In defense of abstractionist theories of repetition priming and word identification.

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Abstract

There is a great deal of interest in characterizing the representations and processes that support visual word priming and written word identification more generally. On one view, these phenomena are supported by abstract orthographic representations that map together visually dissimilar exemplars of letters and words (e.g., the letters A/a map onto a common abstract letter code a*). On a second view, orthographic codes consist in a collection of episodic representations of words that interact in such a way that it sometimes looks as if there are abstract codes. P.L. Tenpenny (1995) contrasted these general approaches, and concluded by endorsing the episodic account, arguing that no evidence demands that we posit abstract orthographic representations. This review re-considers the evidence, and argues that a variety of priming and non-priming research strongly supports the conclusion that abstract orthographic codes exist and support priming and word identification. On this account, episodic representations are represented separately from abstract orthographic knowledge, and contribute minimally to these functions.

In defense of abstractionist theories of repetition priming and word identification

There is a great deal of interest in characterizing the representations and processes that support the improved processing of stimuli repeated during an experiment; the so-called repetition priming effect. Indeed, two different types of repetition priming have been intensively studied from two quite different perspectives. On the one hand, researchers interested in memory have tended to focus on long-term repetition priming, in which facilitation can last minutes, hours, and sometimes longer (Sloman, Hayman, Ohta, Law, & Tulving, 1988). For example, participants are generally faster and more accurate in making lexical decisions to test words encoded a few minutes or hours previously in a study list (e.g., Scarborough, Cortese, & Scarborough, 1977). On the other hand, researches interested in language processing have tended to focus on short-term repetition priming in order to address questions regarding how single words are identified. In a typical short-term priming tasks, a pattern mask (e.g., ######) is replaced by a prime word that is briefly flashed (e.g., 50 ms), which in turn is replaced by the target. Under these conditions, primes are typically unnoticed by the participants, but these items nevertheless facilitate processing of targets when prime and target are the same compared to different. One key attribute of masked priming is that it lasts only a few seconds (e.g., Forster & Davis, 1984).

Amongst memory researchers, interest in long-term repetition priming was inspired by the observation that densely amnesic patients show robust (sometimes normal) priming despite poor (sometimes chance) performance on explicit recall and recognition tests (Warrington & Weiskrantz, 1974). These findings led to important claims regarding the nature of amnesia, and more generally, opened up memory

research to the experimental study of "unconscious" or "implicit" memory. Later work

demonstrated various dissociations between long-term priming and explicit memory in

persons with unimpaired memories. For example, priming is not generally facilitated

by levels-of-processing manipulations (e.g., Graf & Mandler, 1984; Jacoby & Dallas,

1981), whereas recognition and recall are highly sensitive to these procedures (Craik &

Tulving, 1975). In addition, changes in the modality of study-test items reduces or

eliminates priming (e.g., Jackson & Morton, 1984; Jacoby & Dallas, 1981), whereas

these manipulations have little effect on recognition (e.g., Roediger & Weldon, 1987).

These latter two dissociations led to the common view that priming is largely mediated

by perceptual memory representations -- at least when priming is assessed in tests that

stress the perceptual processing of single words, so-called data driven priming tasks

(e.g., Blaxton, 1989). The conclusion that perceptual codes mediate long-term

priming is further supported by the null priming obtained between synonyms (e.g.,

Roediger, & Challis, 1992) or between translation equivalents in bilingual speakers

(e.g., Kirsner, Smith, Lockhart, King, & Jain, 1984), as well as the severely reduced

priming obtained between pictures and their corresponding names (e.g., Rajaram &

Roediger, 1993; but see Masson & Freedman, 1990; Masson & MacLeod, 1992, for

argument that long-term priming is mediated by semantic representations in data driven

tasks).

In this tradition, long-term priming is generally thought to be the product of

new perceptual representations acquired during an earlier study episode (Roediger &

Blaxton, 1987; Schacter, 1990; Tulving & Schacter, 1990); what Tenpenny (1995)

calls episodic theories of priming. The primary question of interest has been to relate

theories of priming to theories of recall and recognition. Indeed, one of the central

debates that has emerged from this perspective is whether priming and explicit memory

can be explained within a single memory system, or whether qualitatively different

memory systems need to be proposed

By contrast, short-term repetition priming was first introduced as a tool to

study the identification processes that support single word reading (e.g., Evett &

Humphreys, 1981; Forster & Davis, 1984). One of the goals of introducing this

procedure was to insulate identification processes from the episodic influences that

were presumed to mediate long-term priming (Forster & Davis, 1984). Instead of

asking questions regarding memory, short-term priming was used to ask question

regarding the visual format of word representations (e.g., Humphreys, Evett, &

Quinlan, 1990), whether and how morphological relations are coded in the

orthographic and related systems (e.g., Forster, Davis, Schoknecht, & Carter, 1987;

Grainger, Cole, & Segui, 1991), the nature of the interactions amongst lexical-

orthographic codes (e.g., Forster et al., 1987; Segui & Grainger, 1990), whether

phonological codes are automatically contacted during visual word identification (e.g.,

Grainger & Ferrand, 1994; Lukatela, & Turvey, 1994), amongst other questions.

The typical conclusion derived from this literature is that the orthographic

representations supporting this priming are coded in an abstract format along various

dimensions, such that different letter (e.g., A/a/**a**) and word (e.g., READ/read/**READ**)

exemplars map onto common abstract orthographic representations (Bowers,

Vigliocco, & Haan, 1998; Humphreys et al., 1990), and morphological variants of a

word contact common abstract root morphemes (Forster et al., 1987). From this

perspective, the task of visual word identification is to reduce or eliminate the

perceptual variability associated with inputs in order to map these inputs onto abstract

lexical-orthographic representations, much like traditional theories of spoken word

processing in which the perceptual representations of phonological segments,

phonemes, syllables, etc. are coded in a format that does not encode the surface details

of the inputs (e.g., Liberman, 1970; Liberman & Mattingly, 1985). Such views of

short-term priming and word identification have been labeled <u>abstractionist</u> by

Tenpenny (1995), as the orthographic (and phonological) representations supporting

these processes are assumed to abstract away from the specific information associated

with particular words encoded in prior episodes.

Although studies of long- and short-term repetition priming have generally

been carried out independently in the memory and language fields, respectively, there

has been some overlap in the literatures from the beginning. For example, Morton

(1979) and Jackson and Morton (1984) used long-term priming in order to address

questions about visual and spoken word identification, and based in part on these

findings, developed an abstractionist model of word perception. More recently, a

number of authors, including Biederman and Cooper (1991), Bowers and Michita

(1998), Ratcliff and McKoon (1997) have also employed long-term priming techniques

to study word and object perception, adopting abstractionist perspectives.

Similarly, long-term priming results have also been used to support so-called

<u>episodic</u> theories of word and object identification (cf., Tenpenny, 1995). From this

perspective, the visual and phonological representations used in word and object

identification are the product of all the past exposures to these stimuli, and episodic

traces of specific words continue to be represented within the visual and phonological

systems. On some views, the different episodic instances are merged together over

many trials within connectionist systems (e.g., McClelland & Rumelhart, 1986;

Seidenberg & McClelland, 1989); on other views, all of the instances are coded

independently and separately from one another (e.g., Goldinger, 1998; Hintzman,

1986). In either case, visual and phonological "prototypes" are the emergent

properties of a large set of highly specific traces that interact in such a way that it sometimes looks <u>as if</u> there are abstract codes.

