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Short term implicit memory in lexical processing

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Declaration

The work presented in this thesis is entirely my own.

Elinor McKone
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Publications arising from the thesis

Experiments 2.1, 2.2, 3.2 and 4.1 will shortly appear in the following article:

Abstract

A single recent presentation of an item can lead to substantial improvement in speed or accuracy of processing when that item is presented subsequently, a phenomenon referred to as repetition priming. This empirical finding has been considered within two general frameworks. The first can be termed a "perceptual" approach, in which the perception of the target occurs more easily due to a transient change in the state of the target's internal representation. The second can be termed a "memory" approach, in which priming is seen as an example of implicit memory, that is, as arising from subconscious, nondeliberate access to a trace of an earlier event.

This thesis examined repetition priming for words and nonwords from both perspectives. A review of priming within a word recognition framework suggested that transient modifications of lexical representations might be able to endure for several seconds, allowing a short-lived priming effect for words and word-like nonwords. A review of priming within a memory framework suggested that there might exist a short-lived implicit memory form, with a duration similar to that of explicit working memory.

Empirical work examined priming over short lags (generally 0–23 items intervening between repeats) using lexical decision and speeded naming tasks. A novel short-lived repetition effect was apparent, superimposed on standard long-lived priming. For words, this effect endured until lag 3 (8 seconds). More rapid decay was apparent for nonwords, producing a lag × lexicality interaction.

Short term priming was distinguished from long term priming on the basis of decay rate, the effects of word frequency, and the effects of the proportion of repeated items in the list. Short term priming was distinguished from explicit working memory on the basis of the effects of lexical status and overall differences in speed and accuracy.

Finally, short term priming was shown to decay through the effects of both spontaneous trace loss and interference. The effect of interference on nonword priming was particularly severe, and the relative effects of interference were shown to be responsible for the form of the lag × lexicality interaction.

The results are interpreted as showing that (a) short term priming reflects the operation of a novel memory form, namely, *short term implicit memory*, (b) this memory arises (for lexical items) within the perceptual system responsible for word recognition, possibly through transient modification of
orthographic representations, and (c) the word recognition system therefore retains a number of partially-active words simultaneously. It is suggested that short term implicit memory might exist to allow the integration of successively-presented stimuli across a short time window of perceptual processing.
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Chapter 1

Background to the study: The time-course of repetition priming over short delays

1.0 INTRODUCTION

1.0.1 Overview

It is commonly found that recent exposure to an item can temporarily produce a substantial improvement in subsequent processing of that item, or of an item similar to it. For example, a picture might be more rapidly named if it has appeared earlier in an experimental list, or a word more accurately recognised from a brief presentation if it is preceded by a semantically or associatively related word. Such empirical findings are examples of priming, or repetition priming in cases where the prime and the target are identical. Priming, by the commonly-accepted definition employed here, refers only to relatively large changes in processing time or accuracy which arise from a single presentation of the prime; gradual improvement in performance with constant practice as required for skill learning, for example, is not considered priming.

There is a long tradition of seeing priming as a reflection of temporary changes in the structures responsible for processing the prime and the target. For example, repetition priming for words has been interpreted by some as arising from residual activation of the target word unit in the lexical processing system, and priming by semantically related items has been explained in terms of spreading activation within a network designed to determine word meaning. This is essentially a "perceptual" approach to explaining priming, in which the perception of the target occurs faster or more accurately due to a change in the state of the target's internal representation.

The perceptual framework has two implications which are of relevance to the work to be presented here. The first is that the properties of any observed priming effect are likely to depend critically on the structure of the system from which the effect arises, and on the nature of the representations present in this system. The second is that priming can, in turn, be used as a tool for studying the
Chapter 1

operation of perceptual systems. The view that priming and perceptual processing are completely intertwined also carries with it the implication that priming in one domain (such as word recognition) may have different properties from priming in other domains (such as visual object recognition or face processing).

A somewhat distinct literature sees priming as an example of implicit memory, defined as a nonconscious influence of memory. Most research within this "memory" tradition has concentrated on delineating the similarities and differences between priming and other manifestations of memory, particularly explicit, conscious, recollection. Within this tradition, there has been much debate as to whether priming relies on a different form of storage than does explicit memory (as is suggested by the standard perceptual approach), or whether the two manifestations of memory differ only in their form of access. Some have proposed that priming, like ordinary explicit memory, relies on a full episodic trace of each new learning event. In this view, differences between priming and explicit memory arise simply from the nature of the tasks designed to assess the two: priming reflects "memory", just as much as does recall of a list of words.

The memory framework implies that priming is a general phenomenon reflecting storage and access procedures that cut across perceptual domains. This approach suggests there might be functional benefits of particular forms of information storage and/or access, regardless of the type of stimulus being retained. Thus, there should be substantial commonalities in the properties of priming in different domains.

Recently, some attempts have been made to integrate the "perception" and the "memory" literature on priming, including a proposal that the phenomenon arises from implicit access to perceptual representation systems. Such an integration implies that some properties of priming should be similar across a variety of domains, while other properties should be highly domain-specific. Most importantly in the present context, it also suggests that empirical priming studies are relevant both to our understanding of the specific perceptual system involved in processing a given type of target and, more generally, to our understanding of forms of memory.

This thesis investigates repetition priming in one particular domain, namely word recognition. The work was motivated by the proposition that considering perceptual and memory approaches to priming together might lead to useful suggestions for empirical studies of priming, and that, in return, the results of such studies may contribute to our understanding of lexical processing and of memory. Chapter 1, therefore, reviews literature relevant to explanations of priming within both the perceptual and memory traditions. Models of word recognition are considered in order to demonstrate the range of potential
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mechanisms for producing priming for words and word-like stimuli. Following this, the implicit memory approach to repetition effects is considered in order to emphasise the distinctions drawn between the manifestations of various forms of memory.

Both literature reviews are directed to the delineation of one area of priming research which deserves more attention than it has so far received; this is the time-course of repetition priming over delays of between one second and one minute. Consideration both of the likely duration of changes in the state of internal lexical representations, and of the distinctions currently made between forms of memory, suggests that a novel repetition priming effect might be identifiable over such delays.

The empirical work presented in Chapters 2 through 5 demonstrates and investigates such a short-lived repetition priming effect. It is claimed in Chapter 6 that this "short term" priming represents a manifestation of a new form of implicit memory, and arises from transient modification of lexical representations. It is suggested that these transient modifications represent a "time window" of orthographic processing, in which several words are maintained "active" simultaneously, and argued that such a time window would be functionally useful in many perceptual domains. Thus, the results are interpreted within an integrated memory and perceptual approach to priming.

While the findings have important implications for both word recognition and human memory, the reader should note in advance two limitations. First, the issues about which the results produce pertinent evidence are limited to general statements about word recognition and memory: for example, the data do not provide evidence for or against any particular model of word recognition or mechanism of priming. Secondly, the scope of the empirical work presented in the thesis is limited to the lexical domain.

1.0.2 Words and nonwords

Within the perceptual domain of word recognition, two classes of stimuli are of primary interest. The obvious stimuli for studies of word recognition are real (English) words, which have stable representations in the lexicon of the mature reader. Equally important, however, are nonwords (e.g. KLPO, SMULE, CREAP). These are "lexical" in that they consist of strings of letters (rather than, say, dots or random squiggles), but do not constitute real words. Despite the fact that a nonword, by definition, cannot have a permanent representation as a familiar whole, there are both empirical and theoretical reasons (discussed in detail shortly) to believe that some nonwords can access the representations
which exist to identify words. Thus, both word and nonword data are of relevance to any perceptual explanation of priming.

1.0.3 The magnitude and duration of priming for words and nonwords

**Tasks.** This thesis investigates repetition priming, and does not consider semantic or associative priming. There are a number of tasks which can be used to study repetition priming for visually presented words and nonwords. In *lexical decision* (eg. Kirsner & Smith, 1974), the subject is required to decide, as rapidly and accurately as possible, whether or not a letter string represents a real English word; priming is revealed in this task when the decision is faster (and generally more accurate) on a second presentation, as compared with decision times either to the first presentation of the target, or to a set of unprimed "baseline" items which are presented only once. In *naming* (eg. Scarborough, Cortese & Scarborough, 1977), the subject is required to read each letter string aloud, and the time from stimulus presentation to the onset of the response is recorded; again, priming is revealed by faster response times to repeats of targets. In *degraded-identification* tasks (eg. Jacoby & Dallas, 1981), stimuli are presented either very briefly or in degraded form; priming is revealed by more accurate identification of the target on second presentation, again as compared either with the first presentation or with an unprimed baseline condition.

In *word-completion* tasks (eg. Warrington & Weiskrantz, 1974), subjects are exposed to target words in an initial study phase (eg. CALENDAR), and then in a later test phase are given initial letters of possible words (stem-completion, eg. CAL------), or letters from throughout possible words (fragment-completion, eg. C-L---AR), and asked to complete each test item with the first word that comes to mind; priming is revealed where the rate of completion with target words is higher than the rate in a baseline condition where words are completed without prior exposure to the study list. Speeded versions of word-completion tasks are also possible (Skinner & Grant, 1992); here, priming is revealed where stem/fragments are completed more quickly, as well as more often, with targets following study-list exposure.

**Duration of priming for words.** For real words, lexical decision, degraded-identification and word-completion tasks have all been found to show substantial, long-lasting priming effects (Connor, Balota & Neely, 1992; Jacoby & Dallas, 1981; Hashtroudi, Ferguson, Rappold & Chrosniak, 1988; Roediger, Weldon, Stadler & Riegler, 1992; Scarborough et al., 1977). Priming with these tasks commonly endures across "study - test" delays of minutes or hours with only a gradual reduction in magnitude. Some studies even report very little decay in priming over days, weeks and months (Jacoby & Dallas, 1981; Komatsu
Background: The time-course of repetition priming

& Ohta, 1984; Tulving, Schacter & Stark, 1982), although others have found complete decay of word priming within a couple of hours (Diamond & Rozin, 1984; Graf & Mandler, 1984). Often, priming effects are large, even after substantial delays. Many studies have found priming of tens of milliseconds with lexical decision, or increases of 20% or more in target completions/identification with word-completion and degraded-identification tasks.

From the few relevant studies, priming effects in naming appear to be smaller than in lexical decision, although still long-lasting (Monsell, 1985 Expt 3; Scarborough et al., 1977). A possible reason for the reduced magnitude of priming is that naming (for words) is a highly practised skill, and thus reaction times even to first presentations are very fast (commonly <500ms for short words). The low levels of priming in naming may reflect simply a ceiling effect: responses to first presentations are already so fast that there is not much room for further improvement to repeats.

In addition to the effects of task, the magnitude of word priming can be influenced by various lexical properties. For example, consistent effects of word frequency have been reported such that more priming is observed for rare (low frequency) words than for common (high frequency) words (Jacoby & Dallas, 1981; Jacoby & Hayman, 1987; Kirsner, Dunn & Standen, 1989; Kirsner, Milech & Stumpfel, 1986; Scarborough et al., 1977). As with task differences, this finding could be interpreted as a ceiling effect, given that baseline lexical decision and naming times are faster for common words, and baseline identification and completion rates are higher.

Duration of priming for nonwords. While priming for real words is generally substantial and long-lasting, the situation regarding the magnitude and duration of priming effects for nonwords is somewhat more complex. For these targets, only lexical decision, naming or degraded-identification tasks can be used to examine priming: word-completion tasks cannot, by definition, be employed with nonwords. In lexical decision, findings regarding priming for nonwords have been mixed, with some studies reporting long-lasting repetition effects (eg. Besner & Swan, 1982; Dannenbring & Briand, 1982; Scarborough et al., 1977), and others reporting no priming (eg. Forbach, Stanners & Hochhaus, 1974; Kerstee-Tucker, 1991; Ratcliff, Hockley & McKoon, 1985). However, a failure to find priming for nonwords in lexical decision does not provide very convincing evidence that no "trace" of the stimulus has been retained (Bowers (1994; Dorfman, 1994; Feustel, Shiffrin & Salasoo, 1983; Humphreys, Besner & Quinlan, 1988). In particular, second-presentation times to respond "no, it isn't a word" could be slowed by the effect of increased familiarity due to the prior exposure. This would be expected to make the decision process (ie. rejection) more difficult, and may mask an underlying repetition effect in which the
processing/identification of the nonword target occurs more rapidly on second presentation.

In identification tasks, where increased processing speed and increased familiarity can be assumed to work in the same direction rather than competing with one another, nonword priming is reliably reported (Feustal et al., 1983; Rueckl, 1990; Rueckl & Olds, 1993; Salasoo, Shiffrin & Feustal, 1985). By the same token, nonword priming should also be found in naming. Very few previous studies use this measure, but those that do report significant priming (eg. Monsell, 1985 Expt 3; Scarborough et al., 1977).

Few studies have systematically examined whether priming for nonwords depends on the properties of the target. There is, however, some suggestion in the literature (Bowers, 1994; Dorfman, 1994; Monsell, 1985 Expt 3; Rugg & Nagy, 1987; Scarborough et al., 1977 Expt 2) that priming for highly word-like nonwords (eg. MAVE, GEN CULE) is stronger than priming for less word-like nonwords (eg. JGTL, ERKTOFE).

Two types of priming. With the appropriate tasks, then, priming is reliably found for (at least some types of) both words and nonwords, commonly after delays of minutes or hours. This long-lasting repetition effect will henceforth be referred to as the standard priming effect, as it is the form of repetition priming which has received the most attention in the literature.

In addition to standard priming, there exists an effect known as masked priming, the duration of which is relevant to the argument to be developed in this thesis. Masked priming (eg. Forster & Davis, 1984; Forster, Davis, Schoknecht & Carter, 1987) is a very short-duration priming effect which decays completely within a second or two. The effect is not based only on repetition; instead, primes are generally different from targets, but related to them in some way, such as by having similar orthography (eg. five out of six letters in common) or pronunciation (eg. rhyming). To examine masked priming effects, the forward-masked prime word is presented for less than 100ms, and usually remains unidentified by the subject. In general, the prime is immediately backward-masked by the target, with a response (eg. lexical decision) required to the target only. For example, a standard masked priming experiment might involve presenting the prime crook for 60ms, then replacing it immediately (ie. masking it) with the target BROOK and leaving the target visible until the subject responds. Reaction times in this primed condition can then be compared to those in various control/baseline conditions in which BROOK follows either brook or a completely unrelated string such as spine or xxxxx. In this example, response times to BROOK should, of course, be slower when preceded by crook than by brook, but would also be expected to be faster when preceded by crook than by either spine or xxxxx, thus revealing a priming effect of orthographic overlap (Forster, 1987). Because the case of presentation is changed between
prime and target, any priming effects must be based on letter- and word-level processing rather than visual processes.

The duration of masked priming is extremely short in comparison to the standard long-lived repetition priming effect. If a delay is added between the presentation of the briefly-presented prime and the presentation of the target, masked priming effects are found to fall off very rapidly, and to disappear altogether within a second or two (Forster & Davis, 1984; Humphreys, Besner & Quinlan, 1988). Such short-lived masked priming have been interpreted as reflecting the merging of the partially-identified prime and the target into a single perceptual event (Humphreys et al., 1988). Full and conscious identification of the prime is apparently required to produce the standard long-lasting priming effect.

1.1 PRIMING FROM A WORD RECOGNITION PERSPECTIVE

There are two literature traditions regarding explanations of repetition priming effects. In the first of these, priming is seen as a perceptual phenomenon, where transient changes in the state of the internal representations used to identify the stimulus allow it to be accessed more easily on repeated presentation. For lexical stimuli, for example, priming has been interpreted as due to leftover activation within the word recognition system. As will be seen in the following review, "perceptual" views of priming have fallen somewhat behind current understanding of the word recognition system, and there are, in fact, multiple ways in which this system might allow priming of various durations.

Interpretations of priming within a memory framework will be considered following the word recognition review.

1.1.1 Functional architecture of the word recognition system

The processes involved in word recognition can be examined at two different levels. At the more general level of analysis, the functional architecture of the systems involved in understanding and producing (single) spoken and written words can be investigated. One conclusion from research

1 The use of the term "recognition" is potentially confusing in the present context. In the language processing literature, "recognition" of a word refers to the process of identifying it. In the memory literature, to be reviewed shortly, "recognition" of a word refers to the process of recollecting a particular previous encounter with it.
directed at this level is that each word with which we are familiar has multiple representations, each of which stores different aspects of the word. In particular, it is now commonly accepted that orthographic, phonological and semantic information are stored separately, leading to proposals of at least three separate "lexicons", dealing with, respectively, the letter-structure, phoneme-structure and meaning of a word. It should be noted that these aspects of word knowledge are more or less logically distinct. For example, an understanding of (some) concepts can come from real world experience without the need for mediating words, a normal child learns to understand spoken words before learning to read, and a child born profoundly deaf may learn to read without having ever heard spoken words.

The fact that these three aspects of words can be logically distinguished does not, of course, require that they are stored and/or treated separately in normally-functioning adults. There are, however, a number of lines of empirical evidence for distinct representations. The first comes from repetition priming studies in which it has been revealed that the repetition advantage on second presentation is much reduced or absent if the modality of input is switched on second presentation from visual to auditory or from auditory to visual (eg. Graf, Shimamura & Squire, 1985; Jacoby & Dallas, 1981; Kirsner & Smith, 1974; Roediger & Blaxton, 1987; Weldon, 1991). The common interpretation of this finding (eg. Coltheart, 1989; Morton, 1979; but see Roediger & Blaxton for an alternative view) is that priming for, say, visually-presented words arises at an orthographic level and that a subsequent auditory presentation accesses a different, phonological, word representation; thus, any change in the state of the relevant orthographic representation is not able to influence the processing of the same word when presented in spoken form.

Second, neuropsychological case-studies of patients with acquired dyslexia sometimes demonstrate selective impairment following brain injury, supporting the distinction between orthographic, phonological and semantic storage (see Ellis & Young, 1988, for review). For example, orthographic and phonological knowledge have been dissociated by reports of patients who can understand spoken words but not written words (ie. who have phonological representations intact but orthographic representations damaged), and of others who can understand written words but not spoken words (ie. have orthographic representations intact but phonological representations damaged). Double dissociations of this form have been used to argue that the three types of word representations are stored in physically separable locations which can be selectively damaged by brain injury.

A final piece of evidence, which again argues for distinct physical storage, comes from positron emission tomography (PET) studies. PET allows the relative usage of different brain regions to be determined in normally functioning adults,
Background: The time-course of repetition priming

via the use of a radioactive blood-flow tracer. Due to limits of the technology, physiological responses to individual stimuli cannot be examined. Instead, the subject is required to perform the same task on multiple stimuli for several minutes, and the activation of various brain regions is determined. By comparing patterns of activation across a number of tasks (eg. a simple monitoring task requiring only attention to a screen, silent reading of individual letters, silent reading of words, naming of written words, semantic categorisation of written words, etc.), the regions more heavily relied upon in each task can be determined via a subtractive method. Results of PET studies using word and nonword stimuli are consistent with the view that the processing of orthographic, phonological and semantic information about words can be localised to distinct brain regions (eg. Petersen & Fiez, 1993; Petersen, Fox, Posner, Mintun & Raichle, 1989; Sergent, Zuck, Levesque & MacDonald, 1992; Wise, Hader, Howard & Patterson, 1991).

In addition to the distinction between orthographic, phonological and semantic lexicons, some proposed architectures of the word recognition system (eg. Coltheart, 1989; Coltheart, Sartori & Job, 1987; Ellis & Young, 1988; Howard & Franklin, 1989) distinguish further between lexicons for orthographic input (reading) and output (spelling) and for phonological input (spoken-word identification) and output (spoken-word production). Each of these various lexicons is commonly considered to contain only a set of discrete whole-word representations (although see further discussion below), leading some to claim that an additional rule-based procedure for converting individual graphemes in the written form to individual phonemes in the spoken form (Venezky, 1970) is necessary to allow for the pronunciation of nonwords (eg. Coltheart, 1978, 1980; Coltheart, Davelaar, Jonasson & Besner, 1977). Evidence for this dual route approach comes from a double dissociation in cases of acquired dyslexia; some patients show poor reading of words with irregular spelling-to-sound correspondences (which presumably require whole-word knowledge), in conjunction with relatively intact reading of nonwords (Coltheart, Masterson, Byng, Prior, & Riddoch, 1983), while others show the opposite pattern (eg. Funnell, 1983).

A number of fundamental questions regarding the structure of the word recognition system are still under debate. These include, for example, whether the meaning of a written word can be determined via a direct "link" between orthography and semantics as opposed to being accessed via phonology (eg. Jared & Seidenberg, 1991), and whether a grapheme-to-phoneme conversion procedure is really necessary for reading nonwords (eg. Coltheart, Curtis, Atkins & Haller, 1993; Seidenberg & McClelland, 1989). These issues, however, are not of direct interest here. The significant point is the idea of distinct orthographic, phonological and semantic representations. This idea is important because of its relevance to explanations of nonword priming: while visually-presented
nonwords cannot access semantic representations, it will be seen below that there is every reason to assume that they can access orthographic representations (whatever the view of the overall architecture of the system), potentially allowing them to change the state of such representations so as to produce priming.

1.1.2 Access to orthographic representations

Models of functional architecture have addressed questions regarding the existence of various lexicons, the way in which these are linked together, and the number of "routes" that can be traced through the word recognition system. However, word recognition can also be examined in terms of detailed models of the forms of representation within, and methods of access to, word knowledge stored within a single lexicon. In order to demonstrate how visually-presented words and nonwords might produce priming via a "perceptual" mechanism of changes in the state of lexical representations, it is necessary to consider access to the orthographic input lexicon in more detail.

A number of theoretical models of word recognition which address this question will shortly be discussed. These share most or all of the assumptions about the functional architecture of word recognition described above (with one notable exception), but are essentially models of orthographic word recognition: they assume that orthographic identification of a visually-presented word occurs (or at least begins) prior to semantic and/or phonological lookup, and are addressed to the problem of how this initial identification occurs. The aim of the following review is not to provide a complete discussion of all possible models of word recognition with a full evaluation of each. Instead, a limited review will be provided which aims to a) introduce some major experimental findings which are of relevance to the models to be discussed (and the empirical work to be presented in Chapters 2 through 5), and b) introduce some ideas regarding lexical access which will become important when priming for words and nonwords is discussed in terms of temporary modification of lexical representations.

1.1.3 Four empirical findings and their general interpretation

Four empirical findings appear fundamental to any explanation of word recognition. They are presented here partly to clarify discussion of various models of orthographic lexical access, and partly because empirical findings involving lexical stimuli, such as those presented in this thesis, would be expected to be influenced by these well-known effects.
Background: The time-course of repetition priming

1) The lexical status effect. Averaged over all types of real words and nonwords and all subjects, naming and lexical decision responses are faster for words than nonwords (eg. Rubenstein, Garfield & Millikan, 1970; Scarborough et al., 1977). This lexical status effect could be seen as an example of a general property of the word recognition system that items which are more familiar (in this case words) are processed more rapidly than those which are less familiar (in this case nonwords).

2) The word frequency effect. Lexical decision and naming times are faster to common than to rare words (eg. Forster & Chambers, 1973; Frederikson & Kroll, 1976; Rubenstein et al., 1970). Again, items which are more familiar (high frequency words) are processed more rapidly than those which are less familiar (low frequency words).

3) Word likeness of nonwords effects. Response times to nonwords vary with the similarity of the nonword target to real words. While it has sometimes been assumed that all nonwords are equivalent, in that they are letter strings unfamiliar to the lexicon, it is apparent that this is not the case; nonwords are, by definition, unfamiliar as whole units, but this does not mean that their subcomponents or their structure are unfamiliar.

For example, nonwords can be more or less similar to real words in orthographic/phonological structure. Illegal nonwords (eg. CGTO) are randomly-formed letter strings which violate the orthographic and phonological rules of English; these are familiar only at the level of individual letters. Legal nonwords, or pseudowords, (eg. FRUNE) are letters strings which satisfy the orthographic rules of English, and are also pronounceable; these are more familiar to the word recognition system in that there are many words with similar spellings (eg. pairs of letters in common in the same position, common word body, etc.). Pseudohomophones (eg. SEET) are nonwords which, when read aloud, sound like a real word; these are more familiar again, as they are phonologically familiar as whole units in addition to being orthographically legal.

In addition to their "legality", individual nonwords may vary in their similarity to known words in a number of ways. These may include, for example: orthographic neighbourhood size (the number of words that can be made by changing one letter in the nonword eg. MAVE has MATE, HAVE, MOVE, MALE, etc. as neighbours; Coltheart et al, 1977); body frequency (eg. there are many words with an -AVE body, ie. HAVE, CAVE, RAVE, SAVE, SHAVE, CRAVE, but few with an -ILK body, ie. MILK and SILK; Patterson & Morton, 1985); whether a nonword has sub-components which are words, morphemes, non-morphemic but real-word syllables, or none of these (eg. BEANBOOK, GENCULE; Dorfman, 1994); and whether the nonword is very close in spelling to a particular real word (eg. "mispellings" such as TRIAN or KONDERGARTEN).
A number of nonword-word similarity effects have been demonstrated. These effects show a general pattern wherein nonwords which are more similar to real words are faster to read aloud in a naming task, but take longer to reject in lexical decision. In naming, for example, it is clearly more difficult to construct a pronunciation for an illegal nonword than for a legal nonword (although I am not aware of an experimental verification of this), and McCann and Besner (1987) found slower naming to nonwords with few neighbours than to those with many. In lexical decision, the opposite pattern is revealed, with reports of nonword rejections being slower for "mispelled real words" than for other nonwords with the same level of orthographic legality (eg. TRIAN versus TRUAN: Chambers, 1979; O'Connor & Forster, 1981), slower for orthographically legal nonwords than for illegal nonwords (eg. FRUPE versus FKWCO: Stanners, Forbach, & Headly, 1971; Stanners & Forbach, 1973), slower for more "wordlike" legal nonwords than for less "wordlike" ones (eg. PLEN versus BYPH: Martin, 1982) and slower for nonwords with many neighbours than for those with few (eg. JATE versus RALP: Andrews, 1989; Coltheart et al, 1977; but see Andrews, 1992, for a qualification of this effect).

In lexical decision, the effects of nonword-word similarity can, in fact, be strong enough to overcome the usual lexical status effect. For example, Rubenstein, Lewis and Rubenstein (1971a, 1971b) found that mean lexical decision times for illegal nonwords such as LIKJ or CREPW were 21ms faster than for low frequency real words. In addition, it is not uncommon to find that, while lexical decision times are on average somewhat slower to nonwords than to words, the difference is quite small (eg. between low frequency words and pseudowords). This suggests that for many subjects and many items, nonword decisions can be faster than word decisions.

The importance of nonword-word similarity effects is that they indicate that nonwords are able to gain access to, and potentially be confused with, real word representations. This is hardly surprising given that, when a string of letters is initially presented, it must be treated as a potential word until the lexical system is able to determine that it is not. What is important is the implication that the degree of access to word representations depends on the type of nonword presented. Clearly, word recognition models need some way of representing this degree of similarity.

4) List structure effects. In lexical decision, there are influences of the nature of list items other than the target type on processing of the target type. One example of such a list structure effect is that lexical decision times to words are quicker when the words are mixed with illegal strings, such as STPNE, than when they are mixed with pseudowords, such as PENST (eg. Rubenstein, Lewis & Rubenstein, 1971a). Another example is the frequency blocking effect, in which the size of the frequency effect on lexical decision times is found to be
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Findings of list structure effects make the general points that a) lexical decision times are dependent on the nature of the items with which the target is being compared as well as on the nature of the target itself, and b) decision times will be faster to all items in the list if a decision is easier because the contrast between word and nonword targets is, on average, more extreme (eg. high frequency words vs. nonwords or words vs. illegal strings are easier decisions than mixed high and low frequency words vs. nonwords, all low frequency words vs. nonwords, or words vs. pseudowords). Thus, list structure effects indicate that, as might be expected, lexical decision times are at least partially reflective of the speed of the decision process as well as the speed of the lexical access process (Balota & Chumbley, 1984).

1.1.4 Models of access to localised orthographic representations

Traditionally, word recognition has been conceptualised as a process which requires matching the input string to one of a collection of discrete whole-word representations, with identification occurring when the correct representation is found. Two possible methods of access to these representations have been considered, namely serial and parallel access.

Serial search models

Search models (Rubenstein, Garfield, & Millikan, 1970; Forster, 1976, 1989) claim that access to whole-word representations occurs by a method of serial search, in which a (written) stimulus is compared to the words stored in an ordered (orthographic) lexicon one at a time until a match is found. This serial search procedure has a major disadvantage, namely that serial comparison is far too slow to be consistent with the few hundred milliseconds (at most) which people require to identify words. (Attempts to reduce search time, by proposing that only a limited "bin" of lexical entries is searched, have met with difficulties in how this bin of entries is determined - see Taft, 1991, for a description of the shortcomings of this approach.)

In addition to the speed problems intrinsic to search models, a serial comparison approach makes it difficult to explain the fact that nonwords differ in their degree of access to real word representations as a function of their similarity to familiar real words. A "no" lexical decision response, for example, can only be made after a complete search of the entire lexicon has failed to match the target stimulus, predicting that all nonword decisions should take
equal time. It could, of course, be argued that nonwords which are very
dissimilar to real words (eg. random letter strings) never access the lexicon at all,
but this is an ad hoc explanation which leaves unspecified the method of
determining which nonwords are word-like enough to gain access and set the
search process in motion.

Parallel access I: Morton's logogen model

Recent models of written word recognition have generally employed a
parallel, rather than serial access procedure to the orthographic lexicon (eg.
Coltheart, Curtis, Atkins & Haller, 1993; McClelland & Rumelhart, 1981; Paap,
Newsome, McDonald, & Schvaneveldt, 1982). Here, all words which are at least
partially consistent with the stimulus are considered at once. All parallel access
models share the assumption that multiple word representations are initially
under consideration, but one representation eventually "wins" over all others
thus identifying the word corresponding to the stimulus (the mechanism varies
depending on the model). This word will usually be the one fully consistent with
the incoming information, although, potentially, an error can be made and a
word only partially consistent with the incoming information identified (eg.
TRAIN for TRIAN, or STEEP for STEP). With a large lexicon, parallel access has
one critical advantage over serial search: it is many times faster.

An important early parallel-access model of single word storage is that of
Morton (1969, 1979). This model (in its 1979 version) shares the assumptions
discussed earlier of separate orthographic, phonological and semantic lexicons.
Morton proposed that, within the orthographic input lexicon, word identification
proceeds via a process of activation of word-level logogens (or nodes). This
process is neurally inspired, in that activation of a node is based on summation of
the excitatory and inhibitory inputs to that unit. Logogens act as evidence-
collecting devices, with the level of activation of a given logogen rising over time
as more information is read out from the stimulus and the features of the
incoming stimulus more closely match the word which that unit represents.

A given string will normally activate several logogens, to varying degrees.
According to Morton, the features which affect logogen activations include word
length, letter identity and letter position, and letter groupings. This means, for
example, that the stimulus CHAIR would slightly activate all words starting with
C or CH, ending in R or AIR, and so on. This process will lead some logogens to be
more strongly activated than others: CHAIR will have received much evidence in
its favour, while CHAIN will have received somewhat less, and BIRD will have
received very little. A similar pattern of activation will arise if the nonword
stimulus CHAIT is presented.

