally possible or impossible objects in the real world. Priming has been obtained for structurally possible objects, but not for impossible objects. Such priming requires encoding of global shape and is sensitive to changes in picture–plane orientation, but not to changes in size (e.g. [33,34]). Thus, novel object priming shares some characteristics with priming of familiar objects. Extending this work, Schacter and Cooper [35•] found similar amounts of priming following encoding tasks that focus on object structure and those that focus on object function, whereas explicit memory was higher following encoding of functional than of structural information. These data support the notion that like familiar object priming, novel object priming depends upon a pre-semantic structural description system.

This structural description system appears to be preserved in amnesic patients. Studies concerning priming of both familiar and novel objects in amnesics dovetail nicely with data from normal subjects. Cave and Squire [36•] found that amnesic patients exhibit a long-lasting facilitation of naming latencies for familiar pictures that is unaffected by study-to-test changes in object size, but is affected by changes in shading and form. Schacter *et al.* [37] found that amnesic patients show normal levels of priming across study-to-test transformations in size of objects on the possible/impossible object decision test. Other researchers have similarly demonstrated preserved priming for novel objects in amnesic patients [38,39]. These studies employed variants of a dot priming task [40] in which subjects are primed to connect dots with a particular configuration of previously exposed lines. It is not entirely clear whether the amnesics in these studies exhibit fully normal priming, however, because the magnitudes of the priming effects in amnesics and controls depends to some extent on the way in which the data are scored. Nevertheless, normal priming of novel patterns can be obtained: Musen and Squire [41] found robust priming of previously exposed dot patterns when amnesics and controls attempted to copy arrays of dots that were flashed briefly.

In summary, the foregoing data are largely consistent with the idea that visual object priming depends heavily on a pre-semantic structural description system.

Repetition priming for auditory words

Relatively little research has examined the nature of auditory priming effects. Recent studies using tasks that require identification of degraded auditory words forms, or completion of auditory word stems, have revealed, however, some important properties of auditory priming. First, priming of auditory word completion is largely modality specific [42]. Second, Schacter and Church [43] found that auditory priming on completion and identification tasks is insensitive to semantic versus non-semantic study-task manipulations that have large effects on explicit memory. Third, auditory word priming can be specific to certain properties of the acoustic input: Church and Schacter [44] found that study-to-test changes in speaker's voice, intonation, or fundamental frequency impaired priming while having little effect on explicit memory (see Fig. 1). Fourth, a case study of a patient with severely impaired comprehension of spoken words revealed normal levels of priming on two different auditory priming tasks despite the patient's nearly complete lack of comprehension of the studied items [45••]. Finally, normal levels of priming on an auditory word identification test were observed in amnesic patients despite their severely impaired explicit memory [46]. Taken together, these data support the notion that auditory priming relies on access to a pre-semantic auditory word-form subsystem of the perceptual representation system.

One recent study (see [2]) indicates that amnesic patients do not exhibit voice-specific priming on an auditory identification test under conditions in which control subjects do. Such priming may require binding together of acoustic and phonological information, and, therefore, require the participation of limbic and diencephalic structures that are damaged in amnesia.

Conclusions

We have considered recent evidence concerning three separate forms of priming, each of which support the

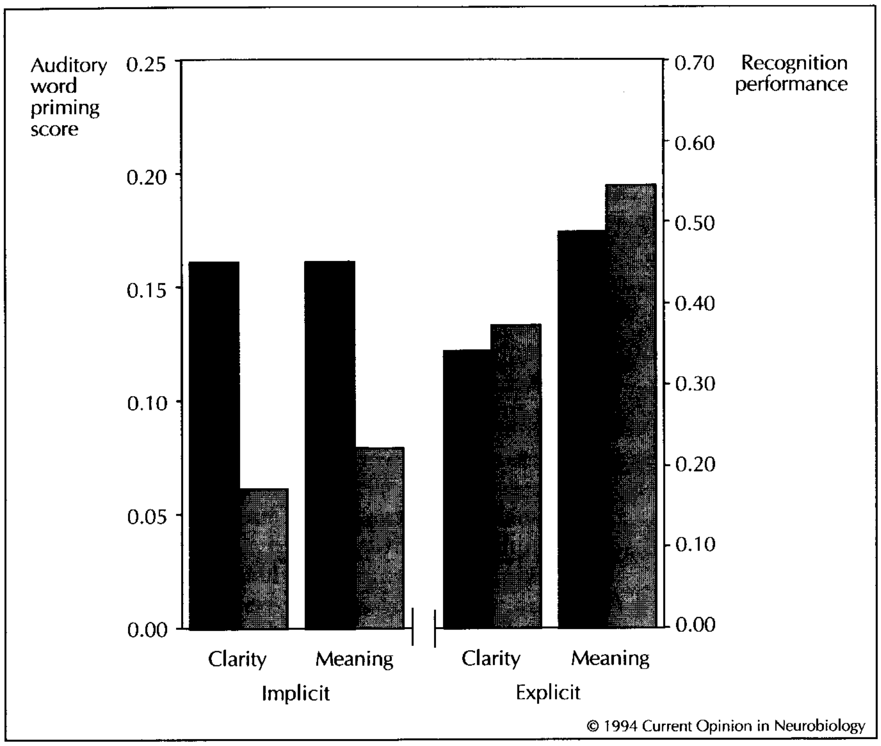

Fig. 1. Effects of encoding manipulations upon auditory priming (implicit memory) and explicit memory. Auditory word priming scores (above baseline performance of 0.07) and recognition memory accuracy (corrected for false alarms) from Experiment 3 of Church and Schacter [44]. During an initial exposure phase, subjects either judge the clarity or number of possible meanings for each item on a list of spoken words. Dark bars indicate no change, and gray bars indicate a change, in the fundamental frequency of the speaker's voice between study and test. These data indicate for the first time that auditory word priming can be specific to certain properties of the acoustic input that do not affect explicit memory, whereas manipulations that enhance explicit memory do not similarly affect priming: priming was reduced by changes in fundamental frequency, whereas recognition memory was enhanced by semantic encoding. In other experiments, study-to-test changes in speaker's voice or intonation similarly impaired priming while having little effect on explicit memory.

proposition that priming is often specific to physical and structural properties of input, insensitive to the amount of semantic processing at encoding, and frequently preserved in amnesic patients, although evidence from both visual and auditory tests indicates that amnesics fail to exhibit complex forms of priming that appear to require binding or association. Thus, although each kind of priming relies to a large extent on perceptual representations that are processed and stored by modality-specific cortical memory subsystems, different types of priming may be subject to constraints that are particular to the type of information that is primed and the particular task on which priming is assessed. Future research should help to refine and clarify these conclusions.

Also of interest are some recently investigated forms of short-term priming that may rely on representations distinct from those supporting long-term priming. For example, Maljkovic and Nakayama [47] have described a visual priming effect that is sensitive to the color and spatial position but not to the global form of objects, which lasts for only a few seconds. Short-lived priming effects have also been documented in investigations of negative priming [48], in which identification of an object is slowed after it has been presented, but ignored, on a previous trial. Importantly, however, recent work indicates that negative priming can last across exposure–test intervals of 200 trials (A Treisman, B DeSchepper, *Invest Opthal Vis Sci Abstr* 1993, 34:1288). As research on these various types of priming progresses, the parallels and discontinuities that are observed should provide important insights into the cognitive and neural bases of memory (see [49] for discussion).

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