In a timely article, Tenpenny (1995) explored the links between these two literatures by providing a thorough review of the repetition priming research relevant to the question of whether words are identified through the use of abstract lexical representations, specific episodic representations, or both. Although primarily concerned with long-term priming, short-term effects were also discussed, as she attempted to provide a unitary account of these priming and word identification processes. Based on this review, she endorsed the view that episodic memory codes mediate word identification and priming, and argued that "there is no clear evidence that abstract representations are used at all, and it may be possible to account for the data without them" (pp. 359-360).

Although Tenpenny achieves a worthwhile goal of linking the two priming literatures, there are other ways in which the data can be interpreted. In the first section of this review, I argue that the various priming results Tenpenny cites in support of the episodic approach can readily be interpreted within an abstractionist framework. Indeed, a number of additional priming results are described that are difficult to explain from an episodic perspective, but that are predicted on abstractionist theories. In a second section, a variety of non-priming results are also described that support abstractionist views, but which are difficult to accommodate with episodic theories. Based on these considerations, I defend a so-called "weakly abstractionist" approach (cf. Tenpenny, 1995), in which pre-existing abstract word codes typically mediate word identification and repetition priming phenomena, but where episodic traces can contribute to these functions under some circumstances. In

the third and final section, I conclude by outlining the types of abstractionist theories

that seem the most promising.

<div align="center">Review of the Priming Results</div>

Tenpenny organized her review of the priming evidence relevant to the

abstractionist/episodic debate into four main sections; namely, studies that assessed

(a) the longevity of priming, (b) the influence of various contextual variables on

priming, (c) word-pseudoword differences in priming, and (d) morphological

constraints on priming. In this first section, I maintain this structure, and deal with

these findings in turn.

The longevity of repetition priming.   Two qualitatively different forms of repetition

priming that have very different time courses need to be distinguished. As noted

above, short-term priming tends to last only a few seconds (e.g., Forster & Davis,

1984) and is generally interpreted within abstractionist theories according to which

priming reflects the activation of abstract orthographic codes (e.g., Grainger &

Ferrand, 1994) or the temporary opening of abstract lexical entries (e.g., Forster &

Davis, 1984). Although Tenpenny (1995) did not endorse these interpretations of

short-term priming, she conceded that the short-lived nature of this priming is

compatible with abstractionist approaches.

Long-term priming, however, can persist for minutes, hours, and sometimes

longer (e.g., Jacoby & Dallas, 1981; Roediger, Weldon, Stadler, & Riegler, 1992;

Sloman et al., 1988). According to the abstractionist approach, this priming reflects

structural changes to orthographic representations that in turn affects the later

processing of repeated items. For example, in Morton's (1979) logogen model, long-

term priming is explained as the lowering of the word's threshold so that less

activation is required to identify the word when it is repeated. Note, the structural

change that is presumed to mediate long-term priming is different than the temporary

activation of pre-existing orthographic codes (or opening of lexical entries) that is

presumed to mediate masked priming.

According to Tenpenny (1995, p. 342), however, long-term effects pose a

serious problem to abstractionist views, because "hundreds or thousands" of abstract

word codes would necessarily be primed given that the typical person reads many

words each day, and this is considered an "implausibly" large set of words. This

problem is thought to become even more acute if an abstractionist model incorporates

competition amongst lexical units, as assumed by various theorists (e.g., Grainger &

Ferrand, 1994; McClelland & Rumelhart, 1981). The argument here is that many

words are identified between the presentation of the prime and target, and these

intervening words should eliminate any priming due to the interference that results

from lexical competition. Based on these considerations, Tenpenny argues that

episodic traces must be mediating these long-lasting effects, and perhaps the short-

term priming effects as well.

However, rejecting abstractionist theories on the basis of the longevity of long-

term priming is unwarranted, for a number of reasons. First, the sheer number of

words that the typical person reads during the day does not preclude priming even if

all read words are automatically primed. Kirsner and Speelman (1996) noted that if a

person reads 25,000 words a day, then a low-frequency word with a frequency count

of one per million would only be encountered once every 40 days! Accordingly, low

frequency words are unlikely to have been read (and primed) just prior to the

experimental setting, and thus there is no reason to presume that these items cannot

benefit from repetition within an experiment, even if the delay is a few minutes, hours

or days. Consistent with this interpretation, priming for high-frequency words is

much reduced compared to low-frequency words, and occasionally, priming for high-frequency words is absent altogether (e.g., Bowers, in press a; Forster & Davis, 1984; Rajaram & Roediger, 1993).

In addition, there is no reason to presume that these structural changes occur automatically each time a word is identified, and there are many circumstances in which it is plausible to assume that the relevant changes do not take place. For example, when reading text, people tend to fixate on each specific word for only a brief moment, with an average fixation of approximately 200-250 ms (Rayner & Sereno, 1994). This may not be sufficient time to support the long-term modification of orthographic codes, particularly when multiple words are processed in quick succession. Indeed, in some models of word recognition word codes are only strengthened if they are activated for a sufficient duration--activation for shorter durations would support masked priming, but not long-term priming (Grossberg & Stone, 1986). To the extent that lexical-orthographic codes are strengthened only under conditions in which sufficient attention is directed at the perceptual level, Tenpenny's argument loses force (for a similar analysis, see Carr & Brown, 1990).

Finally, the role that lexical competition plays in mediating priming is theory dependent, and there is no reason to rule out all abstractionist approaches even if some specific instantiations of competition might eliminate long-term priming. It is worth noting that the lexical competition often postulated between words in abstractionist models is the product of active codes temporarily inhibiting their neighbors. So for example, activation of the word TABLE might temporarily lead to the inhibition of the word CABLE. But, if long-term priming reflects structural changes in the perceptual system involved in identifying words, the temporary inhibition from an active neighbor is irrelevant. Instead, the only relevant form of

competition would be the product of structural changes to the system, perhaps changes in the interconnections between lexical entries. Whether changes of this sort occur, and whether it would eliminate long-term priming, remains unclear.

In sum, the longevity of long-term priming is not incompatible with abstractionist theories. On this approach, long-term priming reflects structural changes in the orthographic system that affect the later processing of the repeated items, with larger improvements associated with lower-frequency words (e.g., Bowers, in press a). Short-term priming, on the other hand, reflects the temporary activation (or opening) of abstract word codes, with short lasting consequences. It is interesting to note that short-term masked-priming, unlike long-term priming, is frequency insensitive (e.g., Bodner, & Masson, 1997; Forster & Davis, 1984; Rajaram & Neely, 1992), with equal benefits accruing to low- and high-frequency words. These contrasting results suggest that there are different underlying mechanisms that support short- and long-term priming, as suggested here. By contrast, Tenpenny (1995) argued that short- and long-term priming reflect the same underlying processes, and that short-term priming is short lived simply because weaker episodic traces support these effects. One question that needs to be addressed is why these weaker episodic memories are frequency insensitive, and stronger episodic traces are frequency sensitive.

The influence of various contextual variables on priming. A common strategy for contrasting abstractionist and episodic theories has been to assess whether priming is affected by various study-to-test changes in the perceptual formats of items, or in the episodic context in which items are presented at study and test. To the extent that priming is sensitive to these manipulations, the results are thought to support episodic

theories of priming and perception. These two forms of study-to-test changes are discussed in turn.