Each logogen has its own threshold level, determined by the number of
times the word has previously been identified, and will "fire" when its activation
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rises above this value. The identity of the presented word is determined by which logogen fires first. Ideally, only one logogen (the correct one) will ever reach threshold, although the model does allow errors to occur. For example, a rare word might be mistaken for a similarly-spelled common one because the commonly-used logogen has a lower threshold and may fire first, even though its activation is lower because it is only partially consistent with the stimulus.

Models including parallel access necessarily allow nonwords to access word representations, with the degree of access depending on the similarity of the nonword to existing logogens. For example, KONDERGARTEN will provide substantial evidence for the logogen corresponding to KINDERGARTEN, while DKNEOTREGRNA will provide little evidence for anything. In general terms, the effect of this difference in activation should be to produce different naming and lexical decision times for various types of nonwords. Specific ways in which this might occur within the logogen model will not be considered, but will be discussed with respect to the "interactive activation model", which shares many features with Morton's approach.

There are a number of forms of "trace" retained for different durations within the logogen model, and these potentially allow the model to produce repetition advantages of various durations. Once the word is identified (or the stimulus is removed) activation decays rapidly and returns to zero in about one second. Priming effects lasting one second or less can therefore be explained in terms of leftover activation - a repeated stimulus already has its corresponding logogen activated part of the way to threshold. In addition, the threshold of a logogen drops substantially immediately following firing and then increases again only relatively slowly. Additional priming effects are allowed for by this mechanism - as information is gradually extracted from the stimulus, the new threshold will be reached more quickly than on the first presentation - and such priming will last somewhat longer than that produced by leftover activation. Finally, a lowered threshold eventually returns to a value very slightly lower than that prior to firing. Frequency effects are explained in terms of this permanent threshold lowering - with each experience of a given word the threshold is reduced by a tiny amount, until common words have noticeably lower thresholds than rare words.

Parallel access models II: The Interactive-Activation Model

The interactive-activation model was introduced by McClelland and Rumelhart (1981; also see McClelland, 1987; Rumelhart & McClelland, 1982), and is closely related to the logogen model. The main changes introduced in the interactive-activation model are a) the addition of feature-level representations, b) more specific assumptions about the connections between feature-, letter- and word-units which underlie the evidence-collecting procedure, and c) the introduction of interaction in the form of feedback from higher levels to lower
levels. The model was originally put forward in order to explain the word superiority effect (the finding that letters are perceived better in words than in random letter strings; Reicher, 1969), which it does by allowing feedback from word units to letter units. The interaction assumption makes the model complex enough to require computer simulation in order to understand many aspects of its behaviour.

The interactive-activation model, as implemented by McClelland and Rumelhart, is structured to accommodate only four-letter strings. It bases the access from letter to word knowledge purely on letter position. At the letter-level, the model includes a node for each letter in each position within a four-letter string (e.g. a node for T---, one for -T--, etc.), while at the word level there is a node for each known word. When a written word is presented, visual feature units begin to activate letter units, which begin to activate word units, which in turn feed back activation to letter units, and so on. These connections can be either excitatory, where the letter- and word-level knowledge are consistent, or inhibitory, where they are inconsistent. For example, the connections from T--- or -H-- to THEN and vice versa would be excitatory, while connections from -T-- or J--- to THEN would be inhibitory. The amount of activation or inhibition passed on by a unit is proportional to its activation at the time, with units at rest passing on no influences. In addition to connections between levels, purely inhibitory connections exist between letters in a given serial position, to ensure that only one letter is identified as being present at that position. Similarly, inhibitory connections exist between nodes at the word level, to ensure that only one word will be identified as matching the stimulus. There are no thresholds in the interactive-activation model, but nodes differ in terms of "resting" or baseline activation level, that is, the level back to which activation decays in the absence of input.

Word identification proceeds via interaction of activation over a number of cycles, during which the word node which matches the stimulus gradually comes to "win" over competing nodes which are only partially consistent with the stimulus. For example, the stimulus WORE initially activates a number of words containing all or most of these letters (in the given positions), such as WORE, WORK, WORD, WIRE, etc. If the stimulus letters have all been correctly identified, WORE should have a higher activation level than any other node, but the advantage at this stage will be only small. The activated word nodes then send feedback to the letter level, affecting W, O, R, E and also K and I. As the word WORE has been most strongly activated initially, it will send relatively strong positive feedback to the correct letters, and relatively strong inhibition to the incorrect ones. WORK and WIRE, however, will return a somewhat weaker excitation to the incorrect letters and a weaker inhibition to the correct letters which they do not contain. The more strongly-activated letters then provide more positive activation to WORE on the second cycle than they did on the first, rapidly
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magnifying the advantage of the correct word unit \textsc{wore} over competing units \textsc{work}, \textsc{word}, \textsc{wire}, etc. Soon, \textsc{wore} gains enough activation to be able to begin to kill its competing neighbours via the word-word inhibition mechanism, and the system stabilises with only \textsc{wore} active. This "rich-get-richer" followed by "winner-take-all" behaviour is demonstrated in Figure 1.1, which shows the relative activation of \textsc{wore} and its competing neighbours as a function of the number of processing cycles (i.e. time).

The rich-get-richer effect, in combination with unequal resting-level activations, allows the interactive-activation model to produce the word frequency effect via a somewhat different mechanism from that proposed by the logogen model. On presentation of a high frequency word, the appropriate word node will have a resting-level activation advantage over neighbouring nodes which might also become activated, allowing it to rapidly begin sending inhibition to these competing nodes. Thus, a high frequency word should appear as the only strong candidate very quickly. For a low frequency word, however, higher frequency competing words will have a chance to inhibit the correct node, and extra time (to extract more information from the stimulus) will be required to overcome this inhibition.

An examination of word-level activation when various types of nonwords are presented to the model makes it clear that a) the parallel access from letters to words allows nonwords to activate the nodes corresponding to similarly-spelled words, and b) the strength of this activation depends on the degree to which the nonword shares position-specific letter combinations with known words (effectively, on the number of orthographic neighbours). Figure 1.1 shows some of the activation which arises at the word level when the pseudoword \textsc{mave} is presented. Initially, several words having two or three letters in common in the same position with the stimulus become activated (if activation from the consistent letters outweighs the inhibition from the inconsistent ones), and, just as for real word stimuli, the word unit most closely matching the stimulus eventually comes to dominate (although sometimes the system will stabilise with two equally-likely alternatives having equivalent activation). Figure 1.1, however, shows that, when an illegal nonword such as \textsc{jglt} is presented to the model, less total word activation results at every cycle number. This is because \textsc{jglt} has no direct neighbours (only "second-order" neighbours which differ by two letters from the stimulus) and thus the activation of word units by any two consistent letters in the stimulus is largely outweighed by the inhibition from the other two inconsistent ones. Thus, the interactive-activation model provides one explanation of at least some forms of nonword-word similarity effects (those based on neighbourhood size), by showing that a highly word-like nonword leaves a pattern of word-level activation more similar to that left by a real word, while a random letter string provides a less similar pattern including less overall activation.
Figure 1.1: Interactive-activation model activations as a function of time (cycle number), for the closest neighbours of WORE, MAVE and JGTP. Simulations were conducted using software provided by McClelland and Rumelhart, 1988.
As noted above, the interactive-activation model was introduced in order to explain the word superiority effect, rather than as a model of word recognition per se. Thus, no discussion of the method of making naming or lexical decision responses was included by McClelland and Rumelhart. Regarding naming responses, no phonological knowledge is implemented in the computational version of the model, although it could easily be assumed that a phoneme level could be added to the model and activated from the word level in the same cascaded, interactive fashion in which letters activate orthographic representations (eg. see Coltheart et al., 1993, and Coltheart & Rastle, 1994). Under this scheme, pronunciations for nonwords may be determinable via synthesis of the phonemes which become active because they are consistent with the words which are partially consistent with the nonword stimulus. (This provides one possible implementation of Glushko's, 1979, idea that nonwords are pronounced by analogy with real words.) This scheme might then allow nonword naming times to be influenced by their similarity to real words.

No method of making a lexical decision is specified in the model, although it appears likely from the examples given above that the pattern of activation over time (if not simply the stable activation level, or the number of word units active) differentiates words as a class from nonwords as a class. In addition, the pattern of activation across cycles seems to distinguish between different types of nonwords, making it entirely plausible that more wordlike nonwords will take longer to reject in a lexical decision task than less wordlike nonwords because their activation pattern is more similar (for more cycles) to that for real words. Note, however, that, due to the assumption of position-specific letter coding, the interactive-activation model's definition of "wordlikeness" is based almost entirely on neighbourhood size (for example, a body-frequency effect could only be apparent in the interactive-activation model if the nonwords with higher frequency bodies also had more neighbours).

The interactive-activation model of word recognition has been discussed in some detail because it is a relatively simple model which has been computationally implemented, and because this implementation allows two...
important points to be made about models sharing the general architecture assumed here. These are, first, that parallel access from letter-knowledge to word-knowledge allows rapid word identification even with a large lexicon (only 20-30 calculational steps in the examples given here), and, secondly, that this mechanism necessarily allows nonwords to access real word representations, with the degree of access depending on their wordlikeness. In addition to these general points, however, it can be noted that the interactive-activation model introduces a new potential locus of priming effects, namely, a temporary increase in the resting-level activations of highly-activated word units.

1.1.5 Models of access to distributed orthographic representations

Taft's "head and body" model

Taft (1991) describes a model of word recognition in which orthographic word representations are partially distributed, in the sense that no whole-word units are allowed for, but some localisation of representation is still assumed. In this model, whole-word units are replaced by "head" units (corresponding to the initial letter or letter cluster of a word, e.g. H- or SP-) and "body" units (corresponding to the word ending, e.g. -ELP or -OON). Representations in the model are distributed to the extent that the representation corresponding to any given familiar word consists of a pattern of activation over two sub-word units, and that each sub-word unit will participate in the representations corresponding to many word stimuli. Sub-word units are each connected directly to phonological (and semantic) knowledge, allowing an implementation of the idea that pronunciation of wordlike nonwords (e.g. SPELP) can be achieved by synthesis of familiar sub-word pronunciations.

The model, while substantially more complex in structure than the interactive-activation model, has not been implemented in computational form. This makes it difficult to determine exactly how the model will respond to different types of words and nonwords. It can be said, however, that Taft's model will allow nonwords to access the representations used in processing real words, partly due to an assumption of parallel access, and partly because of the head-and-body structure of the model. In addition, highly word-like nonwords will gain more access than illegal letter strings, because the former will generally have bodies as well as heads in common with real words.

Taft's model does not propose any novel mechanisms which might be capable of producing priming effects. Presumably, however, mechanisms available in previous models (changes in activations, thresholds, or resting-level
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activations) could all be adapted to operate on partially-distributed head-and-body representations.

Seidenberg and McClelland's parallel distributed processing model.

There has been a recent preference in many areas of cognitive psychology for fully-distributed models of representation, in which a single unit is in no way symbolic of, say, a word or word-part. Instead, a familiar stimulus corresponds to a particular pattern of activation over a large number of units, and each unit participates in a large number of patterns. In this scheme, units, and the strength of the connections between units, do not clearly correspond to any one aspect of the stimulus, but simply represent the similarity structure of the set of items to which they have been exposed.

One well-known model of word recognition which employs distributed representations is Seidenberg and McClelland's (1989) parallel distributed processing (PDP) model. This model is a three-layer network including orthographic units, hidden units and phonological units, which is trained via back-propagation to learn the relationship between spelling and pronunciation in English. Following training with a large training set of written words and their corresponding pronunciations, the model encodes generalities of spelling-to-sound correspondences, plus the irregularities of individual words, in the weights (ie. the strength of links) to and from the hidden units.

When a familiar word is presented as a pattern of activation over the orthographic units, the weights are used to calculate the activation of hidden and phonological units (via a summation of the weighted excitatory and inhibitory inputs to each unit). The pattern of activation over the phonological units then corresponds to the pronunciation of the word, and the pattern of activation over the hidden units could be seen as representing the word itself. Seidenberg and McClelland have shown that the training process does not cause a single hidden unit to come to represent a single word, or simple word-property. Instead, each word is represented across many hidden units (around 24 in their particular implementation), and each of these units are also be used to represent aspects of many other words.

Seidenberg and McClelland's model was one of the first to include, as an intrinsic part of the model, a description of the process of making naming and lexical decision responses. Performance in naming tasks is assumed to be measured by phonological error scores, and performance in lexical decision by orthographic error scores. These error scores provide a measure of the degree of difference between the current pattern of activation over the orthographic/phonological units and the desired pattern, and are calculated by summing \((\text{desired-actual})^2\) across all units. Error scores are assumed to affect
both reaction time and accuracy, such that lower error scores correspond to faster and more accurate responses.

To evaluate a naming response, the pattern of orthographic input is allowed to influence hidden unit activations and then to be passed on to phonological units. Because, however, a phonological unit does not correspond to a whole phoneme, (but instead to a triplet of phonetic features, eg. vowel-fricative-stop) the pronunciation cannot be read off from the activation of these units. Instead, the word which the model is "pronouncing" is determined by comparing the phonological output to the correct pattern for the desired word with that for various others which might be likely mistakes (eg. a replacement of a correct phoneme by an incorrect one). If the correct pronunciation beats the alternatives in terms of having a lower error score, it is assumed to be the pronunciation the model has produced. This BEATENBY criterion has more recently been shown to be a rather liberal way of assessing the model's accuracy (see Coltheart et al., 1993).

A lexical decision response is (usually) made on the basis of orthographic, rather than phonological error scores. Here, the initial orthographic pattern is allowed to feed activation to the hidden units, which then feed back to the orthographic units again. Seidenberg and McClelland provide simulations demonstrating that real words, on average, produce lower error scores than nonwords, allowing a lexical decision to be made by choosing some criterion error score which separates (most) of the real words from (most) of the nonwords. Again, however, recent work has indicated that the procedure of making a lexical decision does not work as well as initially claimed (Besner, Twilley, McCann & Seergobin, 1990; Fera & Besner, 1992).

Following training, the model performs well on the pronunciation of familiar words, and reproduces a number of empirical findings such as the word frequency effect, plus effects of regularity and the frequency x regularity interaction (words with regular spelling-to-sound correspondences are pronounced better than those with irregular correspondences, but the effect becomes less pronounced as word frequency increases, eg. Andrews, 1982; Frederikson & Kroll, 1976; Seidenberg, Waters, Barnes & Tanenhaus, 1984). In addition, Seidenberg and McClelland demonstrate that the model is able to produce pronunciations for nonwords, via a form of synthesis from real-word knowledge. The shared nature of the word representations means that a nonword (ie. an orthographic pattern not in the training set) activates hidden units which are also activated by similarly-spelled words, and that these hidden units in turn activate phonological representations. Seidenberg and McClelland claim that this procedure produces accurate naming of nonwords, although Besner et al. (1990) have demonstrated that more stringent measures than the
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BEATENBY criterion indicate that the performance of the model on nonwords is, in fact, quite poor.

The major advantage of Seidenberg and McClelland's model of word recognition is that it is able to learn: rather than just assuming a certain state of the mature lexical system with hard-wired links between fully-developed nodes, the representations used to process words are shown to form gradually from continual exposure to written words and their corresponding pronunciations. On the other hand, a number of serious problems have emerged in recent years with both Seidenberg and McClelland's particular model (eg. the poor performance in naming of nonwords, the poor accuracy of lexical decision responses, the method of determining phonological output), and with parallel distributed processing models in general (eg. the realism of the back-propagation learning procedure, and the poor stability of already-learned information in the face of new learning without constant re-training; see Murre, 1992).

Thus, as with other theories of word recognition, the status of Seidenberg and McClelland's model is equivocal. Despite this, there are two aspects of the model which are relevant for present purposes. First, the model displays one relevant property of overlapping, distributed representations: as with earlier models including different assumptions about the storage form of word knowledge, nonwords produce substantial activation of the representations used in processing words. (It also seems intuitively likely that more word-like nonwords will produce lower error scores than less word-like ones, as the structure of word-like nonwords is closer to the structure of familiar words coded in the hidden-unit weights. However, this is difficult to confirm without computer simulations of performance with various types of nonwords, which were not provided by Seidenberg and McClelland.)

Secondly, the model suggests yet another mechanism by which repetition priming effects may be produced. Seidenberg and McClelland (1989: pg 541) actually discuss what they call "repetition priming", in which they demonstrate that, after 10 learning trials in a row with the stimulus TINT, error scores for that stimulus have been noticeably lowered. At the same time, error scores for PINT have increased somewhat. This process occurs because the learning procedure adjusts the connection weights in the direction of minimizing the error scores for the stimulus just presented. Thus, the model shows that recent exposure to a particular target biases the model in the direction of that target over others. In fact, the effect demonstrated by Seidenberg and McClelland is not repetition priming - the effect of any single presentation is too small. The effect does, however, suggest a way in which priming might arise within the model, namely by a large but temporary bias in the weights in favour of a recently-presented item. This temporary bias would decay over time, eventually
returning the weights to their stable value or something very close to this (much like, say, the logogen model's temporary reduction in threshold followed by a gradual return to very slightly below the previous value).

1.1.6 Word recognition and priming

The word recognition literature review presented above introduced some of the major experimental findings bearing on the empirical work in this thesis. In particular, the relevant results are that a) lexical status (word or nonword) is a primary variable affecting processing within the word recognition system and thus that examining the processing of nonwords is just as important as examining the processing of real words, b) for real words, word frequency is an important variable which has been consistently shown to influence lexical processing, c) for nonwords, "wordlikeness" is an important variable, with evidence that highly word-like nonwords gain access to word-level representations, and d) list structure influences lexical decision times, that is, decision times to a given class of target are affected by the nature of other items in the list.

The review of word recognition also introduced a number of ideas which are important when considering priming within a "perceptual" framework. This approach sees repetition priming as occurring when the identification of a target occurs more rapidly because of a transient modification of the state of the internal representation(s) involved in its perception. By this view, an explanation of priming requires an understanding of the representations and processes involved in word perception.

The form of internal representation of familiar words and the method by which these representations are accessed are not currently understood. Nevertheless it is widely agreed that a) written word recognition is carried out at least partially on the basis of orthographic representations, and b) nonwords, particularly pseudowords, can activate these orthographic representations. The general term lexical representation will henceforth be used to refer to the representations which are accessed by both words and nonwords: these may include whole-word representations in a localised system, sub-word representations in a partially-distributed system, or hidden units in a fully-distributed system.

In general, then, priming effects are potentially allowed for by what might be termed transient state changes of lexical representations. It is not clear what the physiological correlates might be of the various forms of changes, or the various forms of lexical representation, which could be proposed within the framework of current approaches to word recognition. However, all word
recognition models specify the "existence" of certain mechanisms which are required so the model can successfully identify words and reproduce basic empirical findings observed with lexical stimuli. Several of these computational mechanisms seem possible candidates for producing repetition priming effects. Thus, in terms of the models reviewed, lexical state changes may have a number of different loci.

Previous authors who have wished to explain repetition effects in terms of modification of perceptual representations have mostly restricted their discussion to priming mediated by leftover activation (eg. Graf & Mandler, 1984; Mandler, 1980; Morton, 1969; Warren & Morton, 1982). The "activation account" of priming claims that words are processed more rapidly on a second presentation because their corresponding representations retain some activation from the prior presentation, and so the target word is effectively already partially identified before it is even presented.

While activation is one mechanism by which priming might be produced, the review of models of word recognition suggests at least three other forms of transient state change which could lead to priming. For example, lexical representations which have been strongly activated (by presentation of a given target) could be left with temporarily higher resting-level activations. That is, activation itself is assumed to decay rapidly as soon as the target is removed, but it decays back to a higher resting level, giving the target an advantage on second presentation.

Alternatively, if lexical representations are allowed variable thresholds (as in the logogen model), then priming could be produced by the lowering of threshold that Morton (1969) proposes to follow immediately upon a unit “firing”. In this case, a word presented for the second time would fire on the basis of less evidence because it would reach threshold sooner, leading to faster responses on repeated presentations.

Finally, if distributed rather than localised representations are assumed (as in Seidenberg & McClelland’s model), a transient change in the weights of links to and from the hidden units might occur (eg. see McLaren, Kaye and Mackintosh, 1989). After an extended learning phase in which the PDP model becomes a "mature reader", further exposure to lexical stimuli might cause very little change in the stable weight values, but nevertheless temporarily bias them in the direction of recently-presented items. In this case, priming would result through this temporary bias because the system falls into the state corresponding to a repeated item more rapidly on second presentation. (Of course, a PDP model might also allow priming through activation, resting-level activation or thresholds of hidden units.)
Thus, any one of a number of mechanisms could potentially produce priming in word recognition. These mechanisms differ in terms of the exact locus of the priming effect, but are similar in that all are temporary changes in the state of the abstract orthographic representations used to identify words. Note that changes in the state of such representations could produce priming for nonwords as well as for words: the common assertion that priming cannot be explained in terms of changes in the state of pre-existing representations because nonwords show priming (e.g., Roediger & McDermott, 1993, and Schacter, 1987) is false (Bowers, 1994, and Dorfman, 1994). The evidence that nonwords access lexical representations implies that state changes have the potential to produce priming effects for nonwords as much as for real words.

Given that transient state changes could potentially produce an advantage for repeated targets, the question is whether such changes could explain either or both of the two orthographic (or at least non-semantic) priming effects extant in the empirical literature, namely masked priming and standard long-lived repetition priming for written stimuli. As will be seen below, the most relevant empirical data here are not the detailed properties of masked and standard priming. Instead, they are simply the duration and magnitude of priming.

1.1.7 Transient state changes and the duration of priming

Masked priming

Leftover activation seems an ideal mechanism to explain the very short-lived (<2 second) masked priming effect. Here, the prime is presented for long enough to begin activation of those words which are at least partially consistent with it, but not long enough for complete processing to take place or for the prime to become consciously identified. When the prime is replaced immediately by the target, the incoming target activation merges with the activation already present in the system from the prime (Humphreys, Besner & Quinlan, 1988). Assuming the target is left on for long enough, processing will be completed, the target (only) will become available to conscious awareness, and a lexical decision to the target can be made. If the orthographic information from the prime is consistent with the target, target processing time will be faster than if the prime is inconsistent with the target, producing a standard masked priming finding (e.g., crock-BROOK is faster than spine-BROOK). If a delay is introduced between

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3 One further mechanism which might be seen to produce a type of "priming" effect is the long-lasting change in threshold or resting-level activation or weights which has been used to explain the word frequency effect. While this effect is, indeed, a repetition effect of sorts, it is much smaller than the standard repetition priming effect and is perhaps best interpreted as a form of gradual skill learning.
Background: The time-course of repetition priming

The time-course of repetition priming is such that the offset of the prime and the onset of the target, the prime activation will rapidly decay, thus destroying priming with delays of only a few hundred milliseconds.

**Standard repetition priming**

As noted earlier, the magnitude of standard repetition priming remains at tens of milliseconds (in lexical decision) after minutes or hours. Given that response times to unprimed items in lexical decision are commonly about 650-750ms, a repetition effect of, say, 20ms after 1 hour is clearly a substantial effect.

In terms of the preceding discussion of masked priming, it seems that a transient state change taking the form of leftover activation is unlikely to provide an explanation of standard priming, despite the view of many researchers that this mechanism is a potential contender (e.g., Dean & Young, 1995; Mandler, 1980; Schacter, 1987; Taft, 1991). Activation can only produce priming for as long as it endures, but all computational models of word recognition assume that activation decays extremely rapidly, is immediately cleared following successful identification of the current target, or is completely replaced in the process of identifying the immediately-subsequent item. Consideration of the reason for the assumption of extremely rapid decay/replacement will also indicate that forms of transient modification other than activation are equally unlikely to provide viable explanations of standard priming.

The interactive-activation model illustrates the necessity of rapid decay/replacement of transient state changes. If words are presented sequentially to this model, then the patterns of activation corresponding to the previous trial are completely replaced in order to process a new item. This occurs because identification of the current word is based on a "winner-take-all" approach, in which the appropriate word unit can only be selected by "killing" the activation of all other competing units. These competing units include both alternative word units (partially) consistent with the current stimulus, and word units consistent with previous stimuli. Thus, in order to successfully process the current item, it is assumed that all, or almost all, traces of preceding items must be destroyed. These traces include not only activation; it would be difficult to identify the current word without waiting for the substantial decay of competition from lowered thresholds, raised resting-levels, or biased weights leftover from previous items.

As a second example, consider Seidenberg and McClelland's parallel distributed processing model. Here, word identification relies on achieving a pattern of activation distributed across the hidden units which corresponds to a familiar word. If, however, activation of previous items is allowed to remain in the system, the pattern will become blurred, representing something which
corresponds neither entirely to the current stimulus nor entirely to a previous one.

These examples demonstrate a general property of word recognition systems: leftover state changes, in addition to any repetition advantage they might produce, will interfere with subsequent processing of other words (see Grossberg, 1980, and McClelland & Rumelhart, 1988, pg 16, for discussions relating to this issue). This interference process has been described for transient changes in the level of activation of individual units, but the same problem (perhaps in a slightly less severe form) will clearly arise for any other types of state change. In general, the longer a state change endures to produce priming, the more severe will be the interference from previous items on new processing. In normal reading, many hundreds or thousands of different words are processed within, say, an hour, and thus state changes that can produce large priming effects for many items over delays of this duration would be expected to leave the system in a state where the interference from previous items is so severe that no processing of new words can be achieved. Clearly, this catastrophic interference does not actually occur.

1.1.8 Short term priming?

It appears extremely unlikely that transient changes in the state of lexical representations would be capable of producing a repetition advantage with the duration of standard long-lived priming. Thus, the only priming effect identified to date which has a natural interpretation in terms of these mechanisms is masked priming. How long could one or more forms of transient state change endure without causing catastrophic interference to subsequent processing? As discussed, it is apparent from theoretical considerations that substantial changes in the state of the system cannot last for many minutes or hours. However, it is not clear that if state changes endured for, say, a number of seconds, the problem of massive buildup of leftover effects (via activation, thresholds, etc) in normal reading would necessarily occur. It is possible that state changes might last somewhat longer than is currently assumed. Exactly how long remains unclear: all we can say is that the longer such effects last, the more severe will be the interference to subsequent processing, and thus that there must be some upper limit (which is surely quite short) to the duration of transient state changes.

Potentially, transient state changes might be able to survive interference from at least a few successive items. If this were the case, the implications for word recognition would be quite profound. It would indicate that the lexical processing system has the ability to "retain" several fully-processed words at once (as opposed to a single "winner"). This, in turn, would imply that
Background: The time-course of repetition priming

recognition of new words generally occurs in the context of leftover effects of a number of preceding items, suggesting that mechanisms for selecting the representation which matches the (current) stimulus may need substantial re-thinking.4

Types of transient state change and their decay rates require further exploration in order to determine just how long "perceptual" effects of this sort can last without causing severe interference to subsequent processing. While detailed theoretical consideration of the issue is needed (perhaps by simulation of various mechanisms within various computational models), the existence and decay rate of potential state changes should also be a matter for empirical investigation. This investigation could proceed by examining either interference effects or repetition priming over relatively short delays: longer than the hundreds of milliseconds that masked priming endures for, but less than many minutes to avoid the region in which all state changes from previous targets must surely have been written over. Examining repetition effects appears to be the most natural way of beginning an investigation of retention of preceding items arising from transient state changes (see Chapter 6 for some consideration of the proactive interference effects also expected to be produced). With this method, any priming effect due to transient state changes might be expected to reveal itself as a short-lived repetition effect, overlaid on standard long-lived priming.

Thus, a review of the representations and processes involved in word recognition suggests that there may exist a short-lived repetition priming effect, of a duration intermediate between that of masked priming and that of standard priming, which arises due to transient changes in the state of lexical representations. The perceptual approach to priming also suggests that any such short term priming effect may well differ as a function of at least some of the variables known to affect lexical access, such as lexical status, word frequency and so on.

4 Note that there is evidence that recognition of words in spoken sentences relies on information from more than just the currently-presented word (eg. Miller & Isard, 1963). Thus, it is commonly assumed that auditory word recognition proceeds in the context of leftover influences of quite a number of previously-presented items, and, indeed, is often impossible without these influences due to the (phonological) ambiguity of the spoken stimulus (eg. Marslen-Wilson & Welsh, 1978; McClelland & Elman, 1986). It would perhaps not be surprising if a similar mechanism operated in visual word recognition, even though for (type-) written words the stimulus is (orthographically) unambiguous, and thus it would not be strictly necessary.
1.2 PRIMING FROM A MEMORY PERSPECTIVE

While there is a long tradition of considering priming as a perceptual phenomenon, most literature on repetition priming in fact comes from researchers with a primary interest in forms of memory, rather than in any perceptual changes which might underlie these forms. A limited review of this literature is now presented. As will be seen, examining priming within a memory framework provides an additional reason for studying repetition effects over short delays. It also clarifies the range of delays which might be expected to reveal short term priming.

1.2.1 Forms of memory

Much recent work in human memory has chosen to define "memory" in the broadest possible fashion; that is, as any form of trace or information storage that influences later awareness or behaviour. Thus, the following have all been considered examples of memory: motor skill learning; learning to read; overlearning of the names of familiar people; being biased by recently-presented context to interpret an ambiguous stimulus in a particular way; knowing what important historical event occurred in 1788; recollecting a personal episode; and remembering a new telephone number for long enough to dial it. One important way in which these examples differ is in the degree to which they are available to, or influenced by, conscious awareness. For example, conscious knowledge has at most a limited influence on skill learning, and a skill, once learned, is very difficult to verbalise in order to teach others. Learning to read, or learning names, leads to conscious knowledge of the result of use of the trace (a feeling of recognition of the word), but reading is not (at least in the mature reader) associated with a feeling of recollection of the occasion on which that word was learnt. Recollective memory, on the other hand, is apparently "fully conscious", in the sense that a) the experience of retrieving a personal episode is intrinsically conscious, b) we can only have recollective memory for an event of which we were consciously aware at encoding, c) recollective memories have a sense of personal identity attached, and d) recollective memories are relatively easy to verbalise to others.

Until relatively recently, studies of human memory were restricted almost entirely to the investigation of recollective memory. One motivation for a more general definition of human memory, including non-recollective forms, has come from attempts to reconcile findings regarding animal learning/memory...
Background: The time-course of repetition priming

with our knowledge of human memory (see Lynch & Granger, 1994; Nadel, 1994; Squire, 1987, 1994; Squire & Butters 1992). When studying animal memory or memory at the neurological level, it can simply be observed that an animal's behaviour has altered or that some neuronal change has taken place; it is not possible to identify which, if any, of these traces were accompanied by conscious awareness of a fact or previous event. Given that it is not possible to restrict the study of animal memory to forms corresponding to the recollective memory traditionally studied in humans, the two fields can only be brought closer together by expanding the areas studied as human memory to match those studied in animals.

A second motivation for the broader definition of memory has been the realisation of the theoretical difficulties involved in defining human memory as recollective experience only. As one example, some views of repetition priming argue that the form of trace underlying priming and recollective memory are similar, with only the form of access to that trace differing (eg. Jacoby, 1993a). In addition, it has been argued that performance on memory tests apparently tapping recollective memory can be affected by automatic, non-deliberate influences of past events, while performance on behavioural measures such as priming tests can sometimes be influenced by recollective memory (Jacoby, Toth & Yonelinas, 1993; Richardson-Klavehn & Bjork, 1988; Schacter, Bowers & Booker, 1989; Toth, Reingold & Jacoby, 1994). Thus, it is difficult to clearly distinguish the types of human empirical data relevant to the study of "memory", by the old (recollective) definition, from the types of data not relevant to this study. This also suggests that an inclusive definition of memory is more theoretically useful than a narrow and restricted one.