Surface form Numerous studies have assessed the effects of study-to-test changes in the perceptual format of words on long-term priming, such as changing the letter case (e.g., READ/read) or font (e.g. READ/READ) of items. The standard argument is that abstractionist theories predict no effect of these manipulations, whereas episodic theories expect reduced priming following these changes -- reductions that will be labeled specificity effects henceforth. As noted by Tenpenny (1995), the pattern of results reported in the literature is quite complicated, with a mixed set of results obtained across a large set of conditions.   But, given that large specificity effects have been observed in some studies, and that a trend is found in most experiments, Tenpenny concluded that these results support an episodic interpretation.

However, a number of issues need to be carefully considered when drawing conclusions from these results. First, recognition and recall are affected by study/test perceptual manipulations (e.g., Kirsner, 1973; Marsolek, Squire, Kosslyn, & Lulenski, 1994), and performance on priming tasks is rarely process pure (Jacoby, 1991). Thus, it is important to consider the possibility that any specificity effects obtained on a priming task reflect explicit memory contamination. In this regard, it is worth noting that many of the larger specificity effects were reported in priming tasks involving re-reading text or collections of words (e.g., Kolers & Ostry, 1974). Such studies are particularly susceptible to explicit influences, given that participants often have many episodic cues and sufficient time to employ their explicit memories. Thus, to minimize this concern, only studies that assessed priming for single words will be considered for present purposes.

In addition, there are reasons to question the relevance of studies that assessed priming for words presented in unusual formats, such as upside down or mirror reversed (e.g., Kolers & Ostry, 1974; Masson, 1986). When words are presented in these unusual formats, participants take more time to respond, again raising the possibility that explicit memory strategies may intrude on performance. Furthermore, to the extent that these words are not processed in the normal fashion, they may not gain full access to the abstract lexical-orthographic codes that are presumed to mediate priming on abstractionist theories. Accordingly, failures to obtain abstract priming under these conditions do not provide a strong test for the abstractionist approach. For these reasons, the most relevant studies are those in which single study and test words are presented in familiar formats, but when the items are nevertheless visually dissimilar.

Studies satisfying these constraints are those that manipulate the letter-case or font of the study and test words. When these studies are considered, the vast majority have failed to obtain significant specificity effects, although in most studies there is a small trend in that direction (for review, see Roediger & McDermott, 1993; Tenpenny, 1995). Nevertheless, a number of these studies provide strong support for the abstractionist approach. Perhaps the strongest evidence comes from studies reporting robust priming between study-test items that are arbitrarily related in their perceptual form, but where the priming is nevertheless modality specific. For example, using the perceptual identification task, Bowers (1996) assessed priming for words that are composed of letters that are visually dissimilar (A/a, B/b, D/d, E/e, G/g, L/l, and Q/q) in upper- and lowercase (e.g., DREAD/dread). Similar priming was obtained for study-test items presented in the same case (17% improvement over baseline) and different case (16% improvement), and at the same time, little priming

was obtained when words were spoken at study (5% improvement). More striking, in two studies using the lexical decision task, similar priming was obtained for Japanese words studied and tested in the same script (Kanji-Kanji or Hiragana-Hiragana) or different script (Kanji-Hiragana or Hiragana-Kanji) despite the fact that the scripts are completely unrelated in the visual format (Bowers & Michita, 1998). Averaging across the two studies, same script priming was 28 ms and cross-script priming was 24 ms, a difference that did not approach significance. Once again, little priming was obtained when items were spoken at study (6 ms averaging across studies), suggesting that cross-script priming was mediated by abstract orthographic codes. Lending further support to this conclusion, abstract priming effects have been obtained between visually unrelated Hindi and Urdu scripts in Indian (Brown, Sharma, & Kirsner, 1984) and between Cyrillic and Roman scripts of Serbo-Croatian (Feldman & Moskovljevic, 1987). It should be noted, however, that these latter studies did not compare the abstract visual priming to cross-modal priming, and thus it is possible that the effects were mediated by phonological or semantic representations.

These latter results are difficult to accommodate within an episodic account of priming. According to these theories, specific perceptual traces of words are laid down at study and test, and priming is obtained to the extent that the same perceptual processes are engaged at study and test (e.g., Roediger, 1990). However, it is difficult to see how these theories can account for the robust priming obtained between study-test items that are arbitrarily related in their visual form. Instead, these findings suggest that abstract orthographic codes map together visually dissimilar words, and that it is these abstract codes that support priming. (See Bowers and Michita (1998) and Polk and Farah (1997) for accounts of how such abstract orthographic knowledge may be acquired.)

Still, there is a consistent trend for specificity effects across studies, and if a simple sign test were to be carried out on all of these studies, the effect would be significant. Although an advocate of the episodic approach might focus on this trend and argue that it poses problems for an abstractionist view, there are at least two reasons to argue otherwise. First, even though this trend is obtained in studies that assessed priming for single words displayed in normal formats, the specificity effects may nevertheless be the product of explicit contamination. There is evidence that explicit memory can affect priming in these conditions (e.g., Bowers & Schacter, 1990; Jacoby, 1991), and some studies provide evidence that specificity effects are indeed the product of explicit contamination (Curran, Schacter, & Bessenoff, 1996; Schacter, 1994).

However, there is a second and more interesting way to reconcile these small specificity effects with abstractionist theories, based on a series of studies that was not mentioned in Tenpenny's review. These studies provide evidence for the existence of separate abstract and specific visual perceptual codes for words, perhaps located in the left and right hemispheres, respectively. In which case, both abstractionist and episodic accounts of word perception may be correct, with abstract and specific representations differentially supporting priming under varying conditions.

One form of evidence in support of this conclusion comes from a series of long-term priming studies carried out by Marsolek and colleagues (Marsolek, 1995; Marsolek, Kosslyn, & Squire, 1992; Marsolek, Squire, Kosslyn, & Lulenski, 1994), in which test words were directly presented to the participants' left visual fields (right hemisphere) or right visual fields (left hemisphere). The authors reported that priming is largely insensitive to study-to-test changes in letter-case when items are flashed to the right visual field, and sensitive to changes when items are flashed to the left. In

fact, the specificity effects tended to mirror the task demands, with larger specificity effects obtained when the task requires specific perceptual attributes of items to be encoded (Burgund & Marsolek, 1997). A similar pattern of abstract and specific priming was also observed for objects flashed to the participants' right and left visual fields, respectively (Marsolek, 1999). Furthermore, parallel results have been obtained in the auditory domain. For example, Schacter McGlynn, Milberg, & Church (1993) reported a patient with a large left-hemisphere lesion that led to <u>pure-word deafness</u>, such that he was able to repeat spoken words, but was unable to understand the meaning of these words. The patient showed robust priming for words repeated in the same voice (29% improvement over baseline) but minimal priming for words repeated in a different voice (4% improvement). One interpretation of this finding is that the patient's intact right hemisphere mediated his ability to repeat words and supported same-voice priming, but damage to abstract phonological codes in the left hemisphere (that normally serve as access codes to semantics) prevented him from understanding the meaning of spoken words, and reduced priming following the study/test voice change. Consistent with this hypothesis, control subjects showed much more abstract priming (23% same voice vs. 16% different voice), suggesting that the left hemisphere is indeed important for supporting priming following voice-changes (see Church & Schacter, 1994, for additional evidence in support of this view).

It should be noted that the postulation of lateralized abstract and specific perceptual systems is also compatible with a variety of non-priming results. For example, in the visual modality, perceptual systems in the left and right hemispheres play important roles in word and face identification respectively. Given that reading typically requires recognizing text without regard to any specific perceptual

information (e.g., font), and given that face recognition typically requires the identification of specific perceptual information to distinguish one face from another, these results may reflect abstract/specific hemispheric asymmetries (e.g., Farah, Wilson, Drain, & Tanaka 1998). Similarly, in the auditory modality, a number of studies indicate that patients with right hemisphere lesions show deficits in voice recognition (e.g., Van Lancker & Kreiman, 1987) and in processing prosodic aspects of speech (e.g., Coslett, Roeltgen, Rothi, & Heilman, 1987), whereas word identification disorders such as pure word deafness result from left hemisphere lesions (e.g., Schacter et al., 1993). Along the same lines, dichotic listening studies with non-brain damaged individuals have found a left-ear advantage for processing aspects of voice information, whereas identifying words (irrespective of voice) is best accomplished in the left hemisphere (e.g. Kimura, 1973). Further converging evidence has been reported using brain imaging technologies. Using PET, Zatorre, Evans, Meyer, and Gjedde (1992) reported that the left hemisphere is more active than the right when participants identified phonemes in spoken syllables (conditions in which surface details of the words were irrelevant), and the right hemisphere was more active than the left when participants made pitch discriminations to the same items (conditions in which surface details were critical).

The above pattern of results may reflect a more basic functional constraint for perceptual systems. The visual system is confronted with two separate problems: It must recognize that different items (a) belong to the same abstract category when they are functionally equivalent (e.g., the visual patterns TABLE/table when reading text) yet also (b) belong to different specific categories when items are functionally distinct (e.g., TABLE/table must be distinguished if the task is to categorize upper- and lower-case words). Many contemporary theories ignore these two different

requirements, and instead focus on accomplishing only one of these goals. For example, the GEON theory of Biederman (1987) attempts to account for basic object recognition using abstract shape categories, but this theory cannot explain how different exemplars within a category (e.g. specific faces) are identified. By contrast, theories of face identification often rely on accessing highly specific perceptual memories, but have difficulty accounting for various abstractions (such as categorizing objects at a basic level; for discussion of this contrast see Tarr & Bulthoff, 1998; Hummel & Stankiewicz, 1998). This has led some to argue that these functions are incompatible, thus requiring different systems (e.g., Farah et al., 1998; Marsolek & Burgund, 1997; for a related argument, see Goodale, Milner, Jakobson, & Carey, 1991; but see Hummel & Stankiewicz, 1998).

If two different perceptual systems are involved in identifying information, one abstract and one specific, then it is highly likely that both systems contribute to priming. On this view, then, small specificity effects do not contradict the claim that abstract orthographic knowledge supports both reading and priming phenomena. Instead, these findings only indicate that abstract lexical-orthographic knowledge does not support all priming phenomena.

Before concluding this discussion, it is important to note that similar issues have also been addressed in the masked priming domain. Although Tenpenny (1995) claimed that this issue had not been explored, a number of authors found no correlation between the size of priming and the visual similarity of the primes and targets (e.g., Evett & Humphreys, 1981; Humphreys, Besner, & Quinlan, 1988; for a related finding, see Davis & Forster, 1994). More recently, Bowers et al. (1998) contrasted masked priming for upper- and lowercase words that are visually similar (e.g., kiss/KISS) and dissimilar (e.g., edge/EDGE). No effect of this manipulation

(not even a trend) was found in a lexical decision or a verb/noun categorization task, and only a small effect arose in a perceptual identification task in which the targets were degraded. Furthermore, a phonological basis for this cross-case priming was ruled out, given that little priming was obtained between homophones in the lexical decision task. Perhaps more striking, robust cross-case masked priming between visually dissimilar prime-target pairs was observed in a letter-by-letter surface alexic patient (IH) who could not gain fast access to phonological or semantic knowledge (Bowers, Arguin, & Bub, 1996). Indeed, robust priming was obtained in IH when primes were presented in case alternated format, e.g., rEaD-READ (Arguin, Bub, & Bowers, 1998), as has been observed with individuals with normal reading skills (Forster & Guess, 1996). Given the nature of IH's reading deficit, it is unlikely that this cross-case priming was mediated by phonological or semantic representations.

To summarize, robust long-term priming is obtained between visually dissimilar (sometimes unrelated) study-test words, and at the same time, these effects are largely modality specific. These findings are predicted on abstractionist theories, and cannot easily be accommodated within an episodic framework where the basis for priming is the perceptual overlap between study and test items. Similar results have been obtained in the masked priming paradigm, where equivalent priming is generally obtained between prime-target pairs that are visually similar and dissimilar. Finally, to the extent that there is a consistent trend to observe small specificity effects in long-term priming, these results may be attributed to either explicit memory contamination or priming within a separate perceptually specific system, perhaps located within the right hemisphere.

Episodic context The other common strategy for assessing the influence of specific information on priming is to manipulate the episodic context in which

repeated items are presented at study and test (e.g., presenting repeated target words with different cue words at study and test). To the extent that priming is affected by context manipulations, the results are thought to support episodic theories of priming and word identification. This literature is largely restricted to long-term priming studies, and as reviewed by Tenpenny (1995), the findings are quite complex and often mixed. Nevertheless, she concludes that the results lend more support to episodic theories. But again, this conclusion is unwarranted by the data.

As was the case with the specificity results described above, there is a problem that recall and recognition are sensitive to changes in episodic context, and long-term priming tasks are rarely process pure. Thus, once again, it is important to consider the possibility that any episodic effects obtained in a priming task reflect explicit memory contamination. To minimize this concern, only those studies that assessed priming for target words presented in isolation or in the context of a single cue-word at test will be described. For review of studies that assessed priming for test words presented in the context of paragraphs, sentences, or word-triplets, see Tenpenny (1995).

One of the first demonstrations that single word priming can be affected by context was reported by Jacoby (1983a), who observed greater priming in a perceptual identification task when a high (90%) compared to a low (10%) proportion of the study items were later repeated at test. Allen and Jacoby (1990) replicated this pattern of results using the same task, but included a manipulation intended to assess whether the increased priming in the high overlap condition was the product of participants "catching on" and using explicit memory to enhance their performance. Specifically, two study conditions were included. In one, the participants simply read words at study, and in a second, words were presented in an anagram format in which

participants were required to generate the solution. Based on past research, it was expected that priming would be reduced for the generated words, whereas recognition would be better (Jacoby, 1983b). They further argued that if context effects in priming were the product of explicit memory contamination, then the context effects should be larger for items studied in the anagram format, as these items should be best remembered and thus most subject to explicit memory strategies. However, they failed to observe greater context effects for the generated words in the two priming experiments, and in fact, observed a trend for larger context effects for the read words in both cases. Based on these findings, the authors concluded that performance was not contaminated by explicit memory, thus supporting an episodic account of priming in which context affects priming.

However, there are a number of problems with this conclusion. First, in Experiment 1 of Allen & Jacoby (1990), recognition memory was actually more sensitive to the proportional context manipulation when items were read compared to generated, and there was no significant difference in Experiment 2 (although there was a trend for larger effects in the generate condition). Accordingly, the observed tendency to obtain larger context effects for priming in the read condition in the two studies does not provide strong evidence for a dissociation between priming and recognition memory. Second, these results were not replicated by Challis & Roediger (1993) when they assessed priming in a fragment completion task. Indeed, they observed a nonsignificant trend for more priming in the low compared to the high proportion overlap condition. They also cited the unpublished dissertation of Donnelly (1988) who failed to observe an effect of proportion overlap in the fragment completion task. Third, Challis and Roediger (1993) noted a number of confounds in the Jacoby (1983a) and Allen and Jacoby (1990) studies that raise problems for

interpretation, including the fact that participants in the 90% condition were informed about the relationship between study and test, whereas this was not the case in the 10% condition, as well as the fact that the manipulation of proportion overlap was correlated with test order in Allen and Jacoby's second experiment. Thus, there is no compelling evidence that proportion overlap affects priming independently of explicit memory contamination. Related studies have manipulated episodic context by changing the room, the computer, or the experimenter at study and test, and null effects are typically obtained (e.g., Jacoby, 1983a; Jacoby & Witherspoon, 1982).