One result of the broadening of the definition of memory has been, perhaps inevitably, a desire to distinguish between different forms. The reason for this is that, while it may be useful to consider all forms of information storage as "memory", it is clearly not useful to assume that all such forms necessarily have the same underlying mechanism, especially when the surface manifestations are so different. A number of different forms of memory are commonly distinguished, which are exemplified in the various manifestations of past influence cited at the beginning of this section, and include skill learning, implicit memory, explicit memory, semantic memory, episodic memory, short term (working) memory, and long term memory.

Such distinctions between forms are useful in organising the vast number of empirical facts about memory; they are useful because exemplars of each form of memory share more properties (eg. duration, retrieval method, effects of encoding manipulations, content) with other exemplars of the same form than with exemplars of different forms. It is not necessarily the case (although it might be) that various forms of memory rely on different systems, in the sense of
relying on fundamentally different types of trace or entirely distinct physiological mechanisms or locations. For present purposes, it is not necessary to enter into a long debate regarding which, if any, of the forms of memory distinguished above represent different systems (for consideration of this issue, see: Roediger, Rajaram & Srinivas, 1990; Schacter & Tulving, 1994). Rather, the aim of the discussion of forms of memory is simply to point out that new forms are commonly distinguished when there is sufficient evidence that reference to a new memory form will increase, not decrease, the degree of conceptual structure which can be imposed on the empirical facts.

Two particular distinctions between forms of memory are relevant to this thesis, and so will be examined in some detail. These are, first, the distinction drawn between implicit and explicit memory, and, secondly, that drawn between short term and long term memory.

1.2.2 The explicit/implicit distinction

The explicit/implicit distinction arises from the central division between recollective and non-recollective memories, that is, from the observation that some forms of memory necessarily require and produce conscious awareness, while others do not. The definitions of explicit and implicit memory (Graf & Schacter, 1985; Schacter, 1987) are made in terms of the nature of the subject’s retrieval at test (thus the nature of the encoding, and of any instructions to subjects which do not affect the appropriate aspect of their retrieval, are irrelevant). Explicit memory is defined as memory requiring deliberate and conscious recollection, such as that needed for successful performance on recall and recognition tasks. Implicit memory is non-recollective in nature, and is defined as being an unconscious, automatic use of memory, such as that assumed to underlie repetition priming effects or skill learning.5 The terms "implicit" and "explicit" are descriptive terms for the two forms of memory and are theoretically neutral as to whether or not different physiological systems underlie the two.

A wealth of data exists indicating the value of a distinction between implicit and explicit memory (see Schacter, 1987, for review). This consists partly of evidence that each form of memory can exist without the other, and partly of experimental dissociations. Amnesic patients, who are by definition impaired on explicit, or conscious, recollection of previous events, show intact repetition priming and learning of motor skills (Jacoby & Witherspoon, 1982; Moscovitch, 1982; Warrington & Weiskrantz, 1968). On the other hand, Dagenbach, Horst and Carr (1990) have shown that normal subjects can learn patterns of motor

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5 The issue of whether priming tasks always tap only implicit memory will be addressed at the end of the Chapter.
Background: The time-course of repetition priming

responses, as demonstrated by faster reaction times to patterns following the learned sequence, without being able to report any explicit knowledge of the patterns.

In normal subjects, the most common argument for an implicit/explicit distinction is based on findings of experimental dissociations, in which a variable affects, say, a task assumed to tap explicit memory but not one assumed to tap implicit memory, or affects the two tasks in opposite directions. A few examples are: a) the semantic or structural level of processing at study influences recall/ recognition but not priming (Graf & Mandler, 1984; Jacoby & Dallas, 1981); b) what might be termed "degree" of study (i.e. study time, massed presentations, intentionality of learning, divided attention) also influences recall/recognition but not priming (see Roediger & McDermott, 1993, pg98, for review); and c) changing the modality of presentation between study and test influences priming but not recall/recognition (e.g. Donelly, 1988; Kirsner, Dunn & Standen, 1989; Kirsner & Smith, 1974; Roediger & Blaxton, 1987).

Distinguishing between implicit and explicit memory is one way of bringing some conceptual order to this pattern of dissociations (although see Blaxton, 1989, and Roediger, 1990, for at least one alternative organisation). In addition, the distinction has similar value in interpreting the amnesic syndrome, by providing a reasonable conceptualisation of the aspects of performance which are impaired in amnesia and those which are spared.

1.2.3 Issues in the interpretation of implicit memory

Repetition priming effects, such as those examined in this thesis, are commonly taken to reflect implicit memory, in that (for many situations at least) the observed behavioural change is apparently based on nonconscious access to a record of a target's first presentation.\(^6\) Thus, any studies of repetition priming must be addressed within the framework of the implicit/explicit distinction, and, in particular, considered in the light of theories of implicit memory.

There are three issues in the theoretical interpretation of implicit memory which are of relevance to the argument to be developed here, and/or the interpretation of the empirical work to be presented (see Roediger & McDermott, 1993 and Schacter, 1994, for more complete discussions of the basis of the implicit/explicit distinction.). These are a) the debate regarding whether implicit memory relies on historic or ahistoric traces, b) the proposal that implicit

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\(^6\) This is not to say that the study trials which lead to repetition priming do not also, on many occasions, lead to explicit recognition that an item has been recently encountered; the point is that repetition effects which are mediated by implicit memory are assumed to be independent of any conscious recollection.
memory relies on perceptual representation systems, and c) the duration of implicit memory.

**Historic/ahistoric traces**

The view that repetition priming is usefully interpreted as a form of memory allows at least one explanation of the effect which is fundamentally different from that provided by the tradition of a perceptual approach to priming. In the perceptual approach, standard priming has been seen as arising due to leftover activation (or, more likely, some other modification) of pre-existing internal representations. This approach is *ahistoric*, in that the trace which produces priming retains no history of the original event; instead, all that is retained is a change in the state of an abstract representation. As was discussed earlier, such an ahistoric explanation of standard priming has at least one major problem, namely that state changes capable of producing large repetition effects of many minutes or hours would necessarily produce massive proactive interference on new processing.

As an alternative, some have proposed that *historic* traces underlie priming (see Richardson-Klavehn & Bjork, 1988, for review). An historic trace is one which preserves all details of the original encoding episode. Here, massive interference from old learning would not be expected, as large standard priming effects are assumed to arise only when a complete trace is re-used (i.e. when there is strong overlap in processing at study and test). Proponents of the view that such traces underlie long-lived implicit memory (e.g. Bransford, Franks, Morris & Stein, 1979; Jacoby, 1983a; Kolers & Roediger, 1984) have provided evidence that standard priming is sensitive to the degree of overlap between the form of first and second presentations of a repeated target, suggesting that maximum priming, does, indeed, arise from re-use of a complete, context-specific, processing trace. It can be seen that this view of priming is solely a memory interpretation: the form of trace underlying implicit memory is the same as that underlying explicit memory, and only the form of access differs.

The present status of the historic/ahistoric debate with respect to standard long-lived priming is unclear. While some studies have reported within-modality study-test mismatch effects (e.g. Jacoby & Hayman, 1987; Kolers, 1979; Roediger & Blaxton, 1987), others have failed to do so (e.g. Clarke & Morton, 1983; Rajaram & Roediger, 1993; Scarborough et al., 1977). In addition, a number of studies have failed to find priming, or have found only very small effects, with complete overlap between both presentation format and task on first and second presentation of the target (Carroll & Kirsner, 1982; Dean & Young, 1995). These failures have generally occurred for highly unfamiliar items or new relationships between items. With identical presentation and task, it is hard to argue that the processing carried out by the subject would be anything other than exactly the same on each presentation, and so, by the historic view,
maximum priming should be observed. The failure to find any priming at all suggests that perhaps, after all, contact with some form of internal representation is required in order to produce long-lived repetition priming effects.

**Schacter's perceptual representation systems**

Schacter (1990, 1994) suggested that implicit memory relies on perceptual representation systems (PRSs). This view assumes that traces within a visual word-form system produce priming for written words, traces within an auditory word-form system produce priming for spoken words, and traces within a structural description system produce priming for objects. It can be seen that this approach to priming is very similar to the long-standing perceptual interpretation of priming, with the visual word-form system corresponding to the orthographic input lexicon, and the auditory word-form system corresponding to the phonological input lexicon. Thus, it provides a basis for an integration of the preceptual approach to priming within a memory framework.

There are two ways in which Schacter's PRS view of priming is influenced by the "memory" tradition. First, at least one common mechanism (namely the implicit form of access) is seen to apply to all perceptual systems, implying a single form of memory which cuts across perceptual domains. Secondly, the form of the trace leading to priming is left unspecified, rather than assumed to necessarily be a change in the state of a pre-existing abstract representation. For these reasons, Schacter's PRS view could be seen as a kind of hybrid between the perception and memory approaches to explaining priming.

**The time-course of implicit memory**

Given the assumption that standard repetition priming generally reflects implicit memory, the duration of implicit memory has already received substantial coverage in Section 1.0.3. Here, it will simply be noted that skill learning (eg. learning to ride a bicycle, learning to read) and masked priming can also be seen as examples of implicit memory (neither relies on conscious recollection), making a case for the view that there are at least three sorts of implicit memory, each with a different duration. Skill learning seems the longest-lived effect (practically permanent), with standard repetition priming having an intermediate duration (hours or weeks), and masked priming being the shortest-lived (a few hundred milliseconds).

Interestingly, both skill learning and masked priming have obvious perceptual (and/or motor) interpretations, in which the system responsible for perceiving the stimulus (or producing the response) also stores the changes which produce "memory" (see Squire, 1987, for a discussion of this idea with respect to skill learning). Thus, one possible interpretation of implicit memory is
that all varieties of such memory rely on implicit access to traces left within a perceptual system, with each type presumably relying on a different mechanism within this system. For example, learning to read might arise via gradual adjustment of weights in a network connecting orthographic knowledge to phonological knowledge, while masked priming could arise via pre-activation by the prime of some of the units required to process the target.

1.2.4 The short term / long term distinction (or, The duration of explicit memory)

Explicit memory has traditionally been divided into separate long term (LT) and short term (ST) memory components (see Baddeley, 1990, for review). These differ substantially in duration, with short term memory able to maintain only a few items active for a few seconds (without rehearsal), and long term memory able to store information for minutes, weeks or years (depending partly on the level of elaboration at encoding and the degree of re-recollection after the original encoding event). The concept of a temporary explicit store has been elaborated with the discussion of a number of such stores, each specific to a particular domain. For example, it has been proposed by Baddeley and Hitch (1974) that short-term representations may operate separately for a number of processing domains, such as verbal processing (in the form of an auditory rehearsal loop) and visual processing (in the form of a visuo-spatial sketchpad). This proposed collection of labile explicit memory representations is commonly referred to as working memory.

One of the major arguments for the value of a ST/LT distinction in explicit memory is a substantial difference in decay rate (or "forgetting" rate, in the language of the short term memory literature). In general, recall accuracy of target items is found to fall off rapidly as the number of items (other targets or distractors) and/or time intervening between the target and the test is increased. For example, recall accuracy for nonsense trigrams (e.g. JKI) decays rapidly over a 10-second period of continuous distraction, to around 10% of its immediate-recall value (Brown, 1958; Peterson & Peterson, 1959). A second classic example of this rapid decay is the recency effect (Postman & Phillips, 1965) - with new items constantly being presented for study, a short-lived recall advantage of recently-presented items over those presented at earlier serial positions in the list endures for approximately four or five intervening items. These effects have been interpreted as reflecting a distinct short term memory representation, which dissipates rapidly to leave a fairly stable long term level of performance (although see Anderson, 1995, for an alternative view).

There has been much debate regarding the underlying mechanism of dissipation (Reitman, 1971, 1974; Shiffrin, 1973). It is difficult to disentangle the
Background: The time-course of repetition priming

relative effects of time delay and interference, but it is generally thought that both factors contribute to the observed decay of recall performance (for example, memory span is influenced by both number of individual items and the pronunciation rate of the labels of these items; see Shiffrin & Nosofsky, 1994). On the assumption that interference is a contributor to the short term decay of explicit memory, working memory can be seen as having a limited capacity in terms of the amount of material "stored", as well as the time for which it is retained: interference from successive items will rapidly replace the traces of earlier ones, leaving only a few items "active" at once. Indeed, memory span tasks reveal strict limits on the number of distinct items which can be accurately retained at once, with perfect recall found only for lists of up to about seven unrelated digits (Miller, 1956).

Memory performance of amnesic patients is also in keeping with the existence of a distinct form of ST explicit memory, limited in duration and/or capacity. While amnesics have very poor long term explicit memory, their immediate recollection is generally good. In classic pure amnesia, digit span is normal, and the patient is perfectly capable of, say, following a conversation from one moment to the next. However, a distraction of more than a few seconds is liable to leave the patient with no (explicit) recollection of the activity in which they were previously involved (Kaushall, Zetin & Squire, 1981; Scoville & Milner, 1957).

1.2.5 Short term implicit memory?

While the division of explicit memory into short and long term components has been a major topic of investigation, the possibility of a similar division within implicit memory has received comparatively little attention. Given that implicit access to long-lived traces, explicit access to long-lived traces, and explicit access to short-lived traces have all been demonstrated, there is an obvious question remaining unaddressed in the current literature: Can a new form of memory, namely short term implicit memory, be identified? Such a form of memory would presumably exist for similar reasons to explicit working memory, that is, as a temporary holding-place for information which has an immediate influence on current processing. However, it would differ from working memory in providing temporary retention for the use of nonconscious, rather than conscious, processes: many subconscious processes (such as sentence processing or tracking an extended movement) would seem to require that information be retained over a period of several seconds so that a complete event can be integrated.

The current literature fails, by and large, to address the possibility of a "short term implicit memory". This can be attributed at least in part to the choice
of technique most commonly used to examine repetition priming. The majority of studies investigating such priming have been conducted by researchers with an interest in "memory" explanations of repetition effects. Thus, their methodology has followed a traditional memory approach: target presentations are blocked, with the first occurrence of a target item appearing in a study list and the second appearing in a separate test phase, usually with some distractor task presented between phases. As a result, most studies of repetition priming have employed a relatively long delay of at least several minutes (up to several days) between first and second presentations. Given that this timescale is within the bounds of what has been considered, for explicit memory, "long term" rather than "short term", much of the current literature on repetition effects could be seen as investigating a long term implicit memory form. Very little of it is directly relevant to the possibility of a short term implicit memory form.

The common emphasis on long term implicit memory leaves open the question of whether there exists a short term implicit memory form, of similar duration to the recency effect observed in explicit recall and recognition tasks. Such a memory form might be reflected in a short-lived repetition priming effect, which lasts through perhaps a few intervening items and several seconds without the opportunity for rehearsal, and to be additional to any long-lived implicit memory present.

1.3 THE PRESENT INVESTIGATION

1.3.1 The question

The perceptual and memory frameworks for the interpretation of priming effects are to be viewed as complementary rather than in competition. Empirical work conducted within the memory tradition usually concentrates on distinguishing between forms of memory. This approach, therefore, suggests that any newly-identified influence of past events should be considered for similarities/differences to other known forms of memory. It also suggests that any novel form of influence identified in one stimulus domain is likely to generalise, at least to some extent, to other domains. The perceptual approach, on the other hand, provides a more detailed (possible) explanation of what may give rise to a new implicit memory form within one particular stimulus domain. It suggests that at least some properties of such an effect may be specific to the domain chosen, and that factors which affect the perceptual processing of certain

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7 An investigation of the degree to which this occurs, however, was beyond the scope of this thesis.
Background: The time-course of repetition priming

stimuli may influence their priming. The present investigation is based on the integration of literature from both traditions.

As has been demonstrated in the reviews of the word recognition and memory forms, each framework for understanding priming independently suggests a common conclusion, namely that there might exist a short-lived repetition priming effect lasting longer than masked priming but not nearly as long as standard repetition priming. From a word recognition perspective, it has been argued that transient state changes in the representations used to identify words might be capable of producing short-lived repetition effects surviving through one or more intervening items. However, it was not possible to say what the theoretical maximum duration of priming arising through this mechanism should be; rather, it could only be concluded that the longer such priming lasts, the more interference there will be to processing of subsequent items. From a memory perspective, it has been argued that there might exist a short term form of implicit memory, with a duration similar to that of short term explicit (working) memory. This possibility clarified the region of interest for a short-lived priming effect, by suggesting that the duration of any ST priming should be only a few intervening items and a few seconds. Together, then, these two approaches suggest that the identification of any short-lived priming effect (over and above standard long term priming) will be facilitated by examining repetition effects over delays of the order of 1 second to 1 minute, with particular attention given to shorter delays within this range.

The experimental work presented in this thesis examines repetition priming for lexical stimuli over short delays. The initial question investigated is a purely empirical one: Can a short term repetition priming effect be identified? Chapter 2 provides evidence of such an effect for words and nonwords. Further experiments investigating this novel form of priming are based on issues suggested by both memory and word recognition literature. Short term priming is identified with short term implicit memory by distinguishing it from long term priming (Chapter 3), and from short term explicit memory (Chapter 4). Short term priming is also examined as a function of variables which are known to influence lexical processing, concentrating on lexical status (all Chapters) but also including word frequency (Chapter 3). Finally, the relative effects of time delay and interference on the decay of ST priming are examined for targets of each lexicality (Chapter 5).

Before this experimental work is presented, however, the (few) extant papers which have directly examined repetition priming over the delays of interest will be reviewed. In addition, some relevant methodological issues are considered, and the design of the present experiments discussed.
1.3.2 Directly relevant literature: Short term priming for words and nonwords

In order to measure priming over a small number of intervening items, neither the "study phase - test phase" design commonly used to investigate standard repetition priming, nor the masked priming technique, is appropriate. Instead, continuous presentation of a list of items can be used (eg. Kirsner and Smith, 1974), where a response is required to every item. With this lag paradigm, targets can be repeated at different lags by varying the number of items intervening between the two presentations, and priming can be measured as the reduction in reaction time on the second occasion compared to the first.

A number of studies have used this method to measure repetition effects for words at short lags; of these, most have used a lexical decision task. Using this task, Scarborough, Cortese and Scarborough (1977) have provided the most commonly-cited study. They found no significant decay of word priming across lags 0, 1, 3, 7 and 15 in their first experiment (lag 0 means immediate repeat, ie. no intervening item). They did, however, find a decay across lags 0, 1, 3, 7, and 31 in their second experiment. Unfortunately, no analysis regarding where this decay occurred was presented, although later writers (eg. Monsell, 1985) have interpreted Scarborough et al.'s data as showing a labile lag 0 priming component decaying to a stable longer term component from lag 1 onwards. This interpretation has been loosely supported by work subsequent to that of Scarborough et al: Monsell (1985), using lags 0, 1, 2, 4, 6, 8, 20 and 31, Ratcliff, Hockley and McKoon (1985), using lags 0, 1, 2, 4, 8, 12, and 16, Bentin and Moscovitch (1988), using lags 0, 4 and 15, and Kersteent-Tucker (1991), using lags 0, 1, 4 and 8, have all concluded that a short term priming effect exists, but that it is restricted to immediate repetition (lag 0). A somewhat different pattern of results was obtained by Kirsner and Smith (1974), who found almost as much priming at lag 3 as at lag 0, with both of these shorter lags showing substantially more priming than lags 15 and 63.

The pattern of word priming across lags from these studies is shown in Figures 1.2 and 1.3 (two figures are used simply so that the decay patterns in all experiments can be clearly seen). Serious discrepancies are apparent in the patterns of decay across experiments. There is reasonable support for the view that priming is larger at lag 0 than at any later lag, which suggests that at least some sort of short term priming component is superimposed on a more stable long term effect, although an effect which exists only at lag 0 could be explained simply as a temporary buffer storing a copy of the last item presented. However, the common conclusion that the short term effect disappears with a single intervening item is less well founded. Most of the experiments show some trend towards decay between lags 1 and 4, despite the fact that the effect was not
usually significant (or was not tested), providing a hint of a much more interesting phenomenon.

A number of factors might account for the general failure to find significant short term priming lasting beyond immediate repetition. First, the number of items per lag condition (eg. as few as six in Scarborough et al., 1977; or ten in Monsell, 1985), or the number of subjects (as few as four in Ratcliff et al., 1985), were sometimes very low, possibly giving the experiments low power. Secondly, it is not always clear that a particular set of items appeared in more than one lag condition (ie. that the items were counterbalanced or re-randomised for each subject), leaving the pattern of priming observed open to item-specific effects. Thirdly, the presentation rate of stimuli was often quite slow (commonly 4 or 5 seconds per item). Assuming that any "short-term" traces of a target stimulus decay fairly rapidly over time (as well as possibly through interference from new processing), this lengthy delay may allow such traces to have largely dissipated by the time the item is repeated 8 or 10 seconds later (ie. at lag1). Table 1.1 summarises the relevant aspects of each experiment, making it clear that no experiment provides very convincing evidence against post-lag0 ST priming.

![Figure 1.2: Priming (in ms) for words in lexical decision as a function of lag for four published experiments. SCS = Scarborough, Cortese & Scarborough (1977); M = Monsell (1985)](image)

Figure 1.2: Priming (in ms) for words in lexical decision as a function of lag for four published experiments. SCS = Scarborough, Cortese & Scarborough (1977); M = Monsell (1985)
Figure 1.3: Priming (in ms) for words as a function of lag for four more published experiments. Note the different priming scale from Figure 1.2. RHM = Ratcliff, Hockley & McKoon (1985); K-T = Kersteen-Tucker (1991); KS = Kirsner & Smith (1974)

Turning to the issue of short term priming for nonwords, the existing data are more scant. In general, those papers reporting lag effects on words have shown less interest in nonwords, although each of the papers cited above has reported nonword data in one experiment. Except for Ratcliff et. al. (1985), all studies have reported more priming at lag0 than at later lags, but Figure 1.4 shows that, again, there is some disagreement regarding the form of decay post lag0. (Incidentally, there is also substantial disagreement regarding the existence of non-zero longer term priming for nonwords in these lexical decision experiments: estimates of priming at lags 8 to 15 range from -34 ms to +92 ms.)

Thus, for both words and nonwords, the question of whether short term priming survives beyond lag0 could clearly benefit from more detailed investigation. In particular, there is a need to consider priming for words and nonwords with faster presentation rates, more powerful designs, and better controls for item-specific effects than have previously been used.
**Table 1.1:** Details of previous experiments which examined priming in lexical decision as a function of lag, and employed at least lag0, one or more of lags 1-3, and one or more longer lags. Details given are for words, and include: the lags employed, the number of subjects, the number of items per condition, the approximate interstimulus interval (from the onset of one trial to the onset of the next) in seconds, whether or not items were cycled/randomised across lags for each subject, the magnitude of the lag0 advantage (i.e. the difference between lag0 priming and the average of all later lags) in ms, and the magnitude of the lag1 advantage. A question mark indicates that a detail was not clear from the experimental method reported.

<table>
<thead>
<tr>
<th>Expt</th>
<th>Lags</th>
<th>no. Ss</th>
<th>no. items</th>
<th>ISI</th>
<th>cycled?</th>
<th>lag0 adv</th>
<th>lag1 adv</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCS 1</td>
<td>0,1,3,</td>
<td>16</td>
<td>12</td>
<td>5?</td>
<td>no</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>7,15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCS 2</td>
<td>0,1,3,7</td>
<td>12</td>
<td>6</td>
<td>5?</td>
<td>yes</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>15,31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0,1,2,3</td>
<td>16</td>
<td>?</td>
<td>1.3</td>
<td>?</td>
<td>96</td>
<td>20</td>
</tr>
<tr>
<td>M 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M 3</td>
<td>0,1,2,4,6,</td>
<td>?</td>
<td>10</td>
<td>1.3</td>
<td>1.8</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>8,12,20,30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RHM 1</td>
<td>1,2,3,4,</td>
<td>4</td>
<td>60</td>
<td>5</td>
<td>yes</td>
<td>95</td>
<td>25</td>
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<tr>
<td></td>
<td>6,8,12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RHM 2</td>
<td>0,1,2,4,8</td>
<td>4</td>
<td>90</td>
<td>4</td>
<td>yes</td>
<td>45</td>
<td>-9</td>
</tr>
<tr>
<td>K-T</td>
<td>0,1,4,8</td>
<td>14</td>
<td>20?</td>
<td>2.6</td>
<td>?</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>KS</td>
<td>0.3,15,63</td>
<td>24</td>
<td>10</td>
<td>4</td>
<td>part*</td>
<td>88</td>
<td>115 (lag3)</td>
</tr>
</tbody>
</table>

*Note:* Only five of these experiments also reported nonword data. In general, the experimental details were the same for these targets except that, in some cases, fewer nonwords were employed per condition. Author abbreviations are as given in Figures 1.2 and 1.3.

* Two different random item selections were used in this experiment.
1.3.3 Methodological issues

There are a number of methods and methodological issues which are common to all or most of the experiments reported in this thesis. These general issues are discussed here; issues relevant only to individual experiments are left until those experiments are presented.

Experimental design

All experiments of the present study employed the lag paradigm, in which items were continuously presented at fixed intervals, and repetition priming was measured as a function of the number of items intervening between repeats. In general, a two-second-per-item presentation rate was used. Reasonable numbers of lag conditions (6 - 9), items per condition (17 - 20), and numbers of subjects (18 - 24) were used. Repeated target items were always counterbalanced across lags by cycling them through conditions across a number of versions of the list.
In order to vary lag, it was necessary to control the presentation order of stimuli. To present a large number of items at a large number of lags, it was necessary to closely overlap lag conditions (i.e., intervening items for some conditions were targets for others) so as not to blow out the number of trials required. This fact means that very strict control of the presentation order was necessary (as opposed to being able to, say, randomise the order in which each lag condition appeared for each subject). To achieve this level of control without having to devise a complete order of trials for the entire experimental list, a number of sequence templates was chosen for each experiment. Each template included one occurrence of each lag condition, and the presentation order of the full list could then be determined by stringing together a number of such templates. Each version of the list (created for the purpose of counterbalancing items across conditions) then employed the same template structure, but presented a given subset of target items in a different lag condition.

Given the strict control over trial order, reaction times to particular trials in particular conditions are potentially open to "order effects", or in other words, effects of the differential patterns of trials leading up to target trials. The possible role of any order effects will be considered at some length in Chapter 6 (General Discussion), but, to anticipate, there are a number of reasons to assume that any such effects influenced the results to be presented only minimally. Briefly, these reasons are: a) within any one experiment, a number of different trial sequences preceded both first and second presentations of targets at any given lag, b) given the cycling of items across conditions, any order effects could only be based on order of trial lexicality, not order of individual items, c) results from naming will be shown to support those of lexical decision, indicating that no effect of response order (yes/no) to trial lexicality was apparent, d) a number of experiments employed the same trial sequence, making comparisons across these experiments independent of any order effects, and e) the most important within-experiment finding was replicated with two completely different trial sequences.

A final aspect of the experimental design was the method chosen to measure priming. There are at least three possible ways of determining the size of repetition effects. One of these is to compare reaction times to a target primed by an earlier presentation of itself with reaction times to a (matched/counterbalanced) unprimed target. This method has one major advantage, which is that it allows any order effects to be avoided by using the same trial order to precede target presentations in both the primed and baseline conditions (e.g., for a word repeated at lag 3 compare reaction time to the final trial of the primed sequence \( w_T - w_f - n_f - w_f - w_T \) with that to the final trial of the baseline sequence \( w_f - w_f - n_f - w_f - w_T \), where \( w_T \) refers to the target word, \( w_f \) is a word filler, and \( n_f \) is a nonword filler). Unfortunately, this method has one major disadvantage, namely that it requires vastly more trials (and items) to
present a given number of lag conditions than the method which was selected (see below). To employ the range of lags used in the experiments to be reported in Chapter 2, for example, would require approximately five times as many trials as were actually needed (>5000 instead of 1100). This makes the use of separate baselines impractical in the present context.

Given that a separate baseline condition cannot be used, first presentation times must provide the baseline against which to measure priming. Given this, there are still two possible methods of comparing any repetition advantage across lag conditions. The first of these is to calculate priming as the difference between first and second presentation times, initially for each item for each subject (followed by averaging over items and then subjects). The second is to compare repetition effects across lag conditions via reaction times to second presentations only, optionally subtracting these from an overall first presentation time for each stimulus type in order to gain an estimation of the absolute magnitude of the effect. Both of these methods are perfectly valid; there are no strong grounds for choosing between them, and the literature contains examples of both.

In general, the analyses reported in this thesis are based on repetition effects measured by first-minus-second priming scores. This measure was preferred over second-presentation reaction times mainly because it is easier to interpret graphically (ie. a lower priming score corresponds to a weaker repetition effect), but partly because it was felt that first-minus-second scores were likely to give the most stable estimates of the repetition effect, given that they remove variability due to individual items. Second presentation times, however, are always reported, allowing the interested reader to judge the similarity in pattern across the two measures; it would, of course, be expected that both measures of repetition produce the same pattern of data (although inverted with the second-presentation reaction times, given that a lower score with this measure corresponds to a stronger repetition effect). Incidentally, if the two measures agree, we can be more confident that any order effects have not significantly influenced the pattern of results, as one measure includes effects of trial order on both first and second presentations, while the other includes any lag-specific effects of order only on second presentations.

While reaction times were the primary measure of repetition effects, error rates were generally examined as well. However, given the low error rates normally reported with the tasks used, it was expected that there would be floor effects on any advantage due to repetition, and also that analyses of errors would have very low power.
Stimuli

Stimuli (targets and fillers) were four-letter, single syllable, words and nonwords. The word targets were very low frequency (1–4 occurrences per million according to the count of Kucera and Francis, 1967) in most experiments, but very high frequency (mean 275 occurrences per million) in one. Low frequency (LF) words were initially selected for investigation of short term priming because long term priming is known to be greater for these items than for high frequency (HF) words (Scarborough et al., 1977), and thus the chance of finding differences between lag conditions seemed likely to be maximised by using LF words.

Nonwords were of a single type across all experiments. They obeyed the orthographic and phonological rules of English (ie. they were pseudowords) but, as a rule, did not share their pronunciation with any real word when read aloud (ie. almost none were pseudohomophones). Pseudowords were chosen as nonword targets because of their strong similarity to real words, giving an expectation that they would be able to gain access to (orthographic) lexical representations, and potentially prime these via transient state changes.

Priming tasks

Most experiments used lexical decision in order to examine repetition priming over short delays. This task has the advantages of being suitable for use with the lag paradigm, and of being known to produce large and reliable repetition effects. It has the disadvantage that any observed differences between priming for words and nonwords may be due to the fact that opposite decisions are made to each type of item, rather than to differences in access to the "traces" left by these stimuli per se. To avoid this problem, naming appears to be the ideal task in that responses differ to every target, rather than all words sharing the same response and all nonwords sharing the same response. However, the priming effects which have previously been observed with naming are small (Mitchell & Brown, 1988; Scarborough et al., 1977), and this task seemed less likely to provide a powerful and reliable way of comparing priming between lag conditions. Therefore, lexical decision was selected as the primary task, with naming used to support conclusions drawn from this measure where appropriate.

The other two tasks which have commonly been used to measure standard repetition priming are not appropriate in the present context. Stem- and fragment-completion tasks require separate study and test phases, and thus cannot be used with the continuous presentation procedure required to measure priming over short lags. Degraded identification tasks would seem to be very open to subjects guessing which word/nonword the degraded item represents based on explicit memory of earlier trials (see discussion below), especially with
Chapter 1

a large number of items repeated within close succession of their first presentation, and would also be expected to become very stressful for subjects with the large number of trials required.

Ensuring that priming reflects implicit memory

"Primming" refers simply to an empirical phenomenon, in which behavioural responses are observed to be influenced by prior exposure to target material. The techniques used to assess priming have been termed indirect tests of memory (Johnson & Hasher, 1987) in the sense that no reference to the encoding phase is necessary at "retrieval" in order to complete the test task, and thus that any effect of prior exposure is revealed indirectly. These are contrasted with direct tests of memory, such as recall and recognition, in which the subject must refer back to the study episode to complete the task successfully. In general, it would be expected that direct tests mostly tap explicit memory, and indirect tests mostly tap implicit memory. (Note that this was just assumed in the outline of the evidence presented earlier for the implicit/explicit distinction.) However, it is now widely recognised that there is no straightforward correspondence between test types and forms of memory (eg. Jacoby, 1991; Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993; Schacter, Bowers & Booker, 1989; Toth, Reingold & Jacoby, 1994). Tasks which produce priming, in particular, do not necessarily tap only implicit memory. For example, in stem-completion tasks, some subjects have been reported to become aware of the fact that some test stems can be completed with study-list items (eg. Bowers & Schacter, 1990), and even to then attempt to deliberately recall these items (eg. McKone & Slee, under revision). In such cases, observed priming is clearly based at least partially on explicit memory.

Various techniques have been proposed to overcome the problem of explicit contributions to indirect priming tests, which aim to allow the investigation of pure implicit memory. Many of these (eg. the process dissociation procedure of Jacoby, 1991, or the post-test awareness questionnaire developed by Schacter, Bowers & Booker, 1989) are relevant only to separate study-phase/test-phase designs, usually employing stem- and fragment-completion tasks. As these designs and tasks cannot be used to assess priming over short lags, such techniques will not be discussed here (see Roediger & McDermott, 1993, for a recent review). Instead, the role of explicit memory in reaction time tasks only will be considered.

There are good reasons to assume that lexical decision and naming tasks in general, and the use of these tasks in the design employed here in particular, are likely to provide quite pure measures of implicit memory. First, lexical decision and naming are speeded tasks, in which subjects are trying to respond as quickly as they can. Presumably, then, explicit memory can contribute to a priming effect only if it is easier (and thus faster) for subjects to recognise the
item and recall their earlier response than it is for them to re-make their lexical
decision or naming response to a repeated presentation "from scratch" (ie. with
overt use of only information presented on that trial). Lexical decision and
naming, however, are commonly reported to be the easier tasks, having lower
error rates (<10%) than explicit recognition (commonly 30%) and far lower error
rates than recall (potentially as high as 100% for free recall). In addition,
responses in the priming tasks are fast (commonly 700ms for lexical decision and
500ms for naming), while, intuitively, deliberate recognition/recall would appear
to be substantially slower. Thus, there is little reason to assume that, given a
situation in which the subject cannot predict the upcoming item, explicit memory
operates quickly/accurately enough to contribute to any increased speed of
response to repeats of earlier items. (This is not to say that no explicit memory
for earlier items exists, and cannot be tapped in other ways, but simply that any
such memory does not contribute to the observed priming effect.)

Secondly, two aspects of the lag paradigm used here would seem to make
the lexical decision and naming tasks employed particularly unlikely to be
influenced by explicit memory. With continuous presentation, "encoding" and
"retrieval" trials (ie. first and second presentations) are intermixed throughout
the list, with no advance knowledge of the trial type possible. Thus, subjects
should be treating first and second presentations in the same fashion (at least
until the item is actually presented), making it less likely that they are
attempting to deliberately recognise second presentations. In addition, all
experiments presented here include at least 1000 trials per subject, giving
little incentive for subjects to employ explicit memory by remembering individual
items.

Thus, there is a strong argument that the tasks and designs used here are
likely to provide priming measures which reflect pure implicit memory. In
addition, there is one experimental technique, commonly used in the literature to
argue that performance on an indirect test reflects the operation of implicit
rather than explicit memory, which is appropriate in the present context. This
technique is that of finding a variable which produces a dissociation between
performance on the indirect test and a corresponding direct test. Having found
such a dissociation, it is then argued that the indirect test cannot have tapped
explicit memory, and therefore tapped only implicit memory. For example, level
of processing (LOP) at study is well-known to affect explicit memory, such that
performance improves with semantic processing relative to structural
processing, but priming is commonly found to be uninfluenced by the type of
processing at study (see Schacter, 1987, for review). The lack of an LOP effect on
the indirect task is then interpreted as showing that performance on the indirect
task was due to the operation of implicit memory only, because, if any explicit
contamination were present, an LOP effect must have been found.
In fact, the interpretation of dissociation data is often more difficult than it first appears. For one thing, differences in experimental factors other than the direct/indirect nature of the test instructions (e.g., differences between the stimuli presented at test in, say, free recall and fragment completion) may contribute to the dissociation. In response to this, Schacter, Bowers & Booker (1989) proposed that all factors should remain constant except for the task instructions: if under these conditions, they say, a dissociation between the direct and indirect test is still observed, the retrieval intentionality criterion has been satisfied and the indirect test can be assumed to have employed unintentional retrieval (implicit memory) only. One way in which this idea has been instantiated has been to contrast performance on stem-completion with that on a stem-cued recall task in which the stems are exactly those presented to the indirectly-instructed subjects.\footnote{Also note for future reference that the retrieval intentionality criterion can be satisfied within a lag paradigm by using an explicit recognition task (i.e., an old/new decision to each item in the continuous list) in place of the "implicit" lexical decision or naming tasks. Stimuli and presentation method would be exactly the same in both cases, and so, by Schacter et al's argument, any dissociation then observed between performance on the explicit task and performance on the priming tasks could be attributed to the explicit/implicit nature of the retrieval induced by the task.}

Strictly speaking, however, the criterion of complete matches for everything except task instructions is not sufficient to ensure that differential patterns of performance on the indirect task reflect implicit memory. While a dissociation under these conditions does allow the conclusion that at least one aspect of the way the subjects performed the task differs (i.e., the indirect task is not measuring exactly the same thing as the comparison direct task) it does not follow that this aspect is necessarily the one the experimenter intended it to be, namely, the implicit or explicit nature of the retrieval (Toth, Reingold & Jacoby, 1994). For example, it has been reported by Jacoby, Toth and Yonelinas (1993) that there is no levels of processing effect in the inclusion task of Jacoby (1991), in which subjects are instructed to complete stems with studied words if possible, but to choose any word otherwise. This task clearly involves the use of explicit memory, and yet performance on it is dissociated from that on stem-cued recall because it fails to show a levels of processing effect (exactly why this is so remains unclear). Thus, finding a LOP dissociation between performance under direct and indirect instructions in a given experiment does not necessarily demonstrate that the indirect instructions have provided a pure measure of implicit memory.

Dissociations between explicit and priming task performance, therefore, should be considered as necessary evidence that a priming task is not simply tapping explicit memory, but not as sufficient evidence that it is tapping purely implicit memory. Good dissociation evidence is based on the closest match between as many aspects of the direct and indirect task as possible (excepting...
the direct/indirect nature of the task itself), but also needs to be backed up by considerations of the likelihood that subjects could or would use explicit memory to produce a given empirically observed priming effect. For this thesis, it was felt that the use of reaction time tasks, the lag paradigm and large numbers of trials would provide reasonable assurance that priming results reflect pure implicit memory; the issue is, however, empirically addressed via a comparison of priming with performance on an explicit recognition task.
Chapter 2

Short term repetition priming

2.0 INTRODUCTION

The two experiments presented in this chapter provide a detailed investigation of priming for words and nonwords over short lags. These experiments considered priming with faster presentation rates, more powerful designs, and better controls for item-specific effects than have been used previously. As discussed in Chapter 1, such conditions were expected to provide the best chance of finding any short term priming lasting beyond immediate repetition. They were also expected to allow the details of the decay of early-lag priming to be examined as a function of target lexicality (if, indeed, any short term priming effect were to be found).

The experiments differed only in the task employed to assess priming, with Experiment 2.1 employing lexical decision while Experiment 2.2 used naming. All other aspects of the experiments were identical. In each experiment, repetition effects for word and nonword targets were measured at lags of 0, 1, 2, 3, 4, 5, 9, 23, and 1050 intervening items. Target items were four-letter and single-syllable, and were either very low frequency real words (Kucera-Francis counts of 1-4 per million) or orthographically legal and pronounceable nonwords. There were 20 items per lag condition, with items cycled through conditions across subjects. A delay of only two seconds was employed between the onset of successive items. The list structure (ie. the order of presentation of the various conditions) was the same across both experiments, and lag conditions were overlapped in order to restrict the complete list to 1100 trials.

2.1 SHORT LAG PRIMING IN LEXICAL DECISION: EXPERIMENT 2.1

Experiment 2.1 examined repetition effects over short lags for low frequency (LF) words and nonwords using a lexical decision task.
2.1.1 Method

Subjects. Eighteen undergraduate students attending the Australian National University participated in return for credit in an introductory psychology course. All subjects in this and subsequent experiments had English as their native language, and had normal or corrected-to-normal vision. In general, subjects participated in no more than one of the experiments reported in this thesis.

Design. A 2x9 repeated measures factorial design was used, with items of both types of lexical status (words and nonwords) presented under nine different lag conditions (0, 1, 2, 3, 4, 5, 9, 23 and 1050 items intervening between repetitions). A priming effect was measured as the reduction in lexical decision time to the second presentation of a target item compared to the first.

Materials. The target words (mostly nouns) were all four letters long, singular and of very low frequency according to the Kucera and Francis (1967) norms (between 1 and 4 occurrences per million). There exists a population of around 240 such words, but a number were excluded from use in the experiment for the following reasons. Some words were judged by the experimenter as likely to have substantially increased in frequency since 1967 (eg. DISK), and some were judged as more common in Australian English than in the American norms. On the other hand, it was felt that some words were so rare that they might be expected to be unknown to many undergraduate students, and thus that subjects would treat them as nonwords. In order to address the latter problem, the results of a previously-conducted lexical decision priming experiment ¹ were used to reject those words to which more than 20% of students (5 out of 24) made an incorrect "no" decision on both presentations. This culling left 180 words available for the pool used for target items. To match this set, a pool of 180 target nonwords was developed. These items were four-letter, single-syllable pseudowords which were pronounceable, and which obeyed the orthographic rules of English. None was a pseudohomophone (ie. homophonic to a real word).

The 180 target words were divided into nine sets, allowing 20 words in each of the lag conditions. The sets were equated on average lexical decision time to the first presentation (obtained from the earlier experiment mentioned above), in order to keep error variation to a minimum. This division and matching process was repeated for the 180 nonwords. An additional 185 words and 185 nonwords were chosen as filler items. These satisfied the same criteria as specified for the target items, except that the words were allowed to have Kucera-Francis frequencies of up to 8 counts per million, and a small percentage of the nonwords were pseudohomophones.

¹ Presented here in Appendix A
All of the target items, but only 10 of the filler items (see below), were repeated in the experimental list, giving a total of 1100 items in the full list (targets: 180 × 2 types × 2 presentations, plus fillers: 180 unrepeated × 2 types + 5 × 2 types × 2 presentations). Within the complete list, the first 50 and last 50 trials were used to present the lag1050 condition, in a blocked "study-test" format. The initial group of 50 contained first presentations of 20 target words and 20 target nonwords, plus two presentations of 5 of the 10 repeated filler items. The final group contained second presentations of the target items, plus two presentations of the other five repeated filler items. The presentation order of the target items differed between the initial and final sets.

The remaining 1000 trials were used to present target items at lags 0 to 23, with lag conditions "overlapped" such that the intervening items for one condition were often critical items from another condition. As noted in Chapter 1, it is necessary to strictly control the presentation order to vary lag in this fashion. To avoid specifying the pattern of conditions for 1000 trials, a number of sequence templates (ie. orders of lag conditions) over a limited number of trials was chosen. Specifically, five templates were selected, each 50 trials long, with each used four times to give 1000 trials. (It was felt unlikely that subjects would show any effect of re-use of response patterns 50 trials long.) Each template contained one occurrence (plus a second presentation) of each of the eight remaining lag conditions (for both words and nonwords), plus 18 unrepeated filler items (nine words, nine nonwords). A different set of filler items was used on each subsequent use of that template. As each lag condition appeared in each group of 50 trials throughout the experiment, any practice or fatigue effects over the 1000 trials should have affected all lag conditions equally.

To avoid a possible confounding of lag with item-specific effects, nine versions of the full experimental list were prepared. In each version, a given set appeared in a different lag condition, thus cycling all items through all lag conditions over the nine versions. The sequence of trial types (eg. a first presentation of a lag3 word, a first presentation of a lag0 nonword, the repeat of the lag0 nonword, a filler, the repeat of the lag3 word, and so on) was the same for all versions. Thus, all versions required the same sequence of yes/no responses, although the order in which particular items appeared varied. See Appendix B for the actual trial-type sequence employed.

**Procedure.** Subjects were tested individually, in a single one-hour session. Each subject was randomly assigned to one of the nine versions of the list, with each version used twice over the 18 subjects. Items were presented using PsychLab software on a Macintosh computer, with a new trial beginning every two seconds. Items remained on the screen until the subject responded via one of two buttons on the keyboard, using the preferred hand for a "yes" (word) decision, and the other hand for a "no" (nonword) decision. The key pressed and the
response latency from onset of the item were recorded. Subjects were instructed
to respond as quickly as possible consistent with being correct. No feedback was
given regarding accuracy or speed. If subjects had not responded within two
seconds, the next trial commenced; subjects were instructed that, should this
happen, they could ignore the item they had missed.

The experiment was preceded by a practice trial containing 28 five-letter
words and nonwords. Following this, the experimental list was presented in four
blocks, of 300, 250, 250 and 300 trials. (By using multiples of 50, ie. the length of
each sequence template, the splitting of first and second presentations across
blocks was avoided in the eight shorter lag conditions.) Each block took
approximately 9 minutes to complete, and a short break was allowed between
blocks. The total time taken to present all experimental trials, and thus the time
between presentations in the lag1050 condition, was approximately 45 minutes.

2.1.2 Results and discussion

Repetition priming is shown in Figure 2.1 as a function of lag (the number
of items intervening between presentations) for all but the lag1050 condition.
Means for all conditions are given in Table 2.1. Reaction times for a target item
were excluded if they were <300 ms or >1200 ms, or if either response made to
the target was incorrect. Error rates in the critical conditions (including errors to
either or both presentations) were 6.3% for words, and 4.2% for nonwords. The
percentage of items excluded as outliers was 1.3% for words and 1.7% for
nonwords. Average decision times for first presentations were 659ms for words
and 704ms for nonwords.

It appears from Figure 2.1 that priming for words has two components: a
short term (ST) labile component which decays rapidly (but smoothly) with
intervening items until perhaps lag4 (10 secs), and a longer term (LT)
underlying component of around 50ms which appears stable for up to at least 23
intervening items (48 secs). For nonwords, a positive ST component is visible
only with immediate repetition (lag0), while the presence of any intervening
items apparently leaves only a LT priming effect of around 45 ms. As expected
from an examination of Figure 2.1, a two-way ANOVA including all eight lags
and target type (word or nonword) found a main effect of lag (F(7,119)=17.6,
MSe=2126, p<.001), a main effect of target type, such that words showed more
priming, on average, than nonwords (F(1,17)=26.1, MSe=1726, p<.001), and an
interaction between lag and type (F(7,119)=3.6, MSe=1407, p<.01). Given this
interaction, the pattern of decay was subsequently investigated for words and
nonwords separately.
Table 2.1: Data from Experiment 2.1 for the lexical decision task, including: mean reaction times for first presentations (f), second presentations (s) and priming (p) in ms. Also shown are error rates to first (ef) and second (es) presentations.

<table>
<thead>
<tr>
<th></th>
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<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
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<th>lag6</th>
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<td>4%</td>
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<td>6%</td>
</tr>
</tbody>
</table>

Note: The mean priming does not necessarily equal the difference between the means of first and second presentations, as priming for an individual item was only calculated where both responses to that item were correct.

Figure 2.1. Repetition priming (ms) as a function of lag in Experiment 2.1. Targets were low frequency words (LF words) and word-like nonwords. The average error of the mean is indicated via the error bar shown. Mean lexical decision times were 659 ms for words, and 704 ms for nonwords.
Words. Planned orthogonal contrasts, known as Helmert contrasts (Norusis, 1988), were conducted comparing priming at each lag to the average level of priming across all subsequent lags. This procedure provides some indication of where the decay apparent in Figure 2.1 stops, although it is limited in terms of detecting overall decay when successive values do not differ by very much. Values and significance levels of Helmert contrasts are presented in Table 2.2, from which it can be seen that decay of priming occurred over the first few items (significant decay followed lags 0, 1 and 3) consistent with the existence of a short term priming effect lasting beyond immediate repetition. This ST component had disappeared by lag4 (no further decay took place beyond this point), leaving a stable LT value.

Figure 2.1 gives some hint as to the shape of this ST decay: the fact that the fall off from one lag condition to the next decreases with increasing lag suggests that the decay is exponential. An exponential curve was fitted by the least squares method to the word means, giving an equation of:

\[ p = 93.5 \times e^{-0.63l} + 49.1 \]

where \( l \) is the lag, and \( p \) the amount of priming observed in milliseconds. The variance of the predicted means for the eight lags (\( MS_{\text{fit}} \)) was 926 ms\(^2\), and the variance of the actual means (\( MS_{\text{total}} \)) was 949 ms\(^2\), indicating that 98% of the variance in the observed means was accounted for by the exponential fit. The exponential function suggests that a ST priming effect, initially of 93.5ms (with a standard error of 8.0ms), is superimposed on a LT constant value of 49.1ms. It also implies that, given the decay constant of 0.63 (s.e.=0.14), the ST effect decays to 10% of its initial value after around 3.7 intervening items (9.3 secs), confirming the results of the Helmert contrasts; these indicated that decay continues until roughly lag4. Finally, the exponential fit allows a powerful test of the significance of long term priming: the LT value of 49.1ms was found to have a standard error of 4.9ms, giving a 95% confidence interval of 36.6ms to 61.6ms, and indicating that, as would be expected from Figure 2.1, significant LT priming was present.

Nonwords. Helmert contrasts for the decay of nonword priming are also shown in Table 2.2. Again, the analysis confirmed the pattern apparent in Figure 2.1: significant decay occurred only after lag0, demonstrating an immediate repetition effect followed by decay to a stable baseline with one intervening item. In fact, this interpretation may be an oversimplification: although the effect was far from significant, the negative contrasts at lags 1 and 3 hint that priming at intermediate lags may actually dip below the long term value. Confirmatory evidence of this dip will be presented in some of the later experiments.
**Short term repetition priming**

Table 2.2: Contrasts (in ms) between priming at each lag and average priming at subsequent lags, for Experiment 2.1.

<table>
<thead>
<tr>
<th>value of contrast (ms)</th>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
<th>lag9</th>
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<td>24</td>
<td>13</td>
<td>1</td>
<td>-7</td>
</tr>
<tr>
<td>F-value</td>
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<td>11.0**</td>
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<td>5.1*</td>
<td>1.5</td>
<td>&lt;1</td>
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<tr>
<td>nonwords</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>1</td>
<td>-15</td>
<td>-1</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>F-value</td>
<td>78.2**</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>1.8</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Note: ** = p<.01; * = p<.05; MSe = 1593 (words), 1941 (nonwords)

Lag1050 priming. It should be noted that the "long term" of the priming components shown in Figure 2.1 was not tested over particularly long delays: we can only conclude from the results presented so far that it lasts at least a minute or so. In order to determine whether priming lasts as long as 45 minutes, results of the lag1050 condition can be examined. Unfortunately, a substantial practice effect was observed during the experiment, indicating that the reaction times to first and second presentations of items in the lag1050 condition are not directly comparable. The raw priming effects observed for words and nonwords at lag1050 were 59ms and 52ms, respectively, but there was an average decrease during the experiment in reaction times to first presentations of 39ms for words, and 42ms for nonwords. This would suggest that priming after 45 minutes was, in fact, around 20ms for words, and 10ms for nonwords. From this, it might be tentatively concluded that LT priming decays slowly over 45 minutes, but that there is still a moderate effect left after this time.² This interpretation agrees with the common finding of very long term priming, at least for words.

Error analysis. Collapsing over lags 0 through 23, it was found that more decision errors were made to first presentations of words (8.4%) than to second presentations (4.4%). For nonwords, however, the error rate for first presentations (3.9%) was very similar to that for repeats (4.2%). This pattern of errors appears to reflect an initial difficulty in recognising the low frequency word stimuli as words, which was overcome on the second presentation.

In order to investigate any relationship between the patterns of priming observed over lags and error rates at these lags, a two-way ANOVA was conducted on the error scores for second presentations of targets. Error rates to first and second presentations are included in Table 2.1. The ANOVA revealed

² Due to the severe confounding of lag1050 priming with practice effects, the results of this condition will not be discussed for later experiments.
no effect of lag (Wilks' $\lambda = .475$, $F(7,11)=1.74, p>.1$), no effect of lexical status ($F<1$), and no interaction between the two ($F(7,119)=1.3, MSe=0.9, p>.2$). Thus, the pattern of priming scores reported above cannot be attributed to changes in error rates across lags.

**Summary.** Two components of priming have been identified: a long term effect showing no decay over at least 48 seconds (with possible slow decay over 45 minutes), and, more interestingly, an additional short term effect lasting roughly 8-10 seconds (three or four intervening items) for words and 2 seconds (a single intervening item) for nonwords. The decay of the ST effect appears to be qualitatively different for items of different lexical status: exponential for words but sudden for nonwords. The existence of a separate ST effect agrees with the findings of previous studies using a continuous lexical decision procedure (Bentin and Moscovitch, 1988; Kersteent-Tucker, 1991; Kirsner and Smith, 1974; Monsell, 1985; Ratcliff, Hockley and McKoon, 1985; Scarborough, Cortese and Scarborough, 1977), but the present results extend these findings in showing that, for words at least, this effect lasts beyond immediate repetition.

### 2.2 SHORT LAG PRIMING IN NAMING: EXPERIMENT 2.2

The sharp difference between the decay patterns of ST priming for words and nonwords in Experiment 2.1 may have important implications for any theoretical interpretation of ST repetition effects. However, one rather uninteresting potential explanation of the observed lag x lexicality interaction should be considered before any such interpretation is attempted. This is simply that, in the lexical decision task used in Experiment 2.1, opposite decisions are made to the two types of items; the lag x lexical status interaction in ST priming may have nothing to do with priming of a representation of the target per se, but may be due to some record of the decision. A standard way (eg. Andrews, 1992) of determining whether results gained with a lexical decision task reflect merely the operation of a decision procedure is to repeat a lexical decision experiment using a naming task in which the subject is required to read each item aloud as quickly as possible. The logic here is that, since both lexical decision and naming require processing the target item but naming does not require a decision, factors affecting the two tasks in the same way can be interpreted as being independent of decision processes. Thus, in order to determine if the ST repetition effect

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3 Throughout this thesis, MANOVA results have been presented where the data violated the sphericity assumption of repeated measures ANOVA.
identified with lexical decision is specific to the decision task, Experiment 2.1 was repeated with priming assessed by a naming task.

2.2.1 Method

**Subjects.** Fifteen subjects were undergraduate students of the Australian National University who participated in return for credit in an introductory course. A further four subjects were graduate student volunteers from the Psychology department. One undergraduate subject was removed due to excessive error rates, leaving a total of 18 subjects.

**Materials and Procedure.** The experimental lists and presentation were exactly as described for Experiment 2.1. Across the 18 subjects whose data were retained, each of the nine versions of the list was used twice. The only difference from Experiment 2.1 was the task used: the subject was required to read each item aloud into a microphone, as quickly and accurately as possible. Naming time was measured as the latency from onset of the stimulus to onset of the response, and any errors in pronunciation were noted by the experimenter. For nonwords, where there was not always a clearly “correct” answer, a mispronunciation was recorded if the pronunciation chosen was different from all those of that letter grouping which appear in real words (e.g., FINT was accepted if said to rhyme with MINT or PINT, but not if said as FENT). In addition, an error was recorded when the subject added, missed or swapped letters, or changed their pronunciation on the second presentation.

2.2.2 Results and discussion

For the naming data, reaction times were excluded if they fell more than three standard deviations above the mean for each subject \(^4\), if the subject mispronounced the item, or if the microphone was triggered by an extraneous noise. Data were discarded from one subject who misread 20% of the nonwords (replacing almost all with similarly spelled real words), and whose reaction times were roughly 300ms slower than those of the other subjects. The average “error” rate for the remaining 18 subjects (including both genuine errors and technical faults) was 3.4% for words, and 5.3% for nonwords \(^5\). An additional 1.4% of words and 3.0% of nonwords were excluded as outliers. Mean naming times to first presentations were 495ms for words and 517ms for nonwords.

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\(^4\) A different method of determining outlier cutoff points was used in analysing the naming data because a) naming was much faster than lexical decision and b) there was more inter-subject variability.

\(^5\) Unfortunately, no further analysis of errors in naming is possible, as sessions were not taped, and, with the rapid presentation rate employed, it was not possible to fully code errors online.
Figure 2.2: Priming (ms) as a function of lag in Experiment 2.2, using a naming task, for LF words and nonwords. Mean naming times to first presentations were 495ms for words and 517ms for nonwords.

Priming in the naming task is shown in Figure 2.2 (and Table 2.3). The most obvious difference between the lexical decision and naming results is that the overall magnitude of priming in the latter is very much smaller. This difference in scale will be returned to shortly. The important finding apparent in the naming data, however, is that the patterns of decay for words and nonwords are similar to those found with lexical decision: the words show gradual decay over the first three or so items to a constant LT effect, while the nonwords show substantially more priming at lag 0 than at longer lags. An 8x2 ANOVA revealed a main effect of lag ($F(7,119)=3.95, MS_e=422, p<.01$), a marginal effect of lexical status with the nonwords showing slightly more priming than the words ($F(1,17)=3.27, MS_e=316, p<.1$), and an interaction between lag and status (Wilks' $\lambda = .342, F(7,11)=3.02, p<.05$). Separate analyses were subsequently conducted for words and nonwords.

Words. Helmert contrasts for the word data are presented in Table 2.4. These show that decay occurs after lags 0, 1 and 2, with some hint of further decay after lag 3. However, in agreement with the lexical decision data, no further decay took place after lag 4, indicating that the ST effect had dissipated
by this time. Again, the decay seems most rapid at the earliest lags, and an exponential decay of the form

\[ p = 18.9 e^{-0.44l} + 9.2 \]

gave a good fit to the data, with 84% of the variance in the observed means accounted for by the exponential function (MSfit=37.32, MSTotal=44.47). This function indicates a ST component of 18.9ms (s.e.=3.9) at lag0 superimposed on a stable priming effect of 9.2ms. The LT priming effect was found to be significantly greater than zero (s.e.=2.3ms, 95% confidence interval = 3.3ms to 15.2ms).

**Nonwords.** Helmert contrasts for nonwords are also shown in Table 2.4. As was the case with lexical decision, there is substantial decay following lag0, but no further decay beyond this point, suggesting a sudden decay to a stable baseline. However, again note the hint of a "dip" below the long term priming value at intermediate lags of 2, 3 and 4 intervening items.

*Table 2.3:* Reaction times and priming scores from Experiment 2.2 for the naming task. (No error analysis was possible here.)

<table>
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<th></th>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
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*Table 2.4:* Contrasts (in ms) between priming at each lag and average priming at subsequent lags, for Experiment 2.2.

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<td>6.0*</td>
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<td>-1.6</td>
<td>3.9</td>
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<tr>
<td>F-value</td>
<td>16.2**</td>
<td>&lt;1</td>
<td>1.9</td>
<td>1.2</td>
<td>2.8†</td>
<td>&lt;1</td>
<td>&lt;1</td>
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</table>

Note: ** = p<.01; * = p<.05; † = p<.1; MS_e = 272 (words), 459 (nonwords)
Comparison of lexical decision and naming. The results of Experiments 2.1 and 2.2 agree on the most important issues, namely the existence of a ST repetition effect and the qualitative differences found between the decay patterns for words and nonwords. In both experiments, the initial magnitude of the ST effect for words was around twice the LT priming value, and the decay constants for word priming agree fairly well across lexical decision (0.63; s.e.=0.14) and naming (0.44; s.e.=0.17), indicating that the ST priming effect had roughly the same duration in the two tasks. In addition, Experiments 2.1 and 2.2 agree that ST nonword priming disappears with a single intervening item. These results indicate that the effects of lexical status that were obtained with the lexical decision task are not specific to that task.

The lexical decision and naming data differ in two ways which should be considered. First, the absolute magnitude of the priming effects in naming was substantially smaller than in lexical decision. A likely explanation of this result is simply that the reaction time to the first presentation of an item was faster in naming than in lexical decision (naming: words=495ms, nonwords=517ms; lexical decision: words=659ms, nonwords=704ms). It seems reasonable that the amount of priming would partially depend on the initial speed of response: a slower initial response should allow more "room for improvement" on the second occasion.

Secondly, the relative magnitude of the word and nonword LT priming effects appears to depend on the task. With lexical decision, no difference in LT priming was apparent between words and nonwords ($F(1,17)=2.92$, $MS_e=1276$, $p>.1$ on a comparison of lags 4 to 23), while, with naming, nonwords show more LT priming than words ($F(1,17)=9.25$, $MS_e=363$, $p<.01$). While equivalent decay patterns in lexical decision and naming over very short lags indicate no effect of a decision process on the short term priming component, the difference in pattern found at longer lags may reflect the influence of a decision process on the long term component. The observed task difference for LT priming is consistent with the view that lexical decision underestimates such priming for nonwords. With lexical decision, prior presentation of a target nonword may produce competing positive and negative effects on the ease of making a decision: the processing of an incoming nonword may speed up on a second occasion (an "access" effect), tending to lower response time, while at the same time its increased familiarity may make it more difficult to reject as a word (a "decision" effect), thus tending to raise the response time. However, in a naming task, where no decision process is involved, faster processing and increased familiarity should be working in the same direction to produce faster responses. For real words, these two influences work in the same direction regardless of the task, having the effect of raising the level of nonword priming (relative to words) in naming compared to lexical decision.
Summary. Despite some differences between naming and lexical decision in terms of long term priming and the overall magnitude of priming, the important conclusion to be drawn from this experiment is that the dissociation between the short term decay patterns observed for words and nonwords in this experiment matches that found in Experiment 2.1. Short term priming in naming seems to be essentially a scaled down version of that found with lexical decision. This implies that the lag × lexical status interaction obtained in Experiment 2.1 did not occur merely because a "no" decision was being made to the former type of item and a "yes" decision to the latter.

2.3 CONCLUSIONS

Decay patterns of early-lag priming were found to be very similar across the two experiments presented in this Chapter, with both lexical decision and naming tasks revealing smooth decay over roughly 3 intervening items (8 seconds) for words but precipitous decay to (or perhaps slightly below) a stable long term value with a single intervening item for nonwords. These results differ from the conclusions commonly drawn from previous studies in that, here, ST priming (for words, at least) survived beyond lag0: earlier studies have generally concluded that a labile effect is present only with immediate repetition.