Another way to manipulate episodic context is to change the manner in which words are encoded at study and test. To the extent that priming is sensitive to the specific encoding operations engaged at study and test, the results might appear to support episodic accounts. A striking example of such an effect was reported by Vriezen, Moscovitch and Bellos (1995), who asked participants to make semantic categorizations to written words at study and test. The critical finding was that priming was eliminated when participants performed different categorizations, even though the same perceptual encoding was required at study and test (for example, in one condition, participants categorized the referents of words in terms of their size at study, and as natural vs. man-made at test). This finding suggests that semantic context affects (even eliminates) perceptual priming. A problem with this study, however, was that the authors included relatively high-frequency words, ranging from 4 to 521 per million, with a mean of 80.5 (Francis & Kucera, 1982), and priming tends to be reduced for high- compared to low-frequency words (e.g., Bowers, in press a; Forster & Davis, 1984; Rajaram & Roediger, 1993). When Bowers (submitted) replicated this study with low-frequency words, robust priming was obtained. Gerard and Scarborough (1989) also obtained evidence that semantic

context is not critical for single word priming. They asked Spanish-English bilingual speakers to perform lexical decisions in their different languages at study and test, and compared priming between cognates with the same spellings and pseudo-cognate homographs (Spanish-English words that share the same spelling but have different meanings). They reported equivalent priming for these items, showing that repeated access to orthographic codes is critical for priming, whereas repeated encoding of the same semantic context is not. Consistent with this story, priming is greatly reduced or eliminated between Arabic and French cognates that are orthographically unrelated due to their different scripts (Bowers, Mimouni, & Arguin, submitted).

The most common way to manipulate episodic context, however, has been to embed words in different written contexts at study and test. Although many of these studies are taken to support episodic over abstractionist approaches, a close review of the data does not support this conclusion. For example, Oliphant (1983) failed to obtain priming when participants studied target words embedded in text and were later tested with the same words in isolation, leading him to support an episodic account. However, as noted earlier, there is no guarantee that words presented in the context of sentences are perceptually processed to the same extent as when they are presented in isolation. Accordingly, a reduction in priming is not surprising from an abstractionist position that attributes priming to the strengthening of abstract orthographic codes. Furthermore, as in Vriezen et al.'s (1995) study, Oliphant (1983) assessed priming for high-frequency words. When MacLeod (1989) replicated Oliphant's (1983) study using lower frequency words, significant priming was obtained.

A more common way to manipulate the written context, however, has been to contrast priming when target words were repeated along with the same cue word at

study and test (e.g., study the cue-target pair <u>window-reason</u> and test with the cue-target pair <u>window-reason</u>), compared with a condition in which different cue words served as context at study and test (e.g., study the cue-target pair <u>table-reason</u> and test with the pair <u>window-reason</u>). If priming is enhanced for targets repeated in the same compared to the different context--so-called <u>associative</u> priming--then the results would appear to support an episodic accounts.

Graf and Schacter (1985, 1987, 1989; Schacter and Graf, 1986, 1989) reported robust associative priming in the stem completion task as well as observing various dissociations between priming and recognition performance. However, they did not obtain associative priming in densely amnesic patients (Schacter & Graf, 1986), and Bowers and Schacter (1990) only obtained associative priming when participants were aware that items repeated at study and test. Furthermore, associative priming was only obtained when items were elaboratively encoded at study (Graf & Schacter, 1985; Schacter & Graf, 1986; but see Micco & Masson, 1991), conditions that support good explicit memory. The restricted conditions in which this priming is obtained raises the possibility that these effects are largely the product of explicit contamination. Indeed, Reingold & Goshen-Gottstein (1996a, b) assessed stem completion priming using the process dissociation paradigm (Jacoby, 1991) and found that the associative effects were often the product of intentional memory (although they were able to obtain a small context effect that was attributable to automatic processes when subjects copied the word pairs at study).

Associative effects were also found in a speeded naming task (Moscovitch, Winocur, & McLachlan, 1986). However, Musen and Squire (1993) had difficulty replicating these results for both amnesic patients and normal participants unless multiple study trials were included. Using the lexical decision task, McKoon and

Ratcliff (1979) found association-specific repetition effects, but attempts to replicate this finding have largely been unsuccessful (e.g., Carroll & Kirsner, 1982; Neely & Durgunoglu, 1985; Smith, MacLeod, Bain, & Hoppe, 1989). One possible reason for the discrepant findings is that McKoon and Ratcliff (1979) used long (650-800 ms) stimulus onset asynchronies between items that formed pairs, whereas other investigators did not. Thus once again, the associative effects may have been the product of explicit memory contamination.

The strongest evidence for associative effects in priming was reported in a series of studies by Goshen-Gottstein and Moscovitch (1995a, b). The authors used a simultaneous lexical decision task in which participants were asked to indicate whether two simultaneously presented letter strings were both legal English words. Decisions were faster when words were repeated in the same compared to different pairings at study and test, and further, the effects dissociated from recognition memory. Indeed, they reported that the associative effect was not diminished following shallow relative to elaborative encoding conditions, suggesting that the context effects could not be attributed to explicit contamination.

Although these latter findings appear to indicate that priming can be sensitive to episodic contexts, independently of explicit contamination, a finding by Marsolek, Schacter, & Nicholas (1996) suggests a different way of interpreting these findings that is consistent with an abstractionist framework. The authors assessed associative priming in a stem completion task when test items were presented to the left and right visual fields of participants, and only obtained associative effects for items presented in the left visual field (right hemisphere). Furthermore, the associative effects in the right hemisphere were eliminated when word-pairs were presented in different cases at study and test. This combination of findings suggests that these associative effects

were mediated by a perceptually specific system located in the right hemisphere, and that orthographic representations in the left hemisphere (that normally mediate word identification; e.g., Peterson, Fox, Posner, Mintun, & Raichle, 1989) were insensitive to this contextual manipulation, consistent with abstractionist views. On this view, the associative effects reported by Goshen-Gottstein and Moscovitch (1995a, b) also reflected the contribution of a specific system in the right hemisphere. Consistent with this proposal, both study and test items in these studies were presented in upper case letters (Goshen-Gottstein, personal communication, February 10'th, 1999), and further, the authors obtained the same amount of associative priming for low- and high-frequency words. This contrasts with within- and cross-case priming for single words, which is highly sensitive to frequency manipulations (e.g., Bowers, in press a; Forster & Davis, 1984).

To summarize, only a few studies have reported associative effects under conditions in which explicit contamination cannot be ruled out, and in these cases, it is possible that the effects were mediated by a specific perceptual system, perhaps within the right hemisphere. The orthographic representations within the left hemisphere, by contrast, appear to be insensitive to these context manipulations. Similarly, many of the studies that assessed episodic context effects for test words presented in isolation also may have been affected by explicit memory. Under condition in which these influences are minimized, the priming results are most compatible with abstractionist approaches.