One likely explanation of this discrepancy is that most previous studies have used relatively long delays between presentations of successive target items. A lag of 1 item corresponds to a time delay of 8 to 10 seconds with the commonly-used 4 or 5 seconds between stimuli, and, given the present results showing no ST effect beyond 8 seconds (lag3 here), it is perhaps not surprising that little effect was present at lag2 or beyond with these longer inter-item delays. In addition, as was noted previously, most earlier papers do show some trend towards more priming at (at least) lag1 compared to later lags, and the fact that this effect was generally not significant (if it was tested) may partly reflect low power in these previous designs.

Given that ST repetition effects have been demonstrated to last beyond lag0, it is apparent that ST priming does not simply reflect a temporary "buffer" used for storing the last item processed. A more interesting interpretation of the effect arises from the finding of an interaction between lag and lexical status. A priori, it would seem that a short-lived priming effect could be due to a trace of the stimulus left at any or all of a number of possible levels. At a rather low level, ST priming could result from a purely visual record of the target item; this view, however, would predict no influence of lexical status, as, visually, words and nonwords are equivalent stimuli. At a much higher level, ST priming could
represent an explicit memory phenomenon, such as the deliberate rehearsal of target items in an auditory loop; again, this view would not seem to predict any influence of lexical status. Instead, the observed dissociation between word and nonword priming appears to locate the ST repetition effect reported here as a lexical-level phenomenon, presumably reflecting traces left within the word recognition system. (The reader should be reminded here that a "lexical" level of processing does not mean that priming need be specific to words; the term is meant merely to distinguish word-like processing from other domains, such as visual records, object recognition processes, face recognition processes, letter identification, and so on. As discussed at length in Chapter 1, there is every reason to assume that pseudowords are able to access lexical representations.)

The ST repetition effect revealed in the present experiments is consistent with an effect produced by temporary changes in the state of lexical representations. These changes could perhaps be envisioned as arising (depending on the preferred model of word recognition) through the effects of leftover activation, increments in resting-levels, decrements in thresholds, or biases in link weights, on representations in the form of whole-word nodes, sub-word nodes, or hidden units. It should be noted that this style of explanation relies on the assumption that ST and LT priming are separate effects arising from different processes, as it is highly unlikely that long-lived priming could result from such mechanisms (see Chapter 1, Section 1.1.7).

Prima facie, the reported decay patterns suggest that priming can be divided into two components. One is relatively stable and long-lived, and presumably corresponds to the standard repetition priming effect which is known to last for hours or more. The other is short-lived, and lasts between 2 and 8 seconds (0 to 3 intervening items), a duration consistent with some form of transient change in the state of lexical representations. The observed priming at each lag, then, would be the sum of these two components: at early lags, both ST and LT priming contribute to the total repetition effect, while at longer lags the ST effect has decayed completely and only the LT component contributes.
Chapter 3

Distinguishing short term priming from long term priming

3.0 INTRODUCTION

Chapter 2 presented evidence of a repetition priming effect at short lags, in addition to longer-lived priming. It was proposed that this short-lived effect might be produced by a mechanism different from that underlying standard repetition priming. However, the argument that ST and LT priming reflect different processes relied purely on the apparent differences in the decay rate of the two effects, and even this finding was not completely convincing: the conclusion that "long term" priming decays only very slowly (if at all) was based on only a few lag conditions with delays of up to only 48 seconds. Clearly, then, if ST and LT priming are to be attributed to different mechanisms, stronger evidence of a dissociation between them is needed. The present Chapter reports two experiments which provide such evidence.

Experiment 3.1 examined the decay rate of long term priming, from delays of 20 seconds (lag9) through to 40 minutes. This experiment confirmed that the decay of LT priming is many times slower than the decay of ST priming. Experiment 3.2 investigated the relative influence of word frequency on short and long term priming, by examining priming for high frequency words over lags 0 to 23. This experiment is reported here because it found that word frequency affects only LT priming. Thus, the research described in the present chapter dissociates ST and LT priming on the basis of both decay rate and the influence of word frequency.

In addition, this Chapter presents a combined analysis of those experiments reported in Chapters 2 and 3 which examined ST priming (Experiments 2.1, 2.2 and 3.2). This combined analysis demonstrates that, regardless of task or word frequency, ST priming for words and nonwords took a very similar form across the three experiments.
3.1 DECAY RATE OF LONG TERM PRIMING: EXPERIMENT 3.1

Experiments 2.1 and 2.2 documented the decay of repetition effects over fairly short lags, with delays of between 2 and 48 seconds (lags 0 - 23). In discussing these results, there was a general assumption that the ST priming effect identified was additional to a LT priming effect, and that this LT priming was the standard repetition effect revealed with the more common study-phase / test-phase design. However, such two-phase designs require a relatively long delay between repeats - at least one minute, and commonly several minutes or more.

Only one lag condition used in the first two experiments, namely lag1050, tested priming at delays of longer than one minute, and, as discussed earlier, priming at this lag was highly confounded with practice effects over the whole experiment. Therefore, Experiment 3.1 examined priming effects over delays of up to 40 minutes, with controls for practice effects where appropriate at very long delays. The primary aims were to confirm that the decay rate of long term priming is, as was suggested by the first two experiments, substantially slower than that observed over lags 0 to 4, and to investigate whether this decay rate is slow enough to make priming at lags 5 to 23 consistent with the standard LT repetition priming effect. A finding of only very slow decay of priming following lag23 would support such an interpretation.

Experiment 3.1 employed a lexical decision task. It was designed to be as similar as possible to Experiment 2.1 in all aspects except the number of items intervening between target repeats. The target items were the same LF words and pseudowords as used in the experiments reported in Chapter 2. The block structure of the earlier experiments was retained, that is, four blocks of about 10 minutes each, and the presentation rate remained the same. However, the order of presentation was changed to allow priming to be measured at delays of 2, 5, 10, 20, 30 and 40 minutes. These corresponded to item lags of roughly 60, 150, 250, 500, 750 and 1000 items respectively. In addition, 20-second and 48-second delay conditions were included, to allow points of comparison with the lag9 and lag23 "long term" priming values obtained in Experiment 2.1.

3.1.1 Method

Subjects. Twenty-four undergraduate subjects participated in return for course credit. Three of these were excluded due to excessive error rates, leaving 21 subjects.
**Design.** Time between repeats (20 and 48 seconds, and 2, 5, 10, 20, 30 and 40 minutes), and lexicality of target (word, nonword) were varied within subjects. The dependent variable was the amount of priming in a lexical decision task.

**Stimuli.** For the four shorter time-delay conditions, priming was measured, as in Experiment 2.1, as first minus second lexical decision times. For the four longer delay conditions, however, priming was measured relative to a baseline of unrepeated items presented at the same average position in the list as the repeats. This was done in order to avoid confounding item-specific priming with any overall practice (or fatigue) effects present in the experiment. (On the basis of the practice effect observed in Experiment 2.1, we would expect only very small influences of practice on measured priming at the four shorter lags: around 3ms with 5 minutes between repeats. However, this might be expected to rise to around 20ms in the 40-minute condition.)

This design meant that there were twelve conditions to which items had to be assigned: 20 secs (lag9), 48 secs (lag23), 2 mins (=lag60), 5 mins (=lag150), 10 mins (=lag250), 20 mins (=lag500), 30 mins (=lag750), 40 mins (=lag1000), and baseline conditions for 10 mins, 20 mins, 30 mins and 40 mins. There were 17 items per condition, requiring a total of 204 words and 204 nonwords. The critical items were a superset of the 180 (of each lexical status) chosen for Experiment 2.1. The additional items were also pseudowords or LF words (1-4 occurrences per million), and were chosen from an extra 60 critical items of each status used in an earlier experiment (see Appendix A). The additional LF words were expected to be less familiar than those used in Experiment 2.1, as they were items on which between 15% and 25% of subjects had made the wrong decision on both presentations. Each group of 204 words or nonwords was initially divided randomly into the twelve sets of 17 items; these were then tidied up to equate word frequency and initial response time (from the experiment reported in Appendix A) across each set, in order to reduce error variance to a minimum.

The 23-second, 48-second, 2-minute and 5-minute conditions, for both words and nonwords, appeared throughout the list in an overlapped fashion. However, the 10-, 20-, 30- and 40-minute conditions were blocked, so that all the first presentations of each of these conditions appeared together at one point in the list. All second presentations then appeared together (in a different order with different filler items) later in the list, intermixed with the unrepeated

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1 The use of separate baselines in the four shorter lag conditions would have required further reducing the number of items per condition, given the limited availability of target items.

2 Thus it might be anticipated that slower overall reaction times and/or higher overall error rates would be found in the present experiment than were reported in Chapter 2. Note that the less familiar items were evenly distributed over lag conditions, and so no difference in pattern over lag was expected.
baseline items for that condition. (For example, all first presentations in the 40-minute condition appeared close to the start of the list, and all second presentations and baseline items appeared at the end.)

The total number of trials in the list was 1000 (broken into four blocks of 250 trials for presentation). Of these, 680 were needed to present critical items from the conditions of interest, including repeats where appropriate. The additional 320 filler items were 160 unrepeated words, and 160 unrepeated nonwords. These were subsets of the fillers used in Experiment 2.1.

Twelve versions of the full list were prepared, with the assignment of items to conditions cycled over versions. Two subjects received each version. As in the earlier experiments, the order of presentation of conditions was the same for all versions.

**Procedure.** All details of the procedure were as for Experiment 2.1.

### 3.1.2 Results and Discussion

Data from three subjects who erroneously classified more than 20% of the target real words as nonwords were discarded. Mean error rates for the remaining 21 subjects across the conditions of interest were 8.8% for words, and 5.2% for nonwords. Outlying reaction times were discarded if they were <300ms or >1200ms; this procedure removed 2.6% of the word data, and 3.2% of the nonword data. The mean decision times to first presentations were 690ms for words, and 739ms for nonwords.

As noted above, priming was calculated relative to first presentation time for the 20-second through 5-minute conditions. For the 10-minute through 40-minute conditions it was calculated relative to a separate set of baseline items, in order to avoid confounding priming with generalised practice effects. Priming is plotted in Figure 3.1 as a function of time between repeats (in minutes) and lexicality of the target item. (Reaction times to first and second presentations are given in Table 3.1; note here that second presentation times would be expected to be partly influenced by practice effects at the longer lags.) In Figure 3.1, the two shortest time delays are both less than one minute (lags 9 and 23), and, for the words, the data points lie almost on top of each other. As would be expected from this figure, a two-way ANOVA revealed that priming was significantly influenced by lexical status of target (F(1,20)=119.3, MS_e=1727, p<.001), such that words showed more priming than nonwords, and by delay (F(7,140)=6.9, MS_e=2089, p<.001), such that a slow decline in priming was apparent over time.
Figure 3.1: Decay of lexical-decision priming over long delays in Experiment 3. Mean decision times to first presentations were 690ms for low frequency (LF) words, and 739ms for nonwords.

It is not clear what the shape of the decay of the priming effect is, or whether it differs for words and nonwords. The full ANOVA revealed an interaction between time delay and lexicality that approached, but did not reach, significance \( F(7,140)=1.9, MS_e=2204, p=.074 \). Figure 3.1 does not demonstrate a consistent difference in the pattern of decay for words and nonwords, and it might be that this possible interaction reflects the nonsensical finding that 20-second priming for nonwords was slightly negative, and nearly 30ms smaller than priming in the 48-second condition; indeed, removal of the 20-second points from the analysis destroyed any hint of an interaction \((F=1)\). On the assumption that no genuine interaction exists, the word and nonword data were collapsed to give a better idea of the shape of the decay of LT priming over time. A trend analysis on the collapsed data revealed significant linear \((F(1,20)=15.4, MS_e=1986, p<.01)\) and quadratic components \((F(1,20)=11.4, MS_e=639, p<.01)\), which might indicate that the decay of priming gradually slows down. This is not to say, of course, that the initial decay is very fast: even under the most generous interpretation of the pattern apparent in Figure 3.1, priming for words appears to require a 10 minute delay to reach approximately half of the value it held after 20 seconds.
Table 3.1: Mean lexical decision times (in ms) and error rates for Experiment 3.1, across delays of 20 seconds to 40 minutes. Data shown are for first presentations (f, ef), second presentations (s, ef), baseline items for the 10–40 min delays (b, eb) and priming (p). The average standard error for priming was 10.6 ms.

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Note: For delays of 20s to 5m, the baseline for priming was the decision time to first presentation.

Comparison with literature on standard LT priming. After 40 minutes, priming for words is still substantially above zero (maybe 40ms), while priming for nonwords has been greatly reduced. Both of these findings are consistent with the existing literature on standard (LT) repetition priming in lexical decision: priming remains high for LF words even with long delays, while LT priming for pseudowords disappears more rapidly.

The zero or slightly negative priming for nonwords at 30-and 40-minute delays is also consistent with pre-existing literature. While priming for nonwords is found to remain positive for long periods with other tasks, LT priming for nonwords in lexical decision has been observed to be sometimes positive, sometimes slightly negative and sometimes zero (see Bowers, 1994, for a summary of the relevant literature). The usual explanation of negative priming for nonwords (eg. Feustal, Shiffrin & Salasoo, 1983) is that a record of the
target's previous presentation is still present, but that the effect of increased familiarity of the nonword (biasing a "word" response) has overcome facilitation for the processing of the target item. Presumably, if the magnitudes of these opposite "access" and "decision" influences are equal, there will be no observed priming. Thus, it is not clear that the trace underlying LT priming of nonwords, had, in fact, disappeared by the time priming was observed to reach zero in the present experiment.

Comparison with Experiment 2.1. A comparison of the magnitude of priming for words in the present experiment with that found in Experiment 2.1 shows a higher than expected priming effect for lags 9 and 23, at around 80 ms: given that these were the same conditions as included in Experiment 2.1, the priming effect might be expected to be around the 50 ms that it was in that experiment (see Figure 3.2). One likely reason for this discrepancy is that the initial reaction times were substantially slower than in the earlier lexical decision experiment (690 ms here versus 659 ms previously for words, and 739 ms versus 704 ms for nonwords). Such a finding might have arisen due to the addition of new LF words which were likely (based on their error rates in the experiment from which they were selected) to be less familiar to subjects, and thus to have increased the difficulty of lexical decisions, or simply because subjects in the present experiment had poorer lexical skills. Either interpretation is supported by the increased error rates observed in the present experiment (8.8% versus 6.3% for words, and 5.2% versus 4.2% for nonwords). However, whatever the reason for the slower initial reaction times, the finding of more priming for words in the present experiment is at least empirically consistent with the finding reported in Chapter 2 that priming is larger when initial reaction times are slower.

For nonwords, in contrast, the priming at lags 9 and 23 (and at 2- and 5-minute delays) is substantially smaller than was found previously (perhaps 20ms, compared to roughly 50ms). This seems especially strange given that the initial reaction times were, as for the real words, longer in this experiment, suggesting that, if anything, a larger priming effect should have been found. At this stage, the reason for this discrepancy is unclear, but Experiment 4.2 will present evidence that the lowering of the long term priming value is likely to have been due to the reduced number of close repeats employed in the present experiment.3

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3 For nonwords, it must be assumed that this effect was strong enough to outweigh the presumed advantage of longer initial-presentation decision times.
A comparison of the decay rates of ST and LT priming across Experiments 2.1 and 3.1 can be made by examining Figure 3.2. While the relative magnitudes of LT priming differ considerably across the two experiments, it can be seen that the long-lag decay in Experiment 3.1 is substantially slower than the decay for ST priming in Experiment 2.1. (Note the use of a log scale for the time axis - this is necessary to display all times clearly, but makes the decay rate at longer times appear faster than in fact it is.) The difference in decay rates can be estimated by comparing the average decay rate for ST priming with that for LT priming. Short-term priming decayed at an average rate of about 10 ms/second (ie. by 100 ms in 10 seconds). Long-term priming, on the other hand, appears to decay at a rate of around 1 ms/minute (ie. by 40 ms in 40 minutes), the equivalent of \( \frac{1}{60} \) ms/second. In other words, ST priming appears to decay of the order of 600 times faster than LT priming.

Conclusions. The present results indicate that the decay rate of priming after lag9 (20 seconds) is far slower than that of the ST effect reported earlier (which disappeared within 8 to 12 seconds). This finding dissociates ST and LT priming on the basis of decay rate more clearly than has been done previously. In addition, the magnitude of the priming effects observed here are consistent with the view that the "longer" lag priming identified in the earlier experiments (ie. lag4 or 5 onwards), is, as was earlier assumed, the standard long-lived repetition priming effect. This identification provides support for the earlier assumption that the mechanism responsible for such LT priming operates at all
Short term priming and long term priming

lags, and that the total priming at lags less than about 5 is given by adding any ST priming to this underlying value.

Thus, the present experiment has successfully addressed the two questions of primary interest. It has, however, left three ancillary issues only partially resolved. Specifically: the exact shape of the decay of the LT priming effect remains unclear; there is some doubt regarding whether priming for nonwords genuinely dissipates before priming for words; and the differences in the relative magnitudes of word and nonword priming between this Experiment and Experiment 2.1 have not been fully explained.

3.2 SHORT LAG PRIMING FOR HIGH FREQUENCY WORDS: EXPERIMENT 3.2

Experiment 3.1 has provided clearer evidence than was previously available that ST and LT priming can be differentiated on the basis of decay rate. Experiment 3.2 investigated the effect of word frequency on ST and LT priming; the experiment is reported here because a manipulation of frequency was found to dissociate the two effects.

While the present Chapter (and the next) is organised around a "memory" approach to ST priming, and thus concentrates on dissociations from other forms of memory, the original reason for manipulating word frequency was based on a "perceptual" approach. The effects of lexical status reported in the previous Chapter indicate that ST priming is of relevance to the operation of the word recognition system. Given the strong effects of this variable in Experiments 2.1 and 2.2, it would seem of interest to eventually investigate ST priming as a function of a number of other properties of target items known to influence lexical decision and naming tasks. Potentially, these properties include a wide range of variables such as frequency (eg. Scarborough et al., 1977), neighbourhood size (eg. Coltheart, Davelaar, Jonasson & Besner, 1977; McCann & Besner, 1987), regularity of pronunciation (eg. Andrews, 1982; Baron & Strawson, 1976) and orthographic regularity of nonwords (eg. Chambers, 1979; Coltheart et al., 1977). Of these, frequency is perhaps the most fundamental, and certainly the most commonly investigated.

Experiment 3.2 examined the effects of word frequency on ST repetition by repeating Experiment 2.1 with the very low frequency words which were previously employed replaced with very high frequency words (an average of 275 counts per million). All other aspects of the present experiment were the
same as for Experiment 2.1. In particular, the nonword stimuli were the same 180 pseudowords, and the task (lexical decision), presentation rate (two seconds per item) and lags (0, 1, 2, 3, 4, 5, 9 and 23) remained unchanged.  

3.2.1 Method

Subjects. Eighteen undergraduate subjects, from the pool described in Experiment 2.1, participated for payment of $6.

Materials and Procedure. The design of the experiment, the nonword stimuli, the list structure (i.e. order of conditions and of yes/no responses), and the task (lexical decision) were exactly as for Experiment 2.1. Again, nine versions of the list were used, with two subjects given each version. The only departure from Experiment 2.1 was in the real word stimuli: these were of very high frequency rather than of very low frequency. A list of 180 target words ranging from 70 to 967 counts per million (mean=275) were selected from the Kucera and Francis (1967) norms, and divided into 9 sets of 20 items each. These sets were equated on frequency and neighborhood size, using Coltheart's N (Coltheart et al., 1977), and then assigned to each of the nine lag conditions across each list version, as described in Experiment 2.1. In addition, high frequency filler words replaced the low frequency fillers used in Experiment 2.1. These had a minimum frequency of 32 counts per million. Nonword stimuli (targets and fillers) maintained the positions they had previous occupied in each list version.

3.2.2 Results and Discussion

Priming in lexical decision for HF words and for nonwords is shown in Figure 3.3, and Table 3.2 (note again that the nonwords are exactly the same items used in the previous two experiments). Reaction times were removed if they were <300ms or >1200ms, or if either response to a given item was incorrect. The average error rate (to either or both presentations) was 3.5% for words and 3.2% for nonwords. The percentage of items excluded as outliers was 1.0% for words and 1.2% for nonwords. Average reaction times to first presentations were 590ms for words, and 653ms for nonwords.

Note that the examination of the effect of word frequency relies on an across-experiment comparison. Frequency was not manipulated within a single experiment as this would have required a doubling of the number of trials (to approximately 2000). Instead, the high frequency words were simply slotted into the list positions previously occupied by low frequency targets, in order to give exact matches for all factors except the variable of interest.
Short term priming and long term priming

The basic features of Figure 3.3 are similar to the decay patterns reported in Chapter 2. For the nonwords, the positive ST effect is evident, again, only at lag 0. For HF words, the repetition effect appears to conform to the familiar shape of smooth decay over the short term, but differs from that for LF words in that no LT priming effect is visible. Most interestingly, the ST priming effect for HF words appears of roughly the same magnitude (95ms) and the same duration (3 items) as that found previously for LF words.

A two way ANOVA including all lags (0 to 23) found a main effect of lag ($F(7,119)=19.6$, $MSe=1662$, $p<.001$), no overall effect of target type ($F<1$), and an interaction ($F(7,119)=4.83$, $MSe=1216$, $p<.001$). Decay patterns were again examined separately for words and nonwords.

Figure 3.3: Priming (ms) as a function of lag in Experiment 3.2, using lexical decision, for high frequency words (HF words) and nonwords. Mean decision times to first presentations were 590ms for words, and 653ms for nonwords.
Chapter 3

Table 3.2: Data for high frequency words and nonwords from Experiment 3.2. Mean lexical decision times (in ms) and error rates are shown for first (f, ef) and second (s, es) presentations, and priming (p).

<table>
<thead>
<tr>
<th></th>
<th>lag0</th>
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<th>lag5</th>
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<tr>
<td>f</td>
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<td>579</td>
<td>590</td>
<td>601</td>
<td>590</td>
<td>586</td>
<td>586</td>
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<td>568</td>
</tr>
<tr>
<td>s</td>
<td>506</td>
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<td>574</td>
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<tr>
<td>ef</td>
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<td>3%</td>
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<td>4%</td>
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<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>4%</td>
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<td>3%</td>
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<td>3%</td>
<td>4%</td>
<td>3%</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>es</td>
<td>1%</td>
<td>5%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>8%</td>
</tr>
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</table>

Table 3.3: Helmert contrasts (in ms) between priming at each lag and average priming at subsequent lags in Experiment 3.2.

<table>
<thead>
<tr>
<th>value of contrast (ms)</th>
<th>lag0</th>
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<th>lag4</th>
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<td>10</td>
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<td>F-value</td>
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<td>2.6</td>
<td>2.9†</td>
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<td>&lt;1</td>
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<tr>
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<td></td>
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<td>80</td>
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<td>3</td>
<td>-29</td>
<td>1</td>
<td>-20</td>
<td>7</td>
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<tr>
<td>F-value</td>
<td>64.0**</td>
<td>1.2</td>
<td>&lt;1</td>
<td>7.9*</td>
<td>&lt;1</td>
<td>3.1†</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Note: ** = p<.01; * = p<.05; † = p<.1; MSE = 1296 (words), 1583 (nonwords)

Words. Helmert contrasts for word priming are presented in Table 3.3. These reveal that significant decay occurs following lags 0 and 1, with some hint of further decay after lags 2 and 3. As in Experiments 2.1 and 2.2, no decay occurs after lag 4. The finding that lag 2 priming is not significantly above priming at lags 3 to 23, and that lag 3 priming is not significantly (at the .05 level) above that at lags 4 to 23, could be interpreted as indicating that the ST priming effect for HF words has dissipated by lag 2. However, this analysis ignores the fact that substantial decay occurs between lags 2 and 3, taken together, and later lags.
Evidence that the ST priming effect does, in fact, last as long for HF words as for LF words comes from fitting an exponential decay function to the data. An equation of

\[ p = 97.2 e^{-0.67t} + 3.7 \]

was found to provide an excellent fit, with 92% of the variance in the observed means accounted for (MSfit=1001, MStotal=1087), and the striking thing about this function is the remarkable similarity of the ST effect to that found for LF words in Experiment 2.1. Particularly, there are very close matches in both the magnitude of the ST effect at lag0 (97.2 ms, s.e.=7.6 for HF; 93.5 ms, s.e.=8.0 for LF) and in the decay constant for this effect (0.67, s.e.=0.15; 0.63, s.e.=0.14). Thus, it seems that ST priming for HF words takes the same form, and has the same duration, as for LF words.

The exponential fit also demonstrates that, in contrast to the results for LF words, there is no LT priming effect for HF words: the LT priming value of 3.7 ms is not significantly above zero (s.e. = 4.6 ms, 95% confidence interval = -8.1 ms to +15.5 ms). It is well known that LT priming is substantially smaller for HF words than for LF words (eg. Scarborough et al., 1977), although the complete absence of LT priming is a somewhat unusual finding. The likely explanation of this apparent anomaly is that the words used in the present experiment were of substantially higher frequency (mean Kucera-Francis frequency = 275) than many used as "high" frequency in the experiments reported in these earlier papers. If there is a continuous relationship between frequency and LT priming (Kirsner, Dunn & Standen, 1989), then there might be a frequency level beyond which no priming is evidenced - this level may have been exceeded by the word stimuli in the present experiment.

Nonwords. Helmert contrasts for nonwords, shown in Table 3.3, reveal that, as previously, there is substantial decay following lag0, but no further decay beyond this point. (It should be noted that the significant contrast at lag3 and the close-to-significant effect at lag5 represent a dip below the amount of priming at later lags.) Thus, the pattern of decay for nonwords replicates that found in Experiments 2.1 and 2.2.

For nonwords, the only difference between the results of Experiment 2.1 and the present experiment is the reduced magnitude of the LT priming effect: the LT value (lags 1 to 23) appears roughly 20 ms lower in the current experiment (see Figure 3.3), although it is still substantially above zero, at around 18 ms. This reduced LT value may seem surprising given that the same set of nonwords, and the same task, were used in both experiments. A likely explanation for the difference lies in the reaction times to first presentations across the two experiments: as might be expected, subjects found lexical decisions more difficult in Experiment 2.1 when pseudowords were contrasted.
with extremely low frequency words (initial decision times to nonwords = 704 ms), than they did here when the same nonwords were contrasted with far more familiar items (653 ms). As noted previously, it is reasonable to assume that shorter initial reaction times allow less room for improvement on the second occasion, and so lead to somewhat smaller priming effects.

**Error analysis.** Roughly equal numbers of decision errors were made to first presentations of words (4.1%), second presentations of words (2.7%), first presentations of nonwords (3.3%), and repeats of nonwords (3.0%). A two-way ANOVA on the error rates to second presentations revealed no effect of lag ($F(7,119)=1.26$, $MS_0=0.55$, $p>.2$), no effect of lexical status ($F<1$), and no interaction between the two (Wilks’ $\lambda=.574$, $F(7,11)=1.17$, $p>.2$). Thus, again, the pattern of priming scores observed cannot be attributed to changes in error rates across lags.

**Summary.** For nonwords, the essential findings of Experiments 2.1 and 2.2 have been replicated, that is, a ST priming effect is significant only at lag0 (although a possible modification of this conclusion will shortly be presented). For real words, the short term decay of HF words appears to match that found earlier for LF words, although the LT baseline value is substantially lower.

One implication of the pattern of results obtained across Experiments 2.1, 2.2 and 3.2 is that the ST and LT priming components are independent and additive: word frequency influences the LT component substantially but has no effect on ST priming, dissociating ST and LT priming. A second implication is that the decay shape of ST priming is determined primarily by whether or not the target item has a representation as a whole: words decay at the same rate despite large differences in frequency, while wordlike nonwords decay far more rapidly.

### 3.3 COMBINED ANALYSIS OF EXPERIMENTS 2.1, 2.2 AND 3.2

The decay patterns of short term repetition priming observed in Experiments 2.1, 2.2 and 3.2, all of which used the same lags and list structure, were remarkably similar. Thus, it was decided to combine the data from all three experiments to gain extra power in the investigation of the ST priming effect. This procedure was expected to a) give a clearer indication of the exact duration of the ST effect for words, b) allow further examination of the possible "dip"
below the LT priming value at intermediate lags which was hinted at in the nonword data, and c) allow a reasonably powerful analysis of errors.

Reaction time data. Before a combined analysis of the priming data could be attempted, it was necessary to re-scale the data in order to weight each experiment equally: simply combining the raw data would give far more importance to the results of Experiment 2.1 (which had the largest overall priming effects), than to Experiment 2.2 (which had the smallest). To achieve equal weighting, the condition means for each subject in each experiment were converted to z-scores, calculated relative to that subject's performance across all lag/lexicality conditions. The standardised scores were then analysed via a three-way ANOVA, which included experiment as a third variable in addition to lag and lexical status. No three-way interaction was found ($F<1$), although the expected interaction between lag and lexicality was present ($\lambda=.329$, $F(7,45)=13.1$, $p<.001$); these findings indicate that the form of the lag $\times$ lexical status interaction did not differ across experiments. This is shown graphically in Figure 3.4.

![Figure 3.4: Priming (in z-score units) as a function of lag for the combined analysis of standardised data from Experiments 1-3, for a) words, and b) nonwords.](image-url)
Chapter 3

Words. Helmert contrasts for the combined word data (treating lag as a repeated measures factor) are presented in Table 3.4. While individual experiments did not always show significant differences between lags 2 or 3 and later lags (although all showed a trend in this direction), it can be seen from Table 3.4 that the contrasts at each of these lags are significant when the data from all 54 subjects are combined. The obvious reason for the lack of significance in individual experiments is that the decay of the ST effect is exponential, and thus the size of the effect becomes rapidly smaller at longer lags. (Another reason is that Helmert contrasts may not pick up decay in situations in which, for example, lags 2 and 3 are similar but together are higher than subsequent lags.) However, even with data from 54 subjects, there is no hint of significant decay occurring beyond lag3.

Nonwords. The pattern of ST decay evident for nonwords in Figure 3.4 suggests that the conclusion drawn from each individual experiment, namely that the ST effect exists only with immediate repetition, may have been an oversimplification. In fact, it can be seen that the slight "dip" below the LT value, suggested at intermediate lags in individual experiments, is consistent across all three.

Helmert contrasts for the combined nonword data are shown in Table 3.4. While only one point, lag3, is significantly below successive lags, the contrasts are somewhat negative at all intermediate lags (ie. lags 1 to 5), suggesting a general trend upwards from lag1 onwards. This pattern is consistent with a "dip" following immediate repetition to a minimum at around lag3 (or possibly earlier), with a return to the LT value by lag9. In order to investigate the statistical significance of this apparent dip, a "screening" ANOVA was conducted on the nonword priming scores excluding lag0. There were significant differences amongst the means (F(6,318)=2.46, MSe=.86, p<.025), and thus follow up tests were conducted. These revealed that average priming at lags 1, 2, 3, 4 and 5 was lower than at lags 9 and 23 (F(1,318)=6.35, p<.025), with lag3 priming lower than that at lags 4 and 5 (F(1,318)=4.84, p<.05) but not significantly different from that at lags 1 and 2 (F<1). Thus, nonword priming appears to show a dip below the LT priming value, which is centered somewhere between lags 1 and 3.

Error data. As described earlier, error rates for second presentations in Experiments 2.1 and 3.2, taken individually, were found to be unaffected by either lag or lexicality. (Note that no detailed error data was available for Experiment 2.2.) However, the error rates in all conditions were low, suggesting that these null findings may merely reflect a lack of power in the analyses. Therefore, the error data from the two experiments were combined. This was done without re-scaling, as the overall error rates were similar in the two
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experiments (giving each experiment roughly equal weight by simply collapsing the raw scores).

Table 3.4: Contrasts (in z-score units) between priming at each lag and average priming at subsequent lags, for the combined data of Experiments 2.1, 2.2 and 3.2.

<table>
<thead>
<tr>
<th>value of contrast (ms)</th>
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<td></td>
<td>1.34</td>
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<td></td>
<td>1.57</td>
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<td>-.40</td>
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<td>&lt;1</td>
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</table>

Note: ** = p<.01; * = p<.05; † = p<.1; average MS$_{B}$ = .68 (words); average MSE = .83 (nonwords)

Figure 3.5: Error rates (%) to second presentations as a function of lag, collapsed across Experiments 2.1 and 3.2.
For the combined data, a significant effect of lag was revealed \((F(7,245)=2.79, \text{MS}_{\text{e}}=0.69, p<.01)\), with no main effect of lexicality \((F<1)\), and an interaction between the two \((\text{Wilks' } \lambda = 0.618, F(7,29)=2.56, p<.05)\). Figure 3.5 indicates that this interaction is of the same form as was apparent in the reaction time data: a repetition advantage at lag0 decays gradually for words but precipitously for nonwords. Thus, the lags at which subjects responded most quickly on the second presentation (ie. showed the largest priming effect) were also those at which they were the most accurate. In other words, the ST repetition effect can be seen as a temporary improvement in both accuracy and speed of response, with equivalent effects of target lexicality apparent on both measures.

**Summary.** Overall, the three experiments that investigated priming across lags 0 to 23 showed remarkably similar patterns of decay of ST repetition effects, as measured by both reaction times and error rates. For words, ST priming survived across three intervening items (ie. 8 seconds). For nonwords, the increased power available from combining Experiments 2.1, 2.2 and 3.2 has allowed the conclusion that ST priming actually dipped below the LT value at intermediate lags. It is not at all clear what factors may give rise to such an effect. It will be suggested in Chapter 6 that the dip may have arisen through a confound of repetition with order effects, given that Experiments 2.1, 2.2 and 2.3 all employed the same sequence of trial conditions. If, however, the dip is a genuine reflection of the pattern of repetition influence, its implication is that some form of ST influence must remain after lag0, in order to pull the level of priming back up to the LT level. Whatever the explanation of this "dip" might be, its presence does not change one important conclusion drawn from the results of the three experiments, namely that the form of ST priming is heavily dependent on lexical status.

### 3.4 CONCLUSIONS

The new experimental work reported in this chapter has dissociated ST and LT priming on the basis of two factors, namely decay rate and word frequency. Experiment 3.1 provided direct evidence that the decay rate of long term priming is many times slower than that of the short term priming effect reported in Chapter 2 (by perhaps a factor of 600). In addition, the decay of priming following lags 9 and 23 was found to be slow enough to identify the "long term" priming effect reported in Chapter 2 with the standard long-lasting effect which has been investigated in most of the existing literature on repetition priming.
Experiment 3.2 found that word frequency influenced the level of LT priming but not the magnitude or decay rate of ST priming. It should be noted that the conclusion that word frequency influences only LT priming is open to some question due to the fact that HF and LF words were compared only across experiments. Particularly, the similarity between short term LF and HF word priming may reflect the nature of the interfering items in addition to the nature of the target itself: because of the across-experiment comparison, LF targets necessarily had LF words (and nonwords) intervening between repetitions, while HF targets had HF words (and nonwords) as intervening items. Conceivably, it could be the case that HF targets intrinsically show a longer-lasting priming effect, but that these same words also cause more interference in their role as intervening items. Thus, it may be simply a chance result that the ST decay rate of "stronger" items (HF words) with stronger interference was found to equal that of "weaker" items (LF words) with weaker interference. On the other hand, the fact that LT priming disappeared altogether in Experiment 3.2, while a non-zero ST effect remained, adds weight to the argument that there is a real dissociating effect of target word frequency.

Together, the results of Experiment 3.1 and 3.2 provide reasonably convincing evidence that repetition priming can be dissociated into two components. In addition, Experiment 3.2, in keeping with the proposal put forward in Chapter 2, strongly suggests that ST and LT priming are additive as well as independent. The theoretical implication of the dissociation between ST and LT priming is that they arise through non-identical mechanisms. This in turn suggests that there is no requirement for the properties of LT priming to necessarily extend to ST priming, and no need to assume that the two effects will be explained in the same way. Such a conclusion is consistent with an explanation of ST priming in terms of transient modification of lexical representations, despite the fact that such state changes are highly unlikely to underlie LT priming (see Chapter 1).

Finally, the combined analysis of Experiments 2.1, 2.2 and 3.2 demonstrated that the decay patterns of ST priming were remarkably similar across experiments, regardless of task and word frequency. In all experiments, ST priming decayed smoothly over the first few intervening items for words, but fell to slightly below the LT value with a single intervening item for nonwords. For words, this consistency of pattern across experiments simply confirmed the pattern apparent in each individually. For nonwords, however, it led to a modified interpretation of ST decay shape. In each experiment examined individually, there was a hint of a "dip" below the LT value at intermediate lags, but this was significant (on Helmert contrasts) in only one experiment at one lag (Experiment 3.2, lag 3). However, when the data from all three experiments were combined, a significant intermediate-lag dip was revealed. The dip was
centred somewhere between lags 0 and 3, with priming for nonwords returning to the long term value by perhaps lag 5 (12 seconds).
Chapter 4
Short term implicit memory?

4.0 INTRODUCTION

The experiments reported in the preceding two chapters have demonstrated a ST repetition effect, and have dissociated this effect from LT priming. The primary aim of the present chapter is to report evidence that ST priming can be dissociated from short term explicit, or working, memory. A search for such evidence was suggested by the "memory" approach to priming: evidence of a short term explicit/implicit dissociation would argue that short term priming could usefully be distinguished from both long term implicit memory and short term explicit memory, and thus might be identified as a short-lived form of implicit memory.

Empirical work presented in this chapter also investigates whether ST priming arises through automatic, in addition to implicit, processes. In this context, "automatic" and "implicit" are closely related, but distinct, terms. A priming effect that arises due to automatic processes can be thought of as being unaffected by deliberate efforts to learn a stimulus at "study" (ie. on first presentation). That is, an automatic effect would arise regardless of a subject's conscious strategy on first processing an item (assuming that the subject at least attended to the item). A priming effect that arises due to implicit processes, however, can be thought of as being unaffected by deliberate efforts to retrieve the stimulus at "test" (ie. on second presentation). In other words, the term "automatic" refers to the the nature of operations carried out at encoding while the term "implicit" refers to the nature of those carried out at retrieval. Any explanation of ST priming in terms of perceptual changes (ie. transient changes in the state of the word recognition system) would suggest that the effect should arise automatically as well as implicitly.

It appears reasonable to assume that the ST priming effect demonstrated in Experiments 2.1, 2.2 and 3.2 is, in fact, both implicit and automatic, for a number of reasons related to the design of those experiments. First, the use of speeded lexical decision and naming tasks seems likely to have elicited implicit, rather than explicit, memory. Secondly, with continuous-list presentation, the subjects could not have been aware in advance on any trial as to whether that
trial would be a first or second presentation, giving them no way of distinguishing "encoding" from "retrieval" trials until after processing on each trial was largely complete. Thirdly, the very large number of trials should have discouraged subjects from attempting to remember individual stimuli. Together, these features of the earlier experiments would suggest that ST priming arose through processes both automatic and implicit. The overt task did not require subjects to either "learn" or "remember" individual stimuli, and responses (especially in naming) were usually so fast that it seems unlikely that the subjects would have had time (even if they had found reason) to indulge in such deliberate strategies.

However, there is no direct evidence from these experiments that ST priming is either automatic or implicit. It is possible that subjects were deliberately learning the stimuli on first presentation (perhaps by rehearsing each item in the delay before the next appeared), and/or attempting to use explicit recognition of prior presentation to speed their responses to second presentations. Although most methodological considerations argue against this interpretation of ST priming as relying on deliberate encoding/retrieval strategies, there is one design feature of the preceding experiments which might encourage such an interpretation. This feature was the large proportion of trials in Experiments 2.1, 2.2 and 3.2 which were repeats of recently-presented items: the use of 20 items per lag condition, and many short lags, meant that roughly 30% of trials were repeats of items that had been presented between 1 and 24 trials previously (ie. at lags 0 to 23). If subjects felt that they could improve their performance on the lexical decision and naming tasks by "remembering" individual stimuli, the use of so many close repeats might be expected to have encouraged both deliberate attempts to encode each item on its first presentation, and deliberate attempts to recognise it on its second presentation.

One way of investigating whether ST priming is based on automatic and implicit processing might be to reduce the number of close repeats in the list, on the assumption that this would reduce subjects' enthusiasm for deliberately trying to remember particular list items. This was done in Experiment 4.2, which examined repetition priming across lags 0 to 23 with only 10 items per lag condition, thus reducing the number of trials that were repeats of recently-presented items to around 15% of the total list. If the ST priming effect demonstrated in the earlier experiments were due to the operation of deliberate learning strategies on encoding, or to the use of explicit memory on retrieval, this halving of the number of close repeats might be expected to destroy or reduce ST priming.

First, however, Experiment 4.1 directly investigated whether ST priming was attributable to the operation of short term explicit (working) memory. In the experiment, Experiments 2.1 (LF words) and 3.2 (HF words) were repeated,
but with an explicit recognition task (old/new decision) replacing lexical decision. All other aspects of the experiments remained exactly as before. If working memory were responsible for the ST priming effect observed previously, then the decay of explicit recognition over short lags should take the same form as did the decay of priming.

4.1 SHORT TERM EXPLICIT MEMORY: EXPERIMENT 4.1

Subjects in Experiments 2.1, 2.2 and 3.2 commonly reported in informal post-session discussions that they explicitly recognised many trials as being repeats of previous items. This is hardly surprising for items repeated at short lags, and, indeed, it would be surprising if subjects did not retain working memory representations of items presented only a few trials earlier. There is a question, then, as to whether the ST priming effect demonstrated with the "implicit" tasks was due simply to the operation of short term explicit memory. (This would require that subjects are able to use their working memory representations of previous items to speed their lexical decision and naming times to second presentations.)

The question can be addressed by examining the decay patterns of working memory for the lists used in the previous experiments. Therefore, Experiment 4.1 repeated Experiments 2.1 (LF words) and 3.2 (HF words) with a recognition task (old/new judgement) in place of the lexical decision task (word/nonword judgement), but with all other presentation conditions of the earlier experiments maintained. This procedure allows working memory to be assessed by reaction times to recognise a second presentation as old, and thus allows a comparison of the form of decay of working memory with the form of decay found in the lexical decision and naming tasks. Were it the case that the ST priming effect revealed in Experiments 2.1, 2.2, and 3.2 reflected the use of explicit rather than implicit memory, the ST priming decay patterns found with explicit recognition should match those found with the priming tasks - in particular, the unusual decay pattern for nonwords should be replicated with recognition. On the other hand, a failure to replicate the earlier interaction between lag and lexical status (ie. failure to find smooth decay for words but precipitous decay for nonwords) would provide a dissociation between ST priming and working memory, suggesting that ST priming should be identified as short term implicit memory.
4.1.1 Method

Subjects. Eighteen undergraduate subjects, from the pool described in Experiment 2.1, participated in return for credit towards an introductory psychology course.

Materials and Procedure. The stimulus lists and presentation format were exactly as for Experiment 2.1 (nine subjects) or Experiment 3.2 (nine subjects). The present experiment differed only in the task used. Instead of making a lexical decision, subjects were given a recognition task, where they were required to determine whether or not each item had appeared anywhere earlier in the list. Subjects responded "old" (ie. the second presentation of an item) with their preferred hand, and "new" (ie. the first presentation) with the other. Reaction time and accuracy scores were taken.

4.1.2 Results and discussion

Averaged across lags 0 to 23, error rates for first presentations of targets (ie. false alarms, or falsely recognising a new item as old) were as follows: 16% for HF words, 18% for LF words, 17% for nonwords mixed with HF words, and 12% for nonwords mixed with LF words. Error rates for second presentations (ie. misses, or failing to recognise a repeated item as old) were: 11% for HF words, 13% for LF words, 12% for nonwords mixed with HF words, and 23% for nonwords mixed with LF words. These error rates were somewhat above those found for lexical decision. Nevertheless, recognition performance was well above chance. This indicates that subjects can, on a reasonable number of occasions, at least recollect an earlier presentation of a particular item in a continuous list.

To decide whether such knowledge could have contributed to priming in lexical decision or naming, reaction times to correctly recognised old items, along with lexical decision times (to second presentations) determined from Experiments 2.1 (LF) and 3.2 (HF), are presented in Figure 4.1. Only lags 0 to 9 are plotted, as it was the decay of short term priming and recognition which was of interest; means of all conditions are presented in Table 4.1. (For lexical decision, plotting reaction times to second presentations is conceptually equivalent to plotting priming scores. The only difference is that the decay of the ST priming effect is reflected in a rise in reaction times rather than a decrease in priming).
Short term implicit memory?

Figure 4.1: Explicit recognition times (ms) to second presentations of target items as a function of lag in Experiment 4.1, plus comparable lexical decision times from Experiments 2.1 and 3.2, for a) LF words and nonwords, and b) HF words and nonwords. Rec = recognition; LD = lexical decision; w = words; n = nonwords; rxn time = reaction time.

Low frequency words, and nonwords. Across all eight lags, the explicit recognition times for old items in this experiment were slower than the equivalent lexical decision times in Experiment 2.1. The advantage for lexical decision was 63ms for words (585ms lexical decision, 648ms recognition) and 28ms for nonwords (653ms lexical decision, 681ms recognition). A two-way ANOVA including the recognition times for words and nonwords at all lags, found no interaction between lag and item type (Wilks' $\lambda = .031$, $F(7,2)=8.92$, $p>.1$). Figure 4.1a demonstrates this lack of interaction: in contrast to the sharp dissociation observed between word and nonword data in lexical decision, recognition memory decayed smoothly, and at the same rate, for both words and nonwords.

High frequency words, and nonwords. The results for nonwords and HF words mirrored those for nonwords and LF words. Specifically, lexical decision times for second presentations were substantially faster than recognition times for old items: 156ms faster for words (562ms lexical decision, 718ms recognition), and 104ms faster for nonwords (625ms lexical decision, 729ms recognition). In
addition, no interaction was found between lag and item type for the recognition data (F<1), as is shown for short lags in Figure 4.1b.

**Error analysis.** As only second presentations of targets would be expected to be influenced by lag between repeats, only miss errors were subjected to analysis. For the LF words, and nonwords, a two-way ANOVA on these scores revealed a main effect of lag (F(7,56)=12.29, MS\(_{E}=3.18\), p<.001), representing a decline in accuracy with increasing lag, and a main effect of lexical status (F(1,8)=16.34, MS\(_{E}=10.34\), p<.01), such that words were recognised more accurately than nonwords. More importantly, no interaction was observed between lag and lexical status (F(7,56)=1.35, MS\(_{E}=2.54\) p>.2). A similar pattern

**Table 4.1:** Data for explicit recognition in Experiment 4.1. Data shown are response times for first presentations (f) and second presentations (s) in ms, plus error rates for false alarms to first presentations (e(FA)) and misses to second presentations (e(M)).

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*Note.* Reaction times are not presented for lag1050 as recognition was at chance level for second presentations.
of error scores was apparent for the HF words, and nonwords, with an effect of lag (F(7,56)=7.37, MS_ε=3.11, p<.001), no main effect of lexical status (F<1), and, again, no interaction between the two (F<1). This lack of interaction confirms the pattern observed in the reaction time data: short term explicit memory was apparent as both a temporary increase in accuracy and as a temporary decrease in recognition time, but the decay of the effect was not influenced by lexical status under either measure.

Summary. The failure to replicate the lag x lexicality interaction with explicit recognition provides evidence that working memory can be dissociated from ST priming on the basis of the effects of lexical status. The experimental design leading to this dissociation satisfied the retrieval intentionality criterion proposed by Schacter, Bowers & Booker (1989), in that the lexical decision and explicit recognition experiments were matched as closely as possible in all aspects excepting task. Satisfying this criterion strengthens the interpretation that the dissociation arose from the implicit or explicit nature of the retrieval employed by subjects, and thus that ST priming reflects implicit access to short-lived traces.

However, although dissociations between ST priming and short term explicit memory are necessary to demonstrate that ST priming is implicit in nature, the general point can be made that no dissociation between tasks can ever be sufficient to show that the implicit/explicit nature of subjects' retrieval is the only relevant difference in behaviour enforced by the two tasks (See Section 1.3.3 for a detailed presentation of this argument). In this context, the overall differences in ease of response between the lexical decision and explicit recognition experiments provide valuable support for the view that ST priming relies on implicit rather than explicit access. Explicit recognition was found to be noticeably slower and less accurate than lexical decision (and naming). This makes it highly unlikely that priming in the lexical tasks could have been produced by explicit memory: it seems likely that explicit knowledge of earlier items was available, but arrived too late to speed processing of repeated targets.

The combination of a dissociation with a substantial overall speed difference between explicit recognition and lexical tasks makes a strong case that ST priming does not simply reflect explicit working memory. This does not rule out the possibility of there being some relationship between working memory and short term priming, but it suggests that any such relationship is certainly not a simple one. It appears justified to conclude that ST priming represents a short-lasting form of implicit rather than explicit memory and, more strongly, to suggest that working memory and ST repetition rely on at least partially distinct processes.
4.2 REDUCING THE PROPORTION OF CLOSE REPEATS: EXPERIMENT 4.2

Experiment 4.2 measured repetition priming over lags 0 to 23, for LF words and pseudowords in a lexical decision task. The experiment was identical in all ways to Experiment 2.1, except that the proportion of close repeats in the list was reduced from around 30% to around 15% by reducing the number of items in each lag condition from 20 to 10. It should be noted that the total number of repeats in the full list remained the same (at around 30%); it was only the proportion of close repeats (i.e., repeats at lags 0 to 23) that was lowered. This was achieved by swapping 10 of the second presentations in each lag condition with an item from the same condition appearing two blocks (roughly 20 minutes and 500 trials) away in the full list. (Reducing the total number of all repeats would have required adding new words and nonwords which did not appear in the original experimental list; this was avoided as additional words would need to have come from a higher frequency range than those employed previously.)

The primary reason for the manipulation of the proportion of close repeats was to investigate whether ST priming could be attributed to deliberate learning or retrieval strategies. As noted earlier, when items are frequently repeated at short lags, it may be that subjects attempt to learn each item, in the hope that this will improve their performance on that item on the next occasion (i.e., make a lexical decision response faster if they can recognise an earlier item and/or recall the earlier response).\(^1\) This may lead to a relatively strong "trace" of the first presentation, in comparison to that left when the number of close repeats is lower and a learning strategy does not seem so attractive. On the assumption that a high proportion of repeats in the list is likely to lead subjects to believe it is worthwhile trying to remember individual items, a reduction in the number of close repeats might make them less likely to attempt deliberate learning/retrieval strategies. Thus, a finding that the shape of ST priming is independent of the number of close repeats would be consistent with the view that the effect arises through automatic and implicit processes which are not influenced by deliberate strategies. On the other hand, a finding of reduced ST priming or faster decay with a reduced number of repeats would suggest that ST priming relies on deliberate encoding and/or deliberate retrieval.

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\(^1\) The fact that explicit recognition times to second presentations were substantially longer than lexical decision and naming times (see Experiment 4.1) makes it highly unlikely that explicit knowledge of items would have, in fact, been able to help subjects make faster responses in the priming tasks. However, subjects would not be expected to be aware of this, and might have thought it helpful to deliberately encode/rehearse items so as to make them easier to recognise later.
There was also a simple empirical reason for lowering the number of close repeats in the list. This came from the unexpected finding in Experiment 3.1 (which examined the decay of long term priming) that LT priming for nonwords was substantially lower than found in Experiment 2.1 at lags 9 and 23, even though the initial reaction times were longer. At first glance, it is hard to find a reason for this: most of the nonword stimuli were the same as used previously and the additions did not differ in any obvious way; the task was the same; the presentation rate was the same; and the overall structure of the experiment was the same (four 9-or-so-minute blocks of trials with repeats possible at any point in the list). The only difference of note between the two experiments seemed to be the lags themselves. This difference meant that Experiment 3.1 necessarily had fewer repeats closer together (as, on average, much longer lags were used) than Experiment 2.1. Given that there is evidence that LT repetition priming decreases when the proportion of (all) repeats is decreased (Jacoby, 1983b), a second motivation for Experiment 4.2 was to see if the reduced number of close repeats could explain the unexpectedly low priming for nonwords observed in Experiment 3.1:

4.2.1 Method

Subjects. Eighteen subjects participated in return for credit in an introductory psychology course. Data from one of these were discarded due to excessive error rates.

Materials and procedure. The task (lexical decision), the presentation lists used, and the four presentation blocks were exactly as for Experiment 2.1, with one exception, namely that only half as many items (i.e., 10 instead of 20) appeared in each of the lag conditions (up to lag 23). This was achieved by swapping the second presentations for half the occurrences of each lag condition with a second presentation for the same lag condition two blocks (i.e., roughly 20 mins) away in the list. For example, the repeat of the first occurrence of lag 0 (in the first block) was swapped with the repeat of the eleventh (in the third block) while the third was swapped with the thirteenth, and so on. For lag 1, the repeat of the second occurrence was swapped with the repeat of the twelfth, the fourth with the fourteenth, and so on. This procedure ensured that the total number of repeats remained the same, but that only 10 items (rather than 20) were repeated at lags 0 to 23. Nine versions of the list were created, by carrying out the swapping procedure on each of the nine list versions employed in the earlier experiment. Two subjects received each version, ensuring that items were cycled over conditions across subjects. As before, items were presented at a rate of one every two seconds.
4.2.2 Results and discussion

Data were discarded from one subject who was apparently unfamiliar with many of the (LF) real words used in the experiment, incorrectly classifying 23% of them as nonwords. For the remaining 17 subjects, average error rates were 6.4% for words and 6.0% for nonwords. Reaction times were excluded if they were <300 ms or >1200 ms, or if either response to the target was incorrect. The percentage of items excluded as outliers on this basis was 2.0% for words, and 3.6% for nonwords. Average lexical decision times to first presentations of remaining targets were 663 ms for words, and 711 ms for nonwords.

Priming is shown as a function of lag in Figure 4.2 (and Table 4.2). As is apparent in this figure, there was a main effect of lag ($F(7,112)=15.25$, $MS_e=3160$, $p<.001$), a main effect of lexical status ($F(1,16)=21.02$, $MS_e=4001$, $p<.001$) such that, on average, words showed more priming than nonwords, and an interaction between lag and lexical status ($F(7,112)=3.41$, $MS_e=3641$, $p<.01$). Given this interaction, the effect of lag was examined separately for words and nonwords.

**Words.** Helmhert contrasts, comparing priming at each lag with the average of all later lags, are shown in Table 4.3 for the word data. These indicate that decay was significant following lags 0 and 1, and that there was some hint of further decay following lag 2, although this was far from significant. (It should of course be noted that, with only 10 items per condition, error variance was substantially larger than in the earlier experiments, and so this lack of significance could well arise due to a lack of power in the test.) The best exponential fit to the word data, accounting for 88% of the variance in the eight means ($MS_{fit}=1523$, $MS_{total}=1725$), was:

$$p = 112.2 \cdot e^{-0.73l} + 34.3$$

indicating a ST component of 112.2 ms (s.e.=18.2) at lag0, with a decay rate of 0.73 (s.e.=0.26), and a LT component of 34.3 ms (s.e.=9.3).

**Nonwords.** As shown in Table 4.3, significant decay followed only lag0, although there was some indication of a dip below the LT value at intermediate lags (specifically, lags 1 and 2). This is consistent with the results presented in Chapters 2 and 3, where individual experiments showed a trend towards a dip (centered somewhere between lags 1 and 3), which was significant when data from three experiments was combined.
Figure 4.2: Repetition priming (in ms) for lexical decision in Experiment 4.2, with 10 items per lag condition.

Table 4.2: Data for Experiment 4.2, employing lexical decision with LF words and 10 items per condition. Data shown are mean reaction times (ms) and error rates (%) for first presentations (f, ef), second presentations (s, es) and priming (p).

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<td>697</td>
<td>718</td>
<td>695</td>
<td>726</td>
<td>721</td>
<td>703</td>
<td>695</td>
<td>729</td>
<td>728</td>
</tr>
<tr>
<td>s</td>
<td>571</td>
<td>728</td>
<td>692</td>
<td>684</td>
<td>714</td>
<td>682</td>
<td>685</td>
<td>720</td>
<td>703</td>
</tr>
<tr>
<td>p</td>
<td>126</td>
<td>-10</td>
<td>3</td>
<td>41</td>
<td>7</td>
<td>21</td>
<td>10</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>ef</td>
<td>3.5%</td>
<td>5.9%</td>
<td>4.7%</td>
<td>6.5%</td>
<td>5.3%</td>
<td>8.2%</td>
<td>10%</td>
<td>4.1%</td>
<td>21%</td>
</tr>
<tr>
<td>es</td>
<td>1.8%</td>
<td>8.2%</td>
<td>2.7%</td>
<td>5.9%</td>
<td>6.5%</td>
<td>8.7%</td>
<td>7.1%</td>
<td>7.1%</td>
<td>17%</td>
</tr>
</tbody>
</table>
Table 4.3: Contrasts (in ms) between priming at each lag and average priming at subsequent lags, for Experiment 4.2.

<table>
<thead>
<tr>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
<th>lag6</th>
</tr>
</thead>
<tbody>
<tr>
<td>words</td>
<td>94</td>
<td>59</td>
<td>22</td>
<td>-21</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>nonwords</td>
<td>114</td>
<td>-25</td>
<td>-15</td>
<td>29</td>
<td>-6</td>
<td>12</td>
</tr>
</tbody>
</table>

F-value: words 43.0** 16.5** 2.2 2.0 <1 <1 1.7
F-value: nonwords 51.7** 2.5 <1 3.1† <1 <1 <1

Note: ** = p<.01; * = p<.05; † = p<.1; MSe = 3068 (words), 3733 (nonwords)

Figure 4.3: Error rates to second presentations in Experiment 4.2.
**Short term implicit memory?**

Error data. Average error rates to first presentations were 8.0% for words and 6.0% for nonwords. Error rates to second presentations were 4.8% for words and 6.0% for nonwords. For second presentations, there was no effect of lexicality of target (F<1), a marginal effect of lag (F(7,112)=1.99, MSe=.48, p=.063), and a significant lag x lexicality interaction (F(7,112)=2.69, MSe=.45, p<.02). As can be seen from Figure 4.3, the marginal effect of lag reflected a trend towards more errors at longer lags. The lag x lexicality interaction appears to have arisen from random crossovers at various lags: there is no clear pattern of decay for either words or nonwords.

**Comparison of 20 vs 10 items per condition.** Initial-presentation decision times were equivalent in the present experiment (10 items per condition) and Experiment 2.1 (20 items per condition), with no significant difference in mean decision time across all lag conditions for either words (663ms vs 659ms, t(33)=0.15, p>.2) or nonwords (711ms vs 704ms, t(33)=0.31, p>.2). This equivalence of baselines indicates that priming can validly be compared across the two experiments. The comparison is shown in Figure 4.4.

![Figure 4.4: Comparison of priming across Experiment 2.1 (20 items per condition) and Experiment 4.2 (10 items per condition).](image-url)
It appears from Figure 4.4 that the amount of LT priming has been reduced by lowering the proportion of close repeats. This result is consistent with the common finding that standard repetition priming is sensitive to the number of repeats in the list (eg. Jacoby, 1983b), but extends this finding somewhat to suggest that it may be the number of close repeats which is relevant rather than the number of all repeats. Unlike the LT priming value, ST priming appears largely unaffected by the proportion of close repeats: word priming still decays gradually, and nonword priming suddenly. The exact shape of the ST decay for nonwords is very similar across experiments, although there is some hint that ST priming for words may be initially larger and decay more quickly in the present experiment.

In order to evaluate the similarities and differences in priming across experiments, a 3-way ANOVA (lag x lexicality x experiment) was conducted on the data shown in Figure 4.4. This revealed a main effect of experiment ($F(1,33)=9.08$, $MS_e=4840$, $p<.01$), such that average priming levels were higher with more close repeats, a main effect of lexical status ($F(1,33)=44.74$, $MS_e=2829$, $p<.001$), such that words showed more priming than nonwords, and a main effect of lag ($F(7,231)=32.22$, $MS_e=2627$, $p<.001$). Of the possible two-way interactions, only that involving lag and lexicality was significant ($F(7,231)=5.05$, $MS_e=2490$, $p<.001$); there were no interactions between lag and experiment ($F<1$), or lexical status and experiment ($F(1,33)=1.28$, $MS_e=2829$, $p>.2$). However, the three-way interaction was almost significant ($F(7,231)=2.05$, $MS_e=2490$, $p=.051$).

In the absence of any interactions involving experiment, we could conclude that, while the overall levels of priming differed across experiments, the decay patterns of ST priming were equivalent. However, given that the 3-way interaction was so very close to being significant, we cannot draw this conclusion with certainty: a 3-way interaction might indicate that the form of ST priming for words and/or nonwords differed depending on whether there were 20 repeats in each condition or only 10. It was therefore decided to conduct two 2-way ANOVAs (lag x experiment), one for words and one for nonwords.

For words, there was a main effect of lag ($F(7,231)=19.98$, $MS_e=2308$, $p<.001$), a possible effect of experiment ($F(1,33)=3.30$, $MS_e=3384$, $p=.078$), but no lag x experiment interaction ($F(7,231)=1.39$, $MS_e=2308$, $p>.2$). For nonwords, there were significant main effects of both lag ($F(7,231)=18.20$, $MS_e=2810$, $p<.001$) and experiment ($F(1,33)=8.50$, $MS_e=4825$, $p<.01$), but again no interaction between them ($F(7,231)=1.15$, $MS_e=2810$, $p>.2$). Thus, if there were a 3-way interaction between lag, experiment and lexicality, it is clear that this would not reflect any effect of the proportion of close repeats on ST priming. In fact, the 2-way analyses indicate that, for nonwords, the manipulation of the percentage of close repeats influenced only the LT component of priming (and
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thus the overall magnitude), but that the magnitude and decay shape of ST priming remained unaffected. The same conclusions can be drawn for words, except that the reduction in the LT priming value only approached significance.

Summary. Reducing the percentage of close repeats in the complete list significantly reduced the LT priming level for nonwords, and marginally reduced that for words. However, the ST repetition effect was not significantly influenced by this manipulation. The magnitude of ST priming (over and above the LT value) and the relative decay patterns for words and nonwords remained largely unaffected. While the data were somewhat more variable than previously with only 10 items per condition, ST priming still decayed gradually for words, but precipitously for nonwords.

The substantial reduction in the LT priming for nonwords provides an explanation of the level of nonword priming apparent at lags 9 and 23 in Experiment 3.1. This was lower than expected when compared to Experiment 2.1, with 20 items per lag condition, but is in keeping with the results of the present experiment with only 10 items per lag. (In fact, the present experiment contained even more "close" repeats than Experiment 3.1: 15% of trials were repeats of items that appeared less than 1 minute previously, compared with only 7% in the latter.)