Before concluding, it should be noted that there is one recent demonstration that context can also affect short-term priming. Bodner & Masson (1998) found that masked priming was enhanced when a high compared to a low proportion of the prime target pairs were the same, particularly for low-frequency words. Unlike the

Jacoby (1983a) and Allen and Jacoby (1990) studies, these results cannot be the product of explicit contamination, as the primes were presented for 60 ms and masked, making the primes unavailable to consciousness. Based on these results, the authors supported an episodic account of short-term priming. It will be important to pursue this finding further to determine the extent to which such a finding is problematic for abstractionist theories.

Word-Pseudoword differences The finding that long-priming extends to various novel materials, including pseudowords (e.g., Feustel, Shiffrin, & Salasoo, 1983; see Bowers & Schacter, 1993, for review of pseudoword priming results obtained with amnesic patients) has often been considered incompatible with abstractionist accounts that attribute priming to pre-existing abstract word codes. However, as noted by Dorfman (1994), most studies have assessed priming for pseudowords that are very similar to familiar words, and accordingly, any priming for these items might in principle be mediated by the pre-existing sub-lexical representations these items share with real words (or alternatively, this priming could be supported by a number of orthographically related words). Accordingly, the mere fact that priming extends to pseudowords cannot be used to contradict abstractionist theories.

Tenpenny agreed with this analysis, but challenged another argument that has been put forward in support of abstractionist theories. That is, there are now various reports that word and pseudoword long-term priming differ in a number of ways, which has led some to argue for the existence of abstract lexical-orthographic codes (e.g., Salasoo & Shiffrin, 1985; Whitlow, 1990). The general argument here is that these differences reflect the contribution of pre-existing orthographic representations to which only words have full access. However, Tenpenny argued that that these differences can also be explained within an episodic framework, as the differences may

simply reflect the fact that episodic memory codes for words already exist, which is not the case for pseudowords. Indeed, explanations for some of the word-pseudoword differences have been proposed without positing abstract orthographic codes (Logan, 1990, Rueckl & Olds, 1993). Accordingly, Tenpenny concluded that word-pseudoword differences do not strongly favor one approach over another.

However, one long-term word-pseudoword difference reported subsequent to Tenpenny's (1995) review is more easily interpretable within the abstractionist framework. That is, whereas priming for words is largely insensitive to study-to-test case changes, priming for pseudowords is reduced by approximately 50% when the items are visually dissimilar (e.g., NEGA/nega; Bowers, 1996). One possible interpretation of this finding is that only words have complete access to the abstract lexical-orthographic codes, and thus only words show abstract visual priming (for related findings see Whittlesea & Brooks; 1988; Whittlesea & Cantwell, 1987). On this view, the specific effects for pseudowords reflect the separate contribution from a specific perceptual system, perhaps located in the right hemisphere. Note, the pseudoword priming results parallel Marsolek et al.'s (1996) finding that associative priming is eliminated when items are presented in a different case at study and test.

The suggestion that word and pseudoword priming are mediated by different systems may provide a way to reconcile abstractionist theories with the finding that priming also extends to random letter strings (e.g., Bowers, 1994; Hamann & Squire, 1997). At first, these latter findings appear particularly problematic for abstractionist theories, given that sub-lexical representations cannot support these effects (the claim that single letter codes might support priming for these items is difficult to maintain given that little or no priming is obtained between form related words, such as car-card; e.g. Napps & Fowler, 1987). However, on the present argument, priming for

random letter strings may also be mediated by a specific perceptual system within the right hemisphere. A prediction of this view, then, is that priming for these items should also be case specific. Thus far, this prediction is untested.

With regards to short-term priming, Forster and colleagues have reported a striking contrast between word and pseudoword priming when participants make lexical decisions to targets. Whereas word priming is robust and insensitive to frequency, pseudoword priming is generally absent (e.g., Forster & Davis, 1984, 1991; Forster et al., 1987; for review, see Forster, 1998). Based on these null pseudoword results, Forster and colleagues argued that short-term priming for words is mediated by abstract lexical codes. However, as argued by Humphreys et al. (1990) among others, the absence of pseudoword priming in these studies may reflect an idiosyncratic property of the lexical decision task. That is, the pseudoword primes may improve the perceptual processing of the repeated targets (as is the case for words), but this improved perceptual processing may bias participants to respond "word" to the pseudowords, given that words tend to more easily processed than pseudowords. This bias may counteract the improved perceptual processing of the pseudowords, resulting in no priming. Indeed, in an identification task that does not include the bias associated with the lexical decision task, Humphreys et al. (1990) obtained priming for pseudowords, and Bodner & Masson (1997) observed pseudoword priming in the lexical decision task under conditions designed to reduce this bias. Based on their findings, Bodner and Masson defended an episodic account of short-term priming. (see Forster, in press, for a different interpretation of these findings)

For present purposes, what is important to note is that the presence of short-term priming for pseudowords in some tasks does not by itself support episodic

theories of short-term priming. As is the case with long-term priming, these effects

may be mediated by abstract sub-lexical codes, as argued by Humphreys et al. (1990)

for example. As noted earlier, one property of short-term word priming is that it is

insensitive to the visual changes between prime and targets, with equal priming

obtained between prime and targets that are visually similar (e.g., kiss/KISS) and

dissimilar (e.g., read/READ; Bowers et al., 1998). Thus, on an abstractionist

account, short-term pseudoword priming should also be unaffected by these

perceptual variables (unless items are specifically presented to the right hemisphere).

On an episodic account, such changes should impact on priming. The verdict is still

out.

Morphological Priming Tenpenny claimed that the strongest evidence in

support of an abstractionist approach comes from studies that have assessed long-

term priming between morphologically related words. The typical finding is that

equivalent priming is obtained between inflectionally related (e.g., cars/car) and

repeated words (e.g., car/car), and given that little or no priming is obtained between

orthographic neighbors (e.g., card/car; e.g., Napps & Fowler, 1987; Stolz & Feldman,

1994), this priming cannot be attributed to the visual or phonological overlap between

items. Further, this priming cannot be attributed to semantic representations as

semantic priming does not persist for more than a few seconds under those conditions

that support long-term morphological priming (e.g., Henderson, Wallis, & Knight,

1984).

Similar findings have been obtained in short-term priming paradigms. For

example, Grainger, Cole, & Segui (1991) obtained robust priming between

morphologically related items, and these effects could not be attributed to

orthographic or phonological knowledge given that inhibitory priming was obtained

between non-morphologically related items matched in terms of their orthographic

and phonological overlap (also see Forster, Davis, Schoknecht, & Carter, 1987).

Furthermore, as little priming is obtained between semantically related items in the

masked priming paradigm (e.g., de Groot & Nas, 1991), it is difficult to attribute

these effects to semantic factors. In addition, in a related short-term priming task,

Stolz and Besner (1998) were able to dissociate semantic and morphological priming

following a letter search task on the prime: semantic priming was eliminated under

conditions in which participants searched primes for a specific letter, whereas robust

morphological priming was obtained under the same conditions. Similarly, Laudanna,

Badecker, and Caramazza (1989) obtained short-term (non-masked) morphological

priming between Italian words (e.g., posto (door)-posti (doors) that share the stem

post-), whereas inhibitory priming was obtained between non-morphologically related

words that share homophonic stems (potare (to carry)-porte (doors) that share the

homographic stem port-), indicating that phonological overlap between items is not

responsible for the morphological priming. Based on these findings, these authors

concluded that morphological relations are coded separately from semantic and

phonological codes.

These priming results are compatible with models that explicitly encode

morphological relations within the orthographic system (Caramazza, Laudanna, &

Romani, 1988; Taft and Forster, 1975), but are difficult to accommodate within an

episodic framework in which priming is reflects the perceptual overlap between items.

In defense of the episodic view, Tenpenny noted that some studies observed more

priming between repeated items compared to morphologically related items, indicating

the specific perpetual features can play a role in morphological priming. Further, she

suggested, in accordance with Rueckl and Dror (1994), that morphological priming

may reflect some sort of association between perceptual and semantic factors, although the precise nature of this association is left unspecified, and the way such associations can account for many of the results described above remains unclear. At present, these results fit more naturally within an abstractionist framework, as Tenpenny herself conceded.

Summary of repetition priming results

In sum, none of the priming results reviewed by Tenpenny (1995) are incompatible with abstractionist theories of word priming and word identification, and some of the priming results described above are difficult to accommodate within a purely episodic framework. Particularly problematic are the findings that robust short- and long-term priming is obtained between visually dissimilar prime-target pairs under conditions in which semantic and phonological processes can be ruled out. Tenpenny (1995) argued that episodic word identification models analogous to Medin and Schaffer's (1978) context model of categorization could account for the various abstract cross-case priming effects. However, as priming in this sort of model is a function of the perceptual similarity of the study and test items, it is difficult to see how this approach can accommodate the priming obtained between visually unrelated words (e.g., READ/read). Still, in order to account for all of the data reviewed above, it may be necessary to postulate two different perceptual systems that support priming, one that represents words in an abstract format, and another that encodes the perceptual details of inputs. Interestingly, the hypothesis that separate abstract and specific perceptual codes exist is also supported by various non-priming results (e.g. Farah et al., 1998).

Additional sources of evidence in support of the abstractionist position

Although Tenpenny's review focused on repetition priming studies, her conclusion was not restricted to theories of priming. Rather, she made the more general claim that word identification is mediated by episodic representations, questioning the existence of abstract orthographic codes altogether. This might be a reasonable approach if the only findings relevant to this question were those priming results reviewed by Tenpenny. However, there are numerous other experimental findings relevant to this question, many of which strongly support the existence of abstract orthographic knowledge. In this section, I briefly describe some of these additional findings that need to be considered when contrasting episodic and abstractionist theories of word identification.

One of the more striking forms of evidence in support of abstract orthographic representations was reported by Coltheart (1981). He described a conduction aphasic patient who could not name individual letters or name pseudowords (e.g., nega), but who nevertheless was able to match upper/lower case pseudowords that were perceptually dissimilar (e.g., NEGA/nega) without difficulty. Given that these items are (a) meaningless, (b) perceptually dissimilar in upper/lower case, and (c) unpronounceable by the patient, Coltheart concluded that the patient must have accessed abstract orthographic codes in order to perform the task.   A similar result was obtained with a person with a developmental reading disability (Rynard & Besner, 1987). The patient was only able to name 69% and sound-out 65% of letters, but nevertheless was 100% accurate in performing cross-case letter matching. The letters he was unable to name or sound-out included the letters E, G, and R which are visually dissimilar in upper- and lower-case.

In addition, McClelland (1976) reported that the word superiority effect (WSE) is equally large for words presented in case uniform and mixed-case conditions; for

example the words FADE and fAdE were both better identified than the matched

pseudowords GADE and gAdE in a task in which participants were asked to identify

the complete items. Given that both mixed-case words and pseudowords have

unfamiliar visual patterns, McClelland concluded that the WSE was mediated by

abstract lexical-orthographic representations. Bowers, Bub, and Arguin (1996)

reported the same finding in a letter-by-letter surface alexic patient who had slow

access to phonological and semantic knowledge, suggesting that the abstract effects

were not the product of phonological or semantic representations.

Further evidence for abstract word codes was reported by Besner, Coltheart &

Davelaar (1984) using a matching task. Participants were required to respond "same"

for pseudowords that were physically identical (e.g., hILe/hILe), and "different"

otherwise. The critical finding was that participants took longer to reject items that

shared the same abstract letter codes (e.g., hILe-HilE) than orthographically different

but phonologically identical items (e.g., hILE-HyLE), suggesting that abstract letter

codes are automatically computed, which hinder the "different" response.

Rayner, McConkie, & Zola (1980) used eye-tracking technology to determine

the types of information that are encoded from parafoveally presented words. While

participants focused on a cross, a word was presented away from fixation, and during

a saccade to this item, the word was replaced by a second word that was: (a)

physically identical to the first word, (b) the same word but presented in a different

case, (c) a different word that shared the same initial phoneme, (d) a semantically

related word, or (e) a different word altogether. Latencies to name the parafoveal

words on the next fixation were facilitated equally in conditions (a) and (b), and no

facilitation was obtained in (c) and (d) compared to the baseline condition (e). Based

on this pattern of results, the authors concluded that parafoveal preview facilitation

was the product of the words contacting abstract orthographic codes (see also

McConkie & Zola, 1979).

Finally, Mozer (1989) reported a so-called <u>homogeneity effect</u> in which

participants underestimated the number of letters in a briefly presented display when

the same letters were repeated. A homogeneity effect extended to displays that

contained upper- and lower-case letters that were visually dissimilar. For example,

participants more often failed to report two letter "e"s in the briefly flashed pattern

<u>peb CER</u>, compared to when different letters were presented in the same position.

The finding that the homogeneity effect extended to cross-case letters led Mozer to

argue for the existence of abstract letter codes.

In sum, the studies reviewed in this section strongly support the conclusion that

orthographic knowledge is coded in an abstract format, such that different exemplars

of the same stimulus (e.g., <u>READ/read</u>) map onto common representations. Any

purely episodic account of visual word identification needs to accommodate not only

the various priming results, but these findings as well.

<u>Embedding priming within an abstractionist theory of word identification</u>.

Based on the above considerations, there are strong grounds to argue that

abstract orthographic codes support word identification, and that repetition priming is

mediated, in part, by these orthographic codes. In this final section, I briefly outline

the sorts of abstractionist theories that may satisfy the above constraints.

First, however, it is important to note some problems with the classic

abstractionist theory of Morton (1979) and the related counter model of Ratcliff and

McKoon (1997). Although there are a number of important differences between

these theories, on both accounts, word identification involves activating abstract

lexical-orthographic word codes above some threshold, and priming reflects the

modification of orthographic knowledge such that repeated words are more easily activated beyond threshold. They also share two additional features that are problematic. First, on both accounts, priming reflects a change in bias rather than an improvement in perceiving repeated items. That is, the modification of orthographic knowledge is not thought to improve the efficiency with which words are encoded, but rather, result in a tendency to interpret test words as previously studied words. This improves performance when study and test words are the same (e.g., study word = table, test word = table), and hinders performance otherwise (e.g., study word = cable, test word = table), with benefits equaling costs. As both Morton (1979) and Ratcliff and McKoon (1997) explicitly note, the amount of information available to lexical-orthographic word codes is independent of repetition effects (or frequency effects) and is solely determined by the properties of the stimuli (e.g., duration, contrast, signal-to-noise ratio, etc.).

This bias interpretation is problematic because recent evidence suggests that priming reflects, in part, a change in perceptual sensitivity such that the orthographic system is more efficient in processing repeated words. Specifically, Bowers (in press, b) reported that priming for low-frequency words reflects a change in sensitivity when items were repeated once, whereas priming for high-frequency words under the same conditions reflected a change in bias. Raaijmakers, Schooler, & Shiffrin (1997) reported evidence that priming for high-frequency words also reflects a change of sensitivity when items are repeated multiple times. In addition, using the same procedure, Masson & MacLeod (1996) reported a trend for priming in 7/8 studies they carried out with "common words" (the exact frequency was not specified) studied once, suggesting a change in d'. These results suggest that priming is a manifestation of learning that improves the perceptual encoding of repeated items,

with low-frequency words benefiting more than high-frequency words.[2] This relation

between word learning and priming is denied by the Morton (1979) and Ratcliff and

McKoon (1997) models.