If we can assume that the manipulation of the number of close repeats influences the likelihood that subjects will attempt to deliberately encode and/or retrieve individual items in the list, the results have two interesting implications. First, they suggest that LT priming for nonwords (and, to some extent, words) is influenced by the effort made to learn the item on the first presentation, and thus that standard LT repetition priming has at least some strategic component (probably at encoding rather than retrieval). Secondly, the results are consistent with the view that, in contrast to LT priming, ST priming arises automatically from processing of targets on their first presentation, and is not affected either by the strength of the initial trace or by explicit attempts to recall previous items.

Finally, this experiment has provided unexpected evidence that the proportion of close repeats in the list dissociates ST from LT priming, at least for nonwords. This is the third factor so far reported to distinguish the two effects (the others were word frequency and decay rate), and adds weight to the argument that different mechanisms underlie each.
4.3 CONCLUSIONS

The two experiments reported in this chapter provided empirical evidence consistent with the view that ST repetition priming involves implicit and automatic processes. In Experiment 4.1, a change of task from the (presumably implicit) lexical decision task to an explicit recognition task substantially altered the decay shape of ST memory, at least for nonwords - the lag × lexicality interaction disappeared, and the decay of ST explicit memory was found to be smooth for both words and nonwords - dissociating ST priming from explicit working memory. In Experiment 4.2, a manipulation that would be expected to reduce the effort subjects put into deliberately "remembering" (i.e. encoding and/or retrieving) individual items, namely a halving of the proportion of close repeats in the list, had no effect on the magnitude or decay patterns of ST priming for words or nonwords. This finding is again consistent with the interpretation of ST priming as arising through implicit retrieval processes, and also suggests that the effect arises automatically at encoding.

There are two possible qualifications of the results which should be considered (and discarded). First, in Experiment 4.1, the dissociation observed between ST priming and working memory relies on the fact that a lag × lexicality interaction was observed in the priming tasks but not in explicit recognition. As was discussed in Chapter 2, this interaction may be seen to occur for lexical decision because opposite decisions are being made to real words and to nonwords. However, the reader should be reminded that this interaction was replicated in Experiment 2.2 with a naming task, in which no overt decision was required. This demonstrates that the observed dissociation does not depend on any unusual properties of the lexical decision task.  

Secondly, regarding Experiment 4.2, the conclusion that reducing the number of close repeats in the list reduces the level of LT priming but does not affect ST priming is based on an across-experiment comparison. In this case, however, there is no reason to suspect that this fact could have influenced the results in any way. For one thing, the lists used in the two experiments contained identical items (although of course presented in different orders so as to manipulate the percentage of close repeats). In addition, while subjects from the two experiments could not be randomly assigned to the 20-items-per-condition list or the 10-items-per-condition list, both groups were drawn from

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2 It is always possible, however, that naming involves a kind of covert lexical decision in order to ensure that the item is read aloud correctly.

3 Note the contrast with the across-experiment comparison responsible for the dissociation between ST and LT priming on the basis of word frequency.
the same pool (first-year psychology students at ANU), and their lexical decision times to first presentations did not differ across the two groups. These factors strongly suggest that the comparison of priming levels across the two groups was valid.

The results presented in this chapter could be usefully be extended in a number of ways. First, while lexical status has been found to be one variable which dissociates ST priming and ST explicit memory (Experiment 4.1), this dissociation should ideally be backed up in the future by the identification of further factors which affect only ST priming and not working memory, and vice versa. Secondly, reducing the number of close repeats in the list (Experiment 4.2) is not the optimal technique for changing subjects' encoding strategies. More convincing evidence that the traces underlying ST priming arise automatically on first presentation of the target would come from directly manipulating subjects' encoding at "study" in a variety of ways, and showing that none of these influences ST priming. Unfortunately, most techniques which have been employed to manipulate learning strategies at encoding (eg. using structural versus semantic levels of processing, employing a divided attention task, etc.) would appear difficult, if not impossible, to implement with the continuous-presentation procedure required to measure priming at short lags. Thus, despite some uncertainty about how subjects' learning strategies would be affected by a change in the proportion of close repeats, no obvious alternative manipulation is available. With the technique employed, it can at least be said that if ST priming in Experiments 2.1, 2.2 and 3.2 arose because subjects felt it worthwhile to deliberately learn individual items, then halving the number of close repeats should have substantially reduced ST priming. No such reduction was observed.

Overall, the results of the Chapter 4 confirm the view that ST priming is a new phenomenon which is likely to require explanations different from those proposed for other forms of memory; the evidence for this is that ST priming has now been dissociated from ST explicit memory (Experiment 4.1) as well as from LT implicit memory (Experiments 3.1, 3.2 and 4.2). The novel form of repetition advantage, then, should presumably be identified as reflecting short term implicit memory. In addition, the apparent automaticity of this form of memory is consistent with a possible basis of ST priming suggested in earlier chapters, namely a lexical-level trace, perhaps taking the form of a transient modification of the state of word (or subword) representations.
Chapter 5

Unpacking lag: Spontaneous trace loss or interference?

5.0 INTRODUCTION

In the experiments presented in Chapters 2, 3 and 4, decay of repetition priming was examined as a function of "lag". These experiments allowed the identification of a short-lived repetition priming effect, which is additional to standard long-lived priming. From a "memory" perspective, this ST priming effect has been identified as a short-lived form of implicit memory, while, from a "perceptual" perspective, it has been argued that this short term implicit memory may arise due to transient changes in the state of lexical representations. One important question which has not yet been addressed, however, is the precise cause of the observed reduction in the repetition effect over short lags.

The variable "lag" in fact confounds two possible mechanisms which could be responsible for the decay of ST priming. These mechanisms are spontaneous trace loss (ie. a loss of the record of the target's first presentation which occurs independently of any subsequent processing) and interference (ie. a gradual destruction of this trace, or its effects on behaviour, by the processing of subsequent items). Operationally, these mechanisms correspond, respectively, to the time delay and the number of intervening items between repeats. The manipulation of "lag" necessarily confounded these two factors in the earlier experiments: repeats at lag0 followed 2 seconds and 0 intervening items after their first presentation; repeats at lag1 followed after 4 seconds and 1 intervening item; repeats at lag2 followed after 6 seconds and 2 intervening items, and so on. Therefore, it is possible that the ST decay patterns apparent in

1 The term decay is potentially confusing in this context. In the literature on short term explicit memory, "decay" has been used to refer to what is here called a "spontaneous trace loss". However, it is also common to use "decay" simply to refer to an observed reduction in the dependent variable of interest (ie. to refer to the shape of the empirical decay curve), rather than to a particular mechanism which might produce this observed result. Here, "decay" retains the meaning assigned to it in previous chapters, namely an empirical reduction in repetition priming.
the earlier experiments arose due to a) a spontaneous reduction in trace strength alone, b) an effect of interference alone, or c) a combination of both mechanisms.

Both memory and perceptual approaches to understanding ST priming suggest that further investigation of the mechanism of decay is of interest. Within the memory literature, the decay mechanism of short term explicit memory has been a major topic of investigation, with the general conclusion that both spontaneous loss and interference contribute to observed decay. Thus, knowledge of the relative contributions of each factor to the decay of short term implicit memory may provide a useful comparison between the two memory forms. Within a perceptual approach, the interpretation of ST priming as reflecting transient modification of lexical representations again suggests the importance of independently investigating each contributor to "lag". The potential forms of lexical modification suggested by current word recognition models (eg. activation, threshold-lowering, etc) could naturally be assumed either to decay spontaneously and/or to be replaced by new modifications from subsequent items. Which of these forms of decay actually occurs needs to be assessed.

The two experiments reported in the present Chapter attempted to tease apart the relative influences of time delay and intervening items on the decay of ST priming. Both experiments used a lexical decision task (slightly modified in the second experiment) with LF words and pseudowords as targets, but employed different manipulations to examine the question of interest. In Experiment 5.1, time delay and number of intervening items were each manipulated while holding the other factor constant. With this design, it can be determined whether or not time delay influences priming levels, and whether or not the number of intervening items influences priming levels. In Experiment 5.2, the decay curves of priming over time delays of 2 to 16 seconds were examined with and without the presence of intervening lexical items. Using this design, the patterns of decay due to time alone, and due to time plus interference, can be determined. This technique allows the exact contributions of each factor to the previously-observed word and nonword decay curves to be determined.

5.1 VARYING TIME DELAY OR NUMBER OF INTERVENING ITEMS: EXPERIMENT 5.1

Experiment 5.1 constituted a first step toward determining the relative contributions of spontaneous trace loss and of interference to the decay of ST
Unpacking lag: spontaneous loss or interference? 107

priming, and simply addressed the question of whether or not each factor contributes to decay. The experiment varied either time delay or number of intervening items, holding the other factor constant, with respect to each of three reference conditions. In the *time-changed* condition, the time between repeats was *reduced* in comparison to the appropriate reference condition, while the number of intervening items was held constant. In the *items-changed* condition, the number of items intervening between repeats was *increased* in comparison to the reference conditions, while the time delay remained the same.

The three reference conditions chosen were "lags" 0, 4 and 9. These were assessed in blocks of trials presented at a rate of one every four seconds. The manipulations of time and items were both achieved by increasing the presentation rate to one every two seconds, allowing either the reference number of intervening items to be presented with less time between repeats (time-changed conditions), or a greater number of intervening items to be presented in the reference time delay (items-changed conditions). For example, at "lag 0", the 0-items/4-seconds of the reference condition could be compared with either a 0-items/2-seconds time-changed condition, or a 1-item/4-seconds items-changed condition.

If a spontaneous reduction in trace strength is the only factor which contributes to decay, then priming in the time-changed condition should be greater than that in the appropriate reference condition (as the time delay is shorter in the former), and there should be no difference between the reference and the items-changed condition (as the time delay is the same). On the other hand, if interference is the only factor which contributes to decay, then the time-changed and reference conditions should show equal priming (as the number of intervening items is the same), and both should show more than the items-changed condition (due to the increased number of items in the latter). If both spontaneous trace loss and interference contribute to decay, then priming in the reference condition should lie somewhere between two extremes given by the time-changed condition (maximum priming) and the items-changed condition (minimum priming). Table 5.1 summarises these various possibilities.

5.1.1 Method

**Subjects.** Twenty one undergraduate subjects participated in return for course credit.

**Design.** A repeated measures $3 \times 3 \times 2$ design was used ("lag" $\times$ condition $\times$ lexical status), with priming for repetitions in a lexical decision task as the dependent measure. Three reference lag conditions were chosen with set numbers of items intervening between repeats, and a set time delay between repeats. These
reference conditions were 0-items/4-seconds (ie. "lag0"), 4-items/20-seconds (ie. "lag4"), and 9-items/40-seconds (ie. "lag9"). For each reference condition, two other conditions were used, one of which included the reference number of items but a reduced time delay between presentations (time-changed condition), while the other included the reference time delay but an increased number of items (items-changed condition). The item/time conditions chosen, and the presentation rate necessary to achieve each, are shown in Table 5.2. Note that condition 9/20 was used as a comparison for two reference conditions, giving eight distinct conditions in all. (This condition was measured only once, thus restricting the forms of data analysis possible.) Both word and nonword targets were presented under all conditions.

Materials. Two lists were created, corresponding to the two different presentation rates. The 0/2, 1/4, 4/10, 9/20 and 19/40 comparison conditions all required a 2-second-per-item presentation rate (see Table 5.2), and thus were included in the 2-second list. The 0/4, 4/20 and 9/40 reference conditions all required a 4-second-per-item presentation rate, and thus were included in the 4-second list. In order to balance the structure of the two lists, two "dummy" conditions, namely 1/8 and 19/80 were added to the 4-second list. Items for these dummy conditions were chosen from the same pool as for the critical items. Thus, the 2-second and 4-second blocks of trials were as similar as possible in all aspects apart from presentation rate.

<table>
<thead>
<tr>
<th>Cause of decay</th>
<th>Pattern expected within a &quot;lag&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interference only</td>
<td>( p_{t-ch} = p_r &gt; p_{i-ch} )</td>
</tr>
<tr>
<td>Spontaneous loss only</td>
<td>( p_{t-ch} &gt; p_r = p_{i-ch} )</td>
</tr>
<tr>
<td>Both</td>
<td>( p_{t-ch} &gt; p_r &gt; p_{i-ch} )</td>
</tr>
<tr>
<td>Neither (ie. no decay)</td>
<td>( p_{t-ch} = p_r = p_{i-ch} )</td>
</tr>
</tbody>
</table>

Note: \( p_{t-ch} \) = priming in the time-changed conditions; \( p_{i-ch} \) = priming in the items-changed conditions; \( p_r \) = priming in the reference conditions.

2 "Lag0" was selected as representing a "short term" condition for which decay was definitely expected due to at least one factor. "Lag9" was selected as representing a "long term" condition for which no decay was expected due to either factor. "Lag4" was selected as the probable border of the short term priming effect. Here, there was no particular expectation as to whether or not any decay would be found.
Table 5.2: Details of conditions used (number-of-intervening-items / time-in-seconds) in Experiment 5.1, and the presentation rates necessary to produce these conditions.

<table>
<thead>
<tr>
<th>&quot;Lag&quot; group</th>
<th>Within-lag condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time-changed</td>
</tr>
<tr>
<td>Details of condition</td>
<td></td>
</tr>
<tr>
<td>&quot;lag0&quot;</td>
<td>0-items/2-secs</td>
</tr>
<tr>
<td>&quot;lag4&quot;</td>
<td>4/10</td>
</tr>
<tr>
<td>&quot;lag9&quot;</td>
<td>9/20</td>
</tr>
<tr>
<td>Presentation rate (time per trial)</td>
<td>2 seconds</td>
</tr>
</tbody>
</table>

In total, then, target items were required for 10 word conditions, and 10 nonword conditions. In order to obtain these targets, 10 sets of 18 items were chosen from each of the pools of low frequency words and pseudowords described in Experiment 2.1. Two of these sets were assigned to the dummy conditions for all subjects, while the other eight were cycled through the critical conditions over eight different versions of the lists.

To determine the presentation order for the 2-second list (ie. to manipulate the number of items intervening between repeats), three sequence templates of 45 items were chosen. Each template contained two occurrences (plus repeats) of each of the five item/time conditions appearing in this list, making 40 items (including words and nonwords). The remaining five items were unrepeated fillers chosen from the filler pool described in Experiment 2.1. Each of the three sequence templates was used three times, thus allowing all 18 items in each of the 2-second-per-item conditions to be presented. In total, this list contained 405 trials (targets: 5 conditions \(\times\) 2 occurrences \(\times\) 2 repeats \(\times\) 2 lexicalities \(\times\) 9 templates; plus fillers: 5 per template \(\times\) 9 templates). For the 4-second-per-item list, the number of intervening items in each of the five conditions (the three reference conditions plus the dummies) matched that in a corresponding 2-second condition. Thus, the presentation order for the 4-second list (another 405 items with different fillers) was determined by simply reversing the complete 2-second list order.

Procedure. Each subject was tested individually in a one-hour session. The order of presentation of the 2-second and 4-second lists was counterbalanced across subjects. Each list was split into three blocks, allowing for a short break between each. For the 2-second list, a new item was presented every two seconds (regardless of how long it took the subject to respond to the previous
one), and so each block took 4.5 minutes to complete. For the 4-second list, items appeared every four seconds, and each block took 9 minutes. A practice trial of 25 items, employing the appropriate presentation rate, was included before each of the 2-second and 4-second lists. All other aspects of the procedure were as for Experiment 2.1.

5.1.2 Results and discussion

Mean error rates for words were 11.5% for first presentations and 4.8% for second presentations. Nonword error rates were 4.3% for first presentations and 4.6% for second presentations. Reaction times were excluded from analysis where an error was made to either presentation, or if the response time was <300ms or >1200ms. On this basis, 1.3% of word trials and 1.2% of nonword trials were excluded as outliers.

First-presentation decision times. First-presentation decision times, presented in Table 5.3, were found to be around 30ms slower for the three reference conditions than for the five comparison conditions. Specifically, mean lexical decision times to first presentations were 658ms for words and 679ms for nonwords in the 2-second-per-item blocks (ie. the comparison conditions), but 685ms for words and 711ms for nonwords in the the 4-second-per-item blocks (ie. the reference conditions). A two-way ANOVA (presentation rate x lexical status) revealed that the main effect of presentation rate was, indeed, significant ($F(1,20)=19.0$, $MSe=976$, $p<.001$).

The slower decision times with the 4-second presentation rate may well have arisen due to drifts in subjects' attention during the 3-seconds-plus of waiting for the next item - subjects did, indeed, report that they found the 4-second-per-item blocks particularly boring. Such attention drifts would require re-orientation to the task at hand before a response could be made to the subsequent trial, presumably slowing decision times. However, regardless of the reason for the slower decision times with the slower presentation rate, this finding creates some difficulty in comparing priming levels in the reference conditions with those in the time-changed and items-changed conditions: it might be expected that the longer baseline reaction times in the reference conditions would inflate priming in these conditions relative to the others.

The priming data were analysed in spite of this problem. It will be argued shortly that the problem of unequal baselines is unlikely to have seriously affected the conclusions drawn from these data.

Priming data. Figure 5.1 shows the mean priming effects for words in each condition, calculated as first minus second reaction times. Exact means in all
conditions are presented in Table 5.3. Overall decay from "lag0" through "lag9" is apparent, presumably reflecting the presence of ST priming at the three "lag0" conditions which had disappeared by "lag9". To determine the reason for this ST decay, patterns of priming must be examined within the set of conditions used at each "lag". Thus, each reference condition was compared to its time-changed and items-changed conditions using three 1-way ANOVAs, one for each "lag". 3

For words, these ANOVAs revealed differences between 0/4 and its two test conditions (F(2,40)=46.9, MS_e=1099, p<.001), while no such differences were found within the "lag4" (F=1) or "lag9" (F<1) sets of conditions. The latter two results indicate that no decay due to either time or interference was discernable with respect to either the 4/20 or 9/40 conditions, in keeping with the very slow

Table 5.3: Mean lexical decision times (in ms) to first presentations (f) and second presentations (s), plus priming scores (p) and error rates (ef, es) for Experiment 5.1.

<table>
<thead>
<tr>
<th></th>
<th>words</th>
<th></th>
<th>nonwords</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>time-ch ref items-ch</td>
<td>time-ch ref items-ch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;lag0&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>653 679 657</td>
<td>677 712 683</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>485 533 584</td>
<td>539 611 642</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>168 145 73</td>
<td>139 101 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ef</td>
<td>10.1% 11.9% 10.3%</td>
<td>3.4% 3.4% 5.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>es</td>
<td>3.4% 3.7% 5.3%</td>
<td>1.1% 2.1% 5.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;lag4&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>679 696 655</td>
<td>671 709 689</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>597 609 586</td>
<td>652 676 666</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>81 86 68</td>
<td>18 33 22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ef</td>
<td>10.8% 12.4% 12.9%</td>
<td>2.9% 2.7% 7.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>es</td>
<td>6.1% 5.8% 5.8%</td>
<td>4.2% 4.5% 5.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;lag9&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>655 680 646</td>
<td>689 714 676</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>586 616 588</td>
<td>666 692 672</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>68 64 58</td>
<td>22 21 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ef</td>
<td>12.9% 11.7% 11.7%</td>
<td>7.4% 2.4% 6.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>es</td>
<td>5.8% 5.0% 2.9%</td>
<td>5.6% 5.0% 9.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Note that higher-order ANOVAs (eg. condition × "lag" × lexicality) were not possible, due to the fact that the 9/20 condition was only measured once.
Figure 5.1: Priming in Experiment 5.1 for words.

Figure 5.2: Priming in Experiment 5.1 for nonwords.
Unpacking lag: spontaneous loss or interference?

Decay of LT priming reported in previous chapters. The former result indicates that, as would be expected, significant decay of some form occurred within the "lag0" set of conditions. Figure 5.1 suggests that this significant overall effect reflects influences of both time delay and number of intervening items on priming levels: within "lag0", the reference condition lies between the two extremes and appears different from each. In keeping with this observation, follow-up tests revealed that priming in the reference condition was significantly smaller than in the time-changed condition \( (t(20)=2.74, p<.02, \) for 0/2 vs. 0/4), indicating that "lag0" priming decays partly due to time delay between repeats. In addition, priming in the reference condition was significantly greater than in the items-changed condition \( (t(20)=6.6, p<.001, \) for 0/4 vs. 1/4), indicating that "lag0" priming decays partly due to the presence of intervening items.

The same pattern of results was obtained for nonwords, as can be seen in Figure 5.2. One-way ANOVAs indicated significant overall differences in comparison to 0/4 \( (F(2,40)=28.9, MSe=1519, p<.001), \) but not 4/20 \( (F=1) \) or 9/40 \( (F(2,40)=2.04, MSe=1135, p>.1) \). Within "lag0", decay again arose through both time delay \( (t(20)=2.88, p<.01, \) for 0/2 vs. 0/4) and intervening items \( (t(20)=4.73, p<.001, \) for 0/4 vs. 1/4).

From these results, it can be concluded that the decay over "lag" reported in the earlier experiments (or at least that following lag0) is due partly to spontaneous trace loss, and partly to the effects of interference. This conclusion appears to hold for both word and nonword targets.

Problem of unequal baselines? As noted earlier, the comparisons conducted above on the priming data might be influenced by the fact that the baseline reaction times were slower in the reference conditions that in the comparison conditions, suggesting that priming levels in the reference conditions might be somewhat inflated. However, an examination of Figures 5.1 and 5.2 suggests that any such inflation is unlikely to have seriously affected the conclusions drawn above. First, for the "lag4" and "lag9" conditions, any reasonable adjustment for inflation of the reference condition would still leave this value well within the range of the two comparison conditions. Secondly, for the "lag0" conditions, any downward adjustment of the reference condition with respect to the comparison conditions is unlikely to affect the conclusion that the reference condition is significantly different from both. On raw priming scores, the reference condition is a massive 72ms for words and 61ms for nonwords above the appropriate items-changed condition: it is hardly likely that this difference could be due entirely to the 30-or-so ms difference in baseline reaction times. (With respect to the time-changed conditions, note that any downward adjustment of the reference condition would only serve to further increase the already-significant difference.)
Expressing priming as a percentage decrease in reaction times to second presentations rather than as an absolute decrease did not change the pattern of results (this procedure would be expected to remove at least some of any influence of initial reaction times.) Within "lag0", percentage priming for words was: 25.7% for the time-changed condition, 21.4% for the reference condition, and 11.1% for the items-changed condition. The values for nonwords were 20.5%, 14.2% and 5.9%, respectively. Clearly, priming in the reference condition with this measure was still substantially above that in the appropriate items-changed condition. Overall, there seems little reason to doubt the conclusion that "lag0" priming decays through the effects of both time delay and intervening items, despite the unequal baselines.

Error data. Table 5.3 includes error rates in all conditions. There is a trend towards second-presentation error rates within "lag0" being lowest in the time-changed condition, slightly higher in the reference condition, and higher again in the items-changed condition. This is consistent with the pattern shown in the reaction time data, with most "priming" in the time-changed condition and least in the items-changed. One-way ANOVAs revealed that this trend was not significant for words (F<1), but was for nonwords (F(2,40)=7.0, MS_e=0.47, p<.01). Within "lag4" and "lag9" the patterns of errors appear more random, and no significant differences were found within any "lag" (largest F=2.69, smallest p=.08). These results indicate that speed-accuracy tradeoffs are not responsible for the patterns reported in the reaction time data.

Summary. The present experiment has provided evidence that both spontaneous trace loss and interference contribute to the decay of immediate-repetition priming. With regard to the decay curves reported in Chapters 2 through 4, this conclusion implies that each of the two aspects of the variable "lag" was partially responsible for the observed patterns of decay. While the present experiment has simply demonstrated that both factors do influence priming over short lags, the next experiment will clarify the way in which they combine to produce the observed ST decay curves for words and nonwords.

5.2 PATTERNS OF DECAY WITH AND WITHOUT INTERFERENCE: EXPERIMENT 5.2

The experiments presented in Chapters 2, 3 and 4 consistently found that short term priming decayed over lag in a fixed fashion, which differed for words and nonwords. Priming for words showed a smooth decay pattern and lasted through approximately three intervening items, while priming for nonwords decayed precipitously, being brought down to or below the long term value by a
single intervening item. Experiment 5.1 has indicated that the decay of priming from "lag0", for both words and nonwords, arises partly due to spontaneous loss of the trace of the target’s first presentation, and partly due to interference from items intervening between repeats. That experiment, however, was not able to specify exactly how these two factors combined to produce the decay patterns reported in the earlier chapters. Experiment 5.2, therefore, examined the relative contributions of spontaneous trace loss and of interference to the previously-observed patterns of decay over lag.

The experiment used a design similar to that of the initial experiments which examined priming over short lags (ie. a design quite different from that of Experiment 5.1), but determined priming as a function of the time delay between repeats, rather than as a function of lag per se. Time delays of between 2 and 16 seconds were employed, with a new intervening "item" presented every 2 seconds during the delay. The critical manipulation was the nature of these intervening items. In the \textit{with-interference} conditions, lexical items (ie. words or nonwords) were presented every 2 seconds between target repeats. The manipulation of time delay with interference corresponded to the manipulation of lag employed in Chapters 2, 3 and 4, and so it was expected that priming in these conditions would decay in the same fashion as observed previously. In the \textit{without-interference} conditions, however, "blanks" (two rows of dots containing no letter-like features) replaced the lexical items.

If, as found in Experiment 5.1, both time delay and intervening (lexical) items contribute to the decay of priming, then some decay should be found over time alone, but faster decay should be observed with time plus interference (ie. with lag). In addition to allowing confirmation of this general expectation, the comparison of priming over time with and without interference allows an investigation of the relative contributions of each factor to the lag decay curves for words and nonwords. In particular, the cause of the extremely rapid decay of priming for nonwords can be investigated. If this decay pattern arises (primarily) due to spontaneous trace loss, then priming for nonwords without interference should show precipitous decay, and look much like priming for nonwords with interference. If, however, it arises (primarily) due to interference from intervening items, then priming for nonwords without interference should decay relatively slowly over time alone, and look more like the smooth decay expected for words.

The targets used in Experiment 5.2 consisted of pseudowords and very low frequency words. The task was a modified version of lexical decision, in which subjects responded "yes" to words, "no" to nonwords, and did not respond at all to blanks. Blanks consisted of a row of eight colons (ie. ::::::::). The use of some form of "blank" was required in order to force subjects to maintain their attention on the screen during long delays between lexical items: subjects could
not predict in advance the nature of any particular trial, and so all required full attention in case a response was required. It was assumed that the blanks chosen would provide no interference to the traces underlying ST priming for words and nonwords. This assumption appears reasonable, based on the argument that ST priming arises at a lexical level (see Chapter 2), and on the observation that "blanks" containing no letter-like features should not be able to access representations at this level.

The time delays employed were 2, 4, 6, 8, 10 and 16 seconds between repeats. In the with-interference conditions, these corresponded to lag0, lag1, lag2, lag3, and lag4 (as used in the experiments reported in Chapters 2, 3 and 4), and to lag7 (which was not previously used). Note that, even with interference, only one time delay (16 seconds or lag7) clearly falls outside the region of influence from ST priming. Without interference, where the decay of priming is expected to be slower, it is not clear that even this point will necessarily represent only the LT level of priming. There are two possible problems of interpretation which might be introduced by not including longer time delays. First, it may not be clear (especially for priming without interference) where the decay of ST priming ends (ie. the asymptotic LT value may not have been reached by 16 seconds delay). Secondly, the exact shape of decay of priming for nonwords (particularly, whether or not a "dip" is apparent) will depend critically on the value of priming at a single "long term" point (ie. 16 seconds). Despite these expected limitations, however, it was not possible to include longer time delays: the large number of conditions required to measure priming with and without interference for words and nonwords, plus the large number of blank trials needed, meant that subjects were already required to complete more than 2700 trials (see below for details).

5.2.1 Method

Subjects. Nineteen undergraduate students participated for course credit, and a further 5 members of the ANU community volunteered for the experiment, giving 24 subjects in all.

Design. Three variables were manipulated within subjects, namely lexical status (word or nonword), time between repeats of an item (2, 4, 6, 8, 10 or 16 seconds, plus an across-session condition), and the nature of the stimuli presented in the intervening period (all "blanks" or all four-letter strings). Details of the 12 conditions used are given in Table 5.4, and were repeated with word and nonword targets. The 0-items/2-seconds conditions (ie. the lag0 conditions of earlier experiments) were considered to be the starting point for decay both with and without interference. These were measured only once for targets of each lexical status. An across-sessions condition was included as two sessions were
required to present all trials, allowing an opportunity to examine repetition priming over very long delays. The amount of priming (first minus second) was recorded for each condition in a modified lexical decision task.

Materials. Targets were 204 LF words, and 204 pseudowords. These were the same targets as employed in Experiment 3.1 (which examined long term priming). Note that this pool included some "unfamiliar" low frequency words, which had led to somewhat higher error rates in Experiment 3.1, and also in the experiment presented in Appendix A from which the pool was originally selected. Each pool of 204 words or nonwords was broken up into 12 sets of 17 items, corresponding to the 12 conditions of interest. In addition, seven dummy conditions were included: 1/6, 1/8, 1/10, 1/16, 2/8, 2/10 and 2/16. These conditions, in which a target repeat had a mixture of blanks and letter-strings as intervening items, were used in order to prevent subjects learning that every series of blanks was followed by a repetition of the last non-blank string (this is the case for conditions 0/2 through 0/16). Seventeen items for each of these conditions, plus an extra 136 unrepeated fillers, were chosen as described for fillers in Experiment 2.1 (ie. the word fillers included both some quite unfamiliar very low frequency words, plus some words of slightly higher frequency than the target pool).

Table 5.4: Details of conditions used in Experiment 5.2. Corresponding lag values are given where appropriate, ie. for the with-interference conditions.

<table>
<thead>
<tr>
<th>With/without interference</th>
<th>Type of intervening items</th>
<th>Conditions used</th>
</tr>
</thead>
<tbody>
<tr>
<td>with</td>
<td>lexical</td>
<td>Details of conditions (lexical-items/time)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0/2  1/4  2/6  3/8  4/10  7/16</td>
</tr>
<tr>
<td>without</td>
<td>blanks</td>
<td>0/2  0/4  0/6  0/8  0/10  0/16</td>
</tr>
<tr>
<td>both</td>
<td>both</td>
<td>Corresponding time delay (seconds)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2  4  6  8  10  16</td>
</tr>
<tr>
<td>Corresponding lag</td>
<td></td>
<td>Corresponding lag</td>
</tr>
<tr>
<td>with</td>
<td>lexical</td>
<td>lag0  lag1  lag2  lag3  lag4  lag7</td>
</tr>
</tbody>
</table>

Note: Lexical intervening items include words and nonwords, but not blanks. eg. Condition code 0/6 means that 6 seconds elapsed between repeats with only blanks (two in this case) appearing as intervening items, while 2/6 indicates that 6 seconds elapsed between repeats but that two letter-strings were presented as intervening items (one 2 seconds after the onset of the target's first presentation, and one 4 seconds after).
In order to manipulate items/time between repeats, eight sequence templates were chosen, each containing 153 trials, including 73 blanks. Blanks (:::::::) took up the same screen width as a four letter word or nonword. Each template contained one occurrence of each of the 11 within-session critical conditions and each of the seven dummy conditions, for both words and nonwords. In addition, eight unrepeated fillers were included per template. In order to present 17 items per condition, seven sequence templates were used twice in the complete list, and one three times. This gave a list of 2601 items, which was split approximately in half to be presented in two sessions.