The claim that priming reflects pure bias is related to a second deficiency of

these models; namely, they do not incorporate any mechanisms for learning, and are

thus mute regarding how orthographic knowledge is acquired in the first place. As a

consequence, these models must be hand-wired in order to identify words. Clearly,

this is a limitation, as any complete theory must incorporate learning principles.

Indeed, what may be needed is an abstractionist account of word identification that

incorporates learning principles to support the acquisition of orthographic knowledge,

and where priming is a natural by-product of this learning process.

Unfortunately, many abstractionist models of word identification have not

incorporated learning mechanisms (nor any mechanism that could support long-term

bias), and needless to say, such models cannot account for long-term priming (e.g.,

Forster, 1976, 1985; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, &

Schvaneveldt, 1982). However, connectionist or neural network models of single

word reading have incorporated learning principles (Grossberg, 1980; Grossberg &

Stone, 1987; Plaut, McClelland, Seidenberg, & Patterson, 1995; Seidenberg &

McClelland, 1989; also see Coltheart, Curtis, Atkins, & Haller, 1993). Accordingly, a

promising approach to understanding visual word priming phenomena may be to

embed theories of priming within network models of word identification.

It should be noted that Tenpenny describes network theories of priming as

"weakly episodic", which she contrasted with the abstractionist approach I have been

defending. According to Tenpenny, the crucial difference between the weakly

abstractionist and the weakly episodic views is that the weakly abstractionist view

posits fundamentally different forms of representations for episodes and lexical entries, whereas the weakly episodic view holds that episodes and lexical entries are represented together, with the abstractions being an emergent property of the overlaid episodic instances. Tenpenny argues that connectionist models are of the latter sort, which is a non-abstractionist position.

However, it is quite possible to develop connectionist models that develop separate sets of representations for abstract and specific information. For instance, connectionist models have been developed to represent abstract information, both for the sake of object identification (Hummel & Biederman, 1992) and word identification (Polk & Farah, 1997). Indeed, Polk and Farah (1997) developed a model that can learned abstract letter codes, even between arbitrarily related letters, such as A/a (but see Bowers & Michita, 1998, for findings that require a modification of their model). The critical point to note is that these connectionist models were designed to learn abstractions, and are unable to represent the specific perceptual details of inputs that are often used to support episodic memory.

Based on these considerations, Marsolek and colleagues have argued that separate networks are needed to represent information in abstract and perceptually specific formats, and they have described models that use back-propagation learning principles that categorize inputs at different levels of specificity (Marsolek & Burgund, 1997). Another network approach that can separate specific and abstract information is the Adaptive Resonance Theory (ART) of Grossberg and colleagues (e.g., Carpenter & Grossberg, 1987; Grossberg, 1980; Grossberg & Stone, 1986). On this theory, there is a so-called vigilance parameter that affects the grain-size of the mappings that are learned. With low vigilance parameters, broad categories are learned such that a wide range of perceptual inputs are categorized together, whereas

with high vigilance parameters, visually similar inputs are categorized separately. It is possible that neural networks for pattern recognition in the left and right hemisphere are characterized with different vigilance parameters, such that one operates in a more "abstract" mode, and the other operates in a more "instance" mode. Indeed, a version of ART, namely ARTMAP (Carpenter, Grossberg, & Reynolds, 1991), provides a mechanism by which arbitrary mappings (e.g., A/a) can be learned. These ART models have been used to account for various visual and spoken word recognition results reported in the literature (Grossberg, Boardman, & Cohen, 1997; Grossberg & Stone, 1986), and hold promise for accounting for various priming phenomena as well.

The claim that long-term priming for words is best understood as a by-product of learning within the orthographic system suggests that this phenomenon can be used to constrain theories of word identification, much like short-term priming is typically used. Indeed, long-term priming may provide important constraints into how orthographic (and other perceptual systems) learn -- an issue that short-term priming phenomena cannot address if it reflects the temporary activation of pre-existing orthographic codes, as argued here. To date, long-term priming has not been extensively used in this capacity, but on the present argument, it should.[3]

Overall Summary

Tenpenny (1995) argued that priming results reported in the literature are compatible with a purely episodic account of word identification and priming, and she questioned the need to posit abstract orthographic knowledge to accomplish these functions. However, contrary to this conclusion, various findings indicate that abstract orthographic knowledge exists, and that these codes contribute to both word identification and priming. Given evidence that highly specific perceptual information

also contributes to word identification and priming, it appears that a "weakly abstractionist" position is the most justified on the current evidence, with separate abstract and specific visual codes contributing to priming and word identification. Arguably, abstract orthographic codes within the left hemisphere are largely responsible for word priming phenomena as well as visual word identification processes. Specific perceptual codes may only play a major role in these processes under unusual conditions, such as when words are flashed to the left visual field, or when the words are unfamiliar or presented in novel formats (e.g., upside down or mirror reversed).

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Author notes

Footnotes

1. Note, although priming for low frequency words is not eliminated when different semantic decisions are performed at study and test, priming effects are reduced, as documented by Vriezen et al. (1995) among others. It should be noted, however, that reduced priming following a change in task is consistent with an abstractionist approach. From the abstractionist perspective, priming is a function of repeated access to pre-existing abstract codes, and accordingly, priming is reduced to the extent that the study and test tasks are mediated by different set of representations (in the limit, when tasks do not rely on any shared representations, no priming should be expected). Such an approach is clearly articulated by Coltheart (1989), and is consistent with the general component processing framework (e.g., Moscovitch, 1992).

2. It should be noted that changes in discriminability do not necessarily imply improved perceptual processing, as noted by Norris (1995). Indeed, Masson and MacLeod (1996) argued against the view that priming reflects an improvement in perceptual processing, despite the consistent tendency for a change in d' in their own studies.

3. A few studies have attempted to relate long-term priming to learning (e.g., Kirsner & Speelman, 1996; Logan, 1990; Poldrack, Selco, Field, and Cohen, 1999). Indeed, one finding reported by Kirsner and Speelman (1996) seems to challenge the view that priming is a by-product of learning. The authors found the benefits associated with studying a word in an experiment was much larger than would be expected form from incrementing the number of pre-experimental exposures by one. That is, the authors estimated the number of times low, medium- and high-frequency words were read by an average 22 year old reader, and then in a lexical decision task, measured response latencies and error rates to these items in order to estimate the improvement associated with a single pre-experimental exposure to a word. This benefit was much smaller

than the improvement they observed when repeating words within the experiment, indicating that a pre-experimental encounter with a word cannot support robust experimental priming effects.

However, there are ways to reconcile this finding with the view adopted here. For example, it is important to note that words encountered outside the laboratory tend to be read in the context of sentences, and as noted earlier, this might reduce the amount of attention devoted to the perceptual encoding of the word. Thus, if orthographic learning is related to the amount of attention that is directed to this level (consistent with Grossberg & Stone, 1986), then many pre-experimental encounters with words would have had a relatively small impact on learning compared to the laboratory setting in which words are read out of context. There are other possible ways to reconcile the present account of priming with these findings as well. For example, Poldrack, Selco, Field, and Cohen (1999) recently described two computational models in which the Kirsner and Speelman (1996) results are replicated within a model in which priming and learning reflect the same processes.