As two sessions were necessary, a further set of trials was added to the end of the first-session list and repeated at the beginning of the second-session list, in order to evaluate very long term priming effects. These sets contained 67 trials each, which included 17 critical words, 17 critical nonwords, 21 blanks, and 6 repeated filler items. The complete list was thus 2735 trials in length (2601 + 67 + 67). Twelve versions of this complete list were produced, with the sets of target items cycled over the conditions of interest.

Procedure. Items were presented every two seconds. Subjects were required to perform a variant of the lexical decision task, such that a "yes" response with the preferred hand was required to a real word, a "no" response with the other hand to a nonword, and no response at all to a blank. Note that as subjects could not predict the nature of the next trial, they were forced to continue to pay attention to the screen even during a string of blanks. Word and nonword items remained on the screen until the subject responded, and blanks always remained for 1.4 seconds.

The list for each session was broken into 5 blocks for presentation, with the longest blocks each taking nine minutes to complete. Repeats (with the exception of the across-sessions condition) were not split across blocks. Practice trials of 45 and 29 items preceded the first and second sessions, respectively. Subjects were tested individually in two 1-hour sessions. The time between sessions was not controlled, but varied between 0 and 166 hours.

5.2.2 Results and discussion

Average error rates, across the conditions of interest, were 8.0% for words and 4.7% for nonwords. Using a lower cutoff of 300ms, and an upper cutoff of 1200ms, 0.8% of the word trials and 1.0% of the nonword trials in these conditions were excluded as outliers. Mean reaction times to first presentations were 675ms for words, and 708ms for nonwords.
Figure 5.3 shows priming for words and nonwords as a function of time delay between repeats, where intervening items were blanks (without interference) or four-letter strings (with interference). Table 5.5 includes the exact means for all conditions. The following patterns are apparent in Figure 5.3. In the with-interference conditions, ST priming for words decays smoothly over the first few intervening items, while ST priming for nonwords shows a sudden drop to the LT value with a single intervening item. In contrast, the results for the without-interference conditions show priming decaying more slowly, with priming for both words and nonwords demonstrating smooth decay.

Statistical analysis of the data presented in Figure 5.3 is limited by the fact that the 0/2 (lag0) conditions were measured only once for words, and once for nonwords. Therefore, it is not possible, for example, to conduct a three-way ANOVA (time delay × lexicality × interference condition) as the starting point of analysis. Instead, statistical analyses are presented which address three questions of primary interest: the degree to which the with-interference decay curves replicate those produced in the earlier "lag" experiments; the form of decay for nonwords over time alone, and how this changes when interference is added; and the form of decay for words over time alone, and how this changes when interference is added.

Figure 5.3: Priming in Experiment 5.2 as a function of time, without interference (blanks only) and with interference (lexical items).
Table 5.5: Data for Experiment 5.2. Includes: means for lexical decision times to first (f) and second (s) presentations, in ms; priming (p), in ms; and error rates for first (ef) and second (es) presentations, as a percentage. AS=across sessions

<table>
<thead>
<tr>
<th>Lexicality</th>
<th>Within-session interference/time condition</th>
<th>AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>words</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>without interference</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0/2</td>
<td>0/4</td>
</tr>
<tr>
<td>f</td>
<td>678</td>
<td>681</td>
</tr>
<tr>
<td>s</td>
<td>509</td>
<td>558</td>
</tr>
<tr>
<td>p</td>
<td>169.0</td>
<td>122.8</td>
</tr>
<tr>
<td>ef</td>
<td>13.0%</td>
<td>12.8%</td>
</tr>
<tr>
<td>es</td>
<td>3.7%</td>
<td>3.4%</td>
</tr>
<tr>
<td>with interference</td>
<td>1/4</td>
<td>2/6</td>
</tr>
<tr>
<td>f</td>
<td>662</td>
<td>669</td>
</tr>
<tr>
<td>s</td>
<td>561</td>
<td>580</td>
</tr>
<tr>
<td>p</td>
<td>100.5</td>
<td>88.7</td>
</tr>
<tr>
<td>ef</td>
<td>8.6%</td>
<td>9.1%</td>
</tr>
<tr>
<td>es</td>
<td>5.4%</td>
<td>7.8%</td>
</tr>
<tr>
<td>nonwords</td>
<td>without interference</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0/2</td>
<td>0/4</td>
</tr>
<tr>
<td>f</td>
<td>724</td>
<td>713</td>
</tr>
<tr>
<td>s</td>
<td>568</td>
<td>620</td>
</tr>
<tr>
<td>p</td>
<td>155.5</td>
<td>92.5</td>
</tr>
<tr>
<td>ef</td>
<td>3.7%</td>
<td>5.4%</td>
</tr>
<tr>
<td>es</td>
<td>1.0%</td>
<td>3.7%</td>
</tr>
<tr>
<td>with interference</td>
<td>1/4</td>
<td>2/6</td>
</tr>
<tr>
<td>f</td>
<td>691</td>
<td>715</td>
</tr>
<tr>
<td>s</td>
<td>638</td>
<td>657</td>
</tr>
<tr>
<td>p</td>
<td>52.2</td>
<td>57.3</td>
</tr>
<tr>
<td>ef</td>
<td>4.4%</td>
<td>3.9%</td>
</tr>
<tr>
<td>es</td>
<td>1.7%</td>
<td>5.9%</td>
</tr>
</tbody>
</table>

Note: "b" indicates that a separate baseline was used to assess priming, rather than first presentation times - see text for details.
A replication of the effects of lag. As noted above, the with-interference conditions correspond to the lag 0, 1, 2, 3, and 4 conditions used in the experiments reported in Chapters 2 through 4, and to the equivalent of lag7. Therefore, it would be expected that, with interference, ST priming for words should decay smoothly over a number of intervening items, while ST priming for nonwords should decay precipitously to or below the LT value. Such a pattern is apparent in Figure 5.3, and was confirmed by statistical analyses. A two-way ANOVA (time delay x lexicality) revealed significant main effects of both time delay ($F(1,115)=49.9, \text{MSE}=1642$, $p<.001$) and target lexicality ($F(1,23)=14.9, \text{MSE}=2159$, $p<.01$), and a significant interaction between the two ($F(5,115)=2.64, \text{MSE}=1381$, $p<.03$). In order to investigate the decay patterns of priming for words and nonwords separately, the appropriate Helmert contrasts are presented in Table 5.6. From these, it can be seen that priming (with interference) for words remained significantly above priming averaged over longer delays at 2, 4 and 6 seconds (ie. lags 0, 1 and 2), with some hint of a ST effect remaining at 8 seconds (lag3). For nonwords, however, priming is above the LT value only at lag0.

Table 5.6: Contrasts (in ms) between priming at each time and average priming at subsequent times, for Experiment 5.2.

<table>
<thead>
<tr>
<th></th>
<th>value of contrast (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 sec</td>
</tr>
<tr>
<td>words, no interference</td>
<td>71</td>
</tr>
<tr>
<td>F-value</td>
<td>58.0**</td>
</tr>
<tr>
<td>words, interference</td>
<td>94</td>
</tr>
<tr>
<td>F-value</td>
<td>124**</td>
</tr>
<tr>
<td>nonwords, no interference</td>
<td>94</td>
</tr>
<tr>
<td>F-value</td>
<td>92.7**</td>
</tr>
<tr>
<td>nonwords, interference</td>
<td>103</td>
</tr>
<tr>
<td>F-value</td>
<td>133**</td>
</tr>
</tbody>
</table>

Note: ** = $p<.01$; * = $p<.01$; † = $p<.1$; MSe = 1746 (words, no interference), 1428 (words, interference), 1912 (nonwords, no interference), 1595 (nonwords, interference). The 0/2 condition (no intervening items, 2 second delay between repeats) is considered the starting point of decay both with and without interference.
These results provide a valuable replication of the essential features of the ST decay patterns reported in Experiments 2.1, 2.2, 3.2 and 4.2. The replication is particularly important, because, while all four previous experiments used the same trial-order, the present experiment employed newly-chosen sequences of trials in order to manipulate lag. Thus, the present experiment demonstrates that the lag x lexicality interaction reported in the earlier experiments was not due to effects of a particular sequence of word/nonword trials.

One difference in results from the earlier "lag" experiments is worth noting. This is the complete lack of any apparent dip below the LT priming value in the present data. (All previous experiments showed at least a hint of such a dip.) There are three possible reasons for the lack of an intermediate-lag dip. First, it may be that the small dip in the earlier experiments arose due to order effects, and thus disappeared when the trial-sequence was changed. Secondly, it may be that the dip was real, but has not appeared in the present experiment due to sampling error in the one point (16 seconds delay, ie. lag7) that might be expected to fall in the "long term" region. Thirdly, it may be that the dip actually includes lag7 (the earlier experiments found priming at lags 1-5 to be less than lag9, but included no lags between 5 and 9), and the true LT value would be revealed only with the inclusion of longer time delays.

Decay with and without interference for nonwords. Decay patterns over time alone, and with time plus interference, are discussed initially for nonwords, as the analyses for nonwords are more straightforward than for the word data. A two-way ANOVA (time delay x interference condition) was conducted on the priming scores for nonwords, including only time delays of 4 seconds or greater. (The 2-second delay point was theoretically the starting point for both the with­and without-interference decay curves, but could not be included in the analysis because only one estimate of its value was obtained.) This ANOVA revealed a main effect of time delay (F(4,92)=6.5, MSe=1304, p<.001), and no main effect of interference (F≈1) but an interaction between interference and time (F(4,92)=3.8, MSe=2155, p<.01). It is apparent from Figure 5.3 that the interaction takes the form of a smooth decay of ST priming in the absence of interference, in contrast to the sharp decay with interference demonstrated above.

Helmert contrasts presented in Table 5.6 confirm that decay was smooth for nonword targets in the absence of interference: priming was significantly above later values at 2, 4, 6 and 8 second delays. Further confirmation was provided by a finding that an exponential decay function of

\[ p = 122 e^{-2.7(t-2)} + 31 \]
where $t$ is the time delay between repeats in seconds, and $p$ is the amount of priming observed at each time in ms, explained 96.7% of the variance in the observed means (MSfit=1628, MS\text{tot}=1682). As the decay is expressed in terms of $(t-2)$ rather than simply $t$, the exponential fit indicates a ST priming effect at 2 seconds of 122ms (s.e.=14.1) above the LT value of 31ms (s.e.=12.1), with a decay rate of 0.27 (s.e.=0.08).

One other feature of the data deserves consideration, namely that the decay curve for nonwords without interference reaches a slightly lower LT priming value than when interference is present. In fact, however, a two-way ANOVA (time delay x interference condition) including data at 10 and 16 seconds demonstrated that the apparent effect of interference condition on LT priming was far from significant ($F(1,23)=2.18$, $MSe=3662$, p>.1), and indeed, any such effect would be inexplicable.

For nonwords, then, short term priming in the absence of interference (ie. over time alone) shows smooth decay over approximately 10 seconds. With interference, ST priming decays completely with a single intervening item to reach the same LT value as reached after 10 seconds without interference. Thus, it can be concluded that both spontaneous trace loss and interference due to intervening items contribute to the decay of ST priming for nonwords. In addition, it is apparent that interference is the primary contributor to the decay pattern previously observed over lag: ST nonword priming is extremely sensitive to the presence of intervening items.

Decay with and without interference for words. A two-way ANOVA (time delay x interference condition) for words, including only time delays of 4 seconds or greater, found that priming was, on average, significantly reduced when interfering items were present ($F(1,23)=6.8$, $MSe=4593$, p<.02), and was significantly reduced when the time delay was increased ($F(4,92)=8.0$, $MSe=1804$, p<.001). There was, however, no interaction between time delay and interference condition ($F<1$). This lack of an interaction (from 4 seconds onwards) suggests that priming decays in the same fashion with and without interference. Indeed, Helmert contrasts for word targets without interference, presented in Table 5.6, demonstrate smooth decay lasting perhaps 6 seconds. This decay is similar in form to that described above for words with interference. (Note that Helmert contrasts allow analysis of the pattern of decay which includes the 2-second point.)

Given the decay of priming over time alone, plus the main effect of interference condition, it is clear that both time delay between repeats and the effects of intervening items contribute to the decay patterns previously reported for word targets over short lags. In addition, it is clear that short term priming for words is far less sensitive to interference than is short term priming for nonwords. In fact, the lack of an interaction between time delay and interference...
condition suggests that the short term component of priming for words is not at all influenced by interference; instead the main effect of interference appears to reflect a lowering of the long term priming component, thus reducing priming at all delays (that include at least one interfering item) by a constant amount.

This latter conclusion (and the lack of an interaction), however, is somewhat tenuous. It rests entirely on the assumption that priming has stabilised at its LT value by the longest delay employed in the present experiment, namely 16 seconds (ie. lag7 with interference). This assumption seems reasonable for the with-interference condition, but an examination of the decay pattern of word priming without interference (see Figure 5.3) suggests an alternative interpretation. It may be that priming is still decaying slowly between 6 seconds and 16 seconds delay, and, indeed, may show further decay beyond 16 seconds, even though the Helmert contrasts indicated that priming at 4 seconds delay is the last point to remain significantly above the average of all later points. (Some support for this interpretation is provided by a trend analysis of priming at 6, 8, 10 and 16 second delays, which found a linear component of decay that approached significance, F(1,23)=3.63, MSe=1809, p=.069). If, as is intuitively likely, the with- and without-interference curves eventually rejoin each other at longer time delays, the present results would be consistent with an effect of interference on short term, rather than long term, priming for words.

**Error data.** Error rates to first presentations, across the 2-second to 16-second delays, were 10.7% for words and 5.3% for nonwords. On second presentations, error rates decreased to 5.3% for words and 4.0% for nonwords, demonstrating that, as with previous experiments, priming was manifested in both faster reaction times and fewer errors. With interference, a two-way ANOVA (time delay × lexicality) on second-presentation error rates found a main effect of lexicality (F(1,23)=6.31, MSe=1.27, p<.02), with words still showing more errors than nonwords, and a main effect of time (F(5,115)=4.97, MSe=0.78, p<.001), such that fewer errors tended to occur at shorter delays. There was no time × lexicality interaction (F<1). Two-way ANOVAs (time delay × interference condition) conducted separately for word and nonword targets (at delays of 4 seconds and longer), found no significant influences of either delay or interference on second-presentation error rates (largest F=2.08, smallest p>.1). In general, then, error rates were either not significantly affected by those factors which influenced reaction times, or demonstrated priming effects in keeping with the reaction time priming data.

**Very long term (across-session) priming.** Given that two sessions were required to present the various interference conditions of primary interest, the opportunity was taken to investigate priming over the very long delays between sessions (up to one week, with a mean of 46.5 hrs or nearly two days). Mean priming in this across-sessions condition is shown in Table 5.5 for words and
nonwords. Priming was not calculated here as the difference between first- and second-presentation reaction times, as for the within-session conditions. If it were determined in this fashion, repetition effects might well be confounded with practice and fatigue effects: the first presentation (coming at the end of the first session) would be expected to be speeded by practice but perhaps simultaneously slowed by fatigue, while responses to second presentations (at the beginning of the second session), might be expected to still be highly practised, but not influenced by fatigue. 4

A more accurate idea of the amount of across-session priming should be obtained by comparing second presentation times to a set of baseline items presented for the first time at the beginning of the second session. The baseline items chosen were the first presentations of each critical condition in the second session. These 11 words and 11 nonwords came from the first use of the first sequence template in this second session. (Note that these items were cycled through conditions across subjects.)

With this baseline measure, the mean across-session priming scores were significantly above zero for words (mean=26.2ms, t(23)=2.51, p<.05), but not for nonwords (mean=12.2ms, t(23)=0.86, p>.1). Figure 5.4 plots the priming for individual subjects as a function of the time delay between sessions (0 to 166 hours). As is apparent in this plot, there was no correlation between the across-session time delay and priming for words (r=-.01), but a significant negative correlation for nonwords (r=-.51, p<.05). These results are perhaps best interpreted as showing that, for low frequency words, priming stays significantly above zero (at around 25ms) with no noticeable decay over periods of up to nearly a week. For nonwords, decay in observed priming occurs over this time. However, (as discussed in earlier experiments) reduced long-term priming for nonwords is difficult to interpret where a lexical decision task has been employed: the observed decay across time could be due to a decaying representation of the target, but could equally well be due to the effects of increased familiarity taking over from an initial advantage due to the "trace" of the target.

4 Indeed, an examination of reaction times to first presentations as a function of position within the list presented in each session showed a practice effect within each session, and a substantial decrease in reaction times between the end of session 1 and the beginning of session 2, consistent with a recovery from fatigue.
Summary. The primary focus of the present experiment was on the decay of short-term priming in the absence of interference as compared to priming with "complete" interference (i.e. an interfering item presented every two seconds.) With interference, the sharp interaction observed previously between lag and lexicality was replicated (despite a change in the trial-sequence previously used to vary lag). Without interference, however, priming for both words and nonwords decayed smoothly. For nonwords, it was clear that interference increased the decay rate of ST priming. For words, interference reduced priming, but there was some uncertainty as to whether this arose through an increase in the decay rate of short term priming, or through a reduction in the level of long term priming. Unfortunately, practical constraints allowed only one longer time delay to be employed (the 16 second condition),
making it difficult to tell whether ST priming had decayed completely by this time.

For both words and nonwords, the present results support the view that the decay of priming over "lag" (as reported in Chapters 2, 3 and 4) occurs partly due to spontaneous trace loss caused by time delay, and partly due to the effects of interference caused by intervening items. In addition, the relative influence of these two factors on short-delay priming for targets of different lexicalities has provided an explanation of the specific decay patterns previously observed. In particular, the lag × lexicality interaction, which reflects the precipitous decay of priming for nonwords, has been shown to arise because ST priming for nonwords is extremely sensitive to interference, while ST priming for words is much less so.

5.3 CONCLUSIONS

The experiments examining short-lived priming presented in Chapters 2, 3 and 4 all documented decay of repetition priming over short lags. However, the variable "lag" manipulated in these earlier experiments confounded two underlying factors which might have produced the observed decay, namely spontaneous loss of the "trace" of the first presentation, and destruction of this trace by interference from items intervening between target repeats. The two experiments reported in the present chapter have provided evidence that both of these factors contribute to the decay of priming over short lags, by disentangling the effects of time delay and of intervening items on priming for words and nonwords.

Experiment 5.1 compared priming in reference conditions, in which a given number of items and a given time delay intervened between target repeats, to conditions in which a) the time delay was changed while the number of intervening items was held constant, and b) the number of intervening items was changed while the time delay was held constant. With this method, both factors were found to influence priming levels relative to a 0-items/4-seconds reference condition, such that priming reduced as the number of intervening items was increased, and increased as the time delay was reduced. These influences were observed for both word and nonword targets. Experiment 5.2 examined priming as a function of time delay between repeats, comparing conditions with and without lexical items intervening every two seconds between repeats. With only "blanks" intervening between repeats, decay was found to occur (demonstrating the effects of spontaneous trace loss), and to occur
smoothly for both words and nonwords. With lexical items intervening, decay was faster for both words and nonwords, and the nonword decay pattern reverted to the precipitous decay previously observed (demonstrating the additional effects of interference). Thus, Experiments 5.1 and 5.2 provided evidence that both spontaneous loss and interference contribute to the decay of priming over short lags.

Two further findings of Experiment 5.2 deserve emphasis. First, in the conditions where priming was examined with interfering items appearing every two seconds between target repeats, a replication of the lag x lexicality interaction reported in Chapter 1 was provided: priming for words decayed smoothly through a few intervening items while priming for nonwords decayed precipitously with a single intervening item. This replication is particularly valuable given that a different list structure (and so a different trial order) was used in this experiment from that used in the earlier experiments. Secondly, the disentangling of the effects of time delay and interference has established that this lag x lexicality interaction in ST priming occurs primarily because of the differential sensitivity to interference of word and nonword "traces". Specifically, nonword priming is far more sensitive to interference than word priming, and it is the presence of a single intervening item (rather than a 4 second time delay) which produces precipitous decay of priming for nonwords.

If ST priming for words and nonwords arises from transient changes in the state of lexical representations, the results presented in this chapter are clearly of relevance to models of word recognition. First, they suggest that lexical representations are able to maintain state changes for as long as 10 seconds (or perhaps longer for real words) in the absence of interference, and that these temporary modifications gradually decay of their own accord over this time. Secondly, the present results suggest that, whatever form of change may underlie ST priming, state changes for different target items in some way sum or interact to determine the ease of processing for any single one: processing intervening items is capable of changing response times to previously-presented targets.

In terms of models of word recognition, it may be noted that ST priming is not consistent with an effect produced by a transient modification taking the form of activation. As discussed in Chapter 1, activation is generally seen as the "online" processing mechanism, and is therefore assumed to be overwritten completely by processing of a single subsequent item so that the correct identification of the current stimulus may "win" over competing alternatives. Thus, while the severe effect of interference on nonword targets might be consistent with an explanation of ST priming in terms of leftover activation, the relatively mild effect of interference on word targets is most definitely not.
Within a memory framework, the finding that ST priming decays through both time and interference points to some similarity between ST implicit memory and ST explicit memory. However, in contrast to ST priming, ST explicit memory seems to show equivalent effects of each factor on word and nonword targets. The decay patterns over lag which were apparent for explicit recognition in Experiment 4.2 support this view. The most parsimonious interpretation of matching word and nonword patterns for explicit memory is that, in ST explicit memory, the relative effects of time delay and interference are the same for words and nonwords. Thus, while both mechanisms of decay appear to affect both implicit and explicit forms of ST memory, the two forms might well show differential sensitivity to each mechanism for different types of stimuli.
Chapter 6
General discussion

6.0 SUMMARY OF RESULTS

Findings will be summarised in three groups. The first group bears on the primary focus of this thesis, namely short term priming. The other two bear on issues which are only peripheral to the thesis, namely long term priming and general methodological questions. To clarify these summaries, Table 6.1 provides a reminder of the distinguishing features of the various experiments.

Table 6.1: Experiment numbers and distinguishing aspects of corresponding designs.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Short lags, low frequency words, lexical decision</td>
</tr>
<tr>
<td>2.2</td>
<td>As for 2.1, but naming</td>
</tr>
<tr>
<td>3.1</td>
<td>Long lags, low frequency words, lexical decision</td>
</tr>
<tr>
<td>3.2</td>
<td>As for 2.1, but high frequency words</td>
</tr>
<tr>
<td>4.1</td>
<td>As for 2.1 and 3.2, but explicit recognition</td>
</tr>
<tr>
<td>4.2</td>
<td>As for 2.1, but half the number of close repeats</td>
</tr>
<tr>
<td>5.1</td>
<td>Low frequency words, lexical decision, different presentation rates to independently vary time or interference between repeats</td>
</tr>
<tr>
<td>5.2</td>
<td>Short lags, low frequency words, lexical decision, plotted decay with and without interfering items</td>
</tr>
<tr>
<td>App. A</td>
<td>Short lags, low frequency words, lexical decision, varied visual mismatch (mild, severe) between first and second presentation. Design problems.</td>
</tr>
<tr>
<td>App. C</td>
<td>Short lags, medium and high frequency words, 4 and 5 letters, naming, crossed target and interference lexicality. Unexpected confounding.</td>
</tr>
</tbody>
</table>

Note: The two experiments presented in Appendices will be discussed later in the text.
6.0.1 Results pertinent to short term priming

Prior to the work presented in this thesis, the literature contained only a few investigations of repetition priming as a function of lag. These studies indicated that lag0 priming was greater than longer-lag priming, but they were, as a general rule, not well designed to examine the form of decay after lag0. They often employed slow presentation rates, rarely reported nonword data, and sometimes left suspicions of low power and/or item-specific effects.

The experiments reported in this thesis extend previous work in a number of important directions. First, it was demonstrated that a distinct short-lived priming effect can last beyond immediate repetition. This ability to survive some interference makes ST priming a much more interesting phenomenon than it would be otherwise, as it demonstrates that the effect cannot be explained in terms of a simple buffer storing the last item presented. Secondly, the effects of lexical status on ST priming were clearly specified for the first time. Here, the differential priming for word and nonword targets demonstrates that ST priming (for word-like stimuli) must have an explanation in terms of the process of word recognition. Thirdly, ST priming was dissociated both from standard long-lived priming and from explicit working memory. These dissociations suggest that ST priming can usefully be identified as a novel form of memory, namely short term implicit memory. Finally, ST priming was found to decay due to the presence of both time delay and intervening items, indicating that the "traces" which give rise to the effect undergo spontaneous loss, but also suffer interference.

The specific findings are summarised below. These findings were based primarily on analyses of reaction times. Analyses of error rates produced either no significant effects (perhaps reflecting low power due to low error rates) or effects that paralleled the findings apparent in the reaction time data, such that where subjects were faster they were also, in general, more accurate. Findings could not be explained in terms of speed-accuracy tradeoffs: ST priming tended to be apparent as both a temporary reduction in reaction times and as a temporary reduction in error rates.

**Duration and decay form for words.** With fast presentation rates, short-term priming for words lasted for roughly 8 seconds with three intervening items (Expts. 2.1, 2.2, 3.2, 4.2 and 5.2). Smooth decay over early lags was observed regardless of the task used (naming versus lexical decision) or the frequency of the target items (1-4 versus mean=275 counts per million).

**Duration and decay form for nonwords.** Short-term priming for nonwords was initially as large as for words, but remained positive only with immediate
repetition. Over four experiments using the same trial order (Expts. 2.1, 2.2, 3.2 and 4.2), negative ST priming at intermediate lags (ie. priming below the LT value) suggested that some short-term influence of the target was retained for perhaps 12 seconds with five intervening items. However, another experiment employing a different trial order (Expt. 5.2) failed to find any hint of such a dip. Instead, an immediate drop to, not below, the LT value was found with a single intervening item. Whatever the exact shape of decay of ST nonword priming, the pattern always differed sharply from that found for real words. This differential decay pattern is referred to as the lag \( \times \) lexicality interaction.

**Differences between ST and LT priming.** Four empirical reasons were found for distinguishing between ST priming and LT priming. The decay rate of ST priming (Expts. 2.1, 2.2, 3.2, 4.2 and 5.2) was much higher than the decay rate of LT priming (Expt. 3.1), for both words and nonwords. Word frequency was found to influence the level of LT priming, but to have no effect on either the magnitude or the decay rate of the short-term advantage over and above this level (Expt. 2.1 vs Expt. 3.2; however, note that this cross-experiment comparison confounded target frequency with the frequency of intervening words). Similarly, the proportion of close repeats in the list was found to influence LT but not ST priming (Expt. 2.1 vs Expt. 4.2). One example of ST priming in the absence of LT priming was observed (for very high frequency words in Expt. 3.2). The latter three findings strongly suggest that ST and LT priming are independent and additive, in that decay curves had the same shape over short lags regardless of the level of LT (and thus overall) priming.

**Differences between ST priming and ST explicit memory.** Three empirical reasons were found for distinguishing ST priming from ST explicit (working) memory. Lexical status influenced ST priming (producing the lag \( \times \) lexicality interaction described above), but did not affect recognition memory over short lags: explicit recognition showed matching smooth decay functions for both words and nonwords (Expt. 4.1). Overall explicit recognition times were slower than either lexical decision or naming times (Expt. 4.1), suggesting that priming (ie. a speed increase) in these latter tasks was unlikely to be produced via the use of explicit recollection of earlier items/responses. Halving the proportion of close repeats did not reduce the magnitude of ST priming or increase its decay rate by very much (Expt. 4.2); thus, manipulating the apparent incentive for subjects to use explicit encoding/retrieval strategies had little or no influence on ST priming.

**Relative effects of spontaneous trace loss and interference.** Both time delay and the presence of intervening items between repeats contributed to the decay of ST priming, for both word and nonword targets (Expts. 5.1 and 5.2). Differential sensitivity to interference was found to be responsible for the lag \( \times \) lexicality interaction, with ST priming for nonword targets suffering
substantially greater interference from intervening items. For words, the form of
decay over time was smooth both with and without interference. For nonwords,
decay was smooth over time alone, but returned to the previously-observed
sharp decay when interference was present (Expt. 5.2).

6.0.2 Order effects: A possible methodological problem

In all experiments evaluating ST priming, highly specified trial orders
were employed to vary lag. The same fixed order of conditions was used for
every subject in Experiments 2.1, 2.2, 3.2 and 4.1 (see Appendix B for the actual
order). In Experiment 4.2, this same order of word- and nonword- trials was
used, but half of the occurrences of each short-lag condition had one
presentation swapped across blocks. A different fixed order of conditions was
employed in Experiment 5.2.

Fixed orders were employed because of the difficulty of manipulating lag.
Including lag as a variable means that trial orders will, by definition, not be
random, and in order to include as many lag conditions as possible in as few
trials as possible, it was necessary to overlap conditions and so very strictly
control trial order. (There was already a minimum of 1100 trials per experiment,
and any alternative manipulations of lag would have involved an unreasonable
increase in this number.) Although necessary, the use of fixed orders makes it
possible that trial order influenced the observed patterns of priming. It will be
argued, however, that such influences are highly unlikely to have affected the
main conclusions drawn above regarding ST priming.

Several important findings came from across-experiment comparisons
where the same trial order was used in both experiments. In these cases, the
advantage of having maintained the same trial order is that differences, or lack
of differences, across experiments cannot be attributed to order effects. Thus, we
can trust that the agreement in ST decay patterns across priming tasks, and the
dissociations of ST priming from LT priming and ST explicit memory, were not
due to order effects. However, one critical finding came from the within-
experiment comparison of decay patterns for words and nonwords, namely the
lag x lexicality interaction. Given that most of the experiments which produced
this lag x lexicality interaction employed the same trial order, the effect might
have arisen partly from having the same confounding effects of order present
within each of these experiments.

In evaluating any possible confounding effects of trial order on the lag x
lexicality interaction, note first that only a very specific form of order effect could
have influenced the pattern of results, namely the effects of processing items in
a fixed sequence of lexicality. There can be no effect on the data of the order of
particular stimuli, given that stimuli were cycled through lag conditions across subjects and thus that each subject received a different order of individual items. In addition, there can be no effect of the order of response, given that priming patterns in naming (where all responses differ) paralleled those in lexical decision (where there are only two possible responses). However, there might have been effects of the order of lexicality itself.

This could only be the case if there actually was a confounding between the lexical status of the target (at a given lag) and the lexicality of the trials leading up to its second (and possibly first) presentation. In the case of Experiments 2.1, 2.2 and 3.2, such a confounding existed. At lag1, which is particularly important in the lag x lexicality interaction, the item intervening between target repeats was a word on 20/20 trials with words as repeated targets, and 16/20 trials with nonwords as repeated targets. To be assured that no form of order effect could have influenced the pattern of results, one would wish to have 50% of intervening items being of each lexicality for both types of targets. (Lags 2 and 3 were reasonably close to this ideal.)

Despite this confounding, there are three reasons for having confidence that order effects were not responsible for the basic form of the lag x lexicality interaction. Most convincingly, Experiment 5.2 employed similar lag conditions to those used in the earlier experiments but with a completely different trial order, and found the same smooth decay of ST priming for words and the same precipitous decay for nonwords. This experiment (by chance) had a much more desirable trial order in the lag1 conditions, with 9/17 intervening items being words for both word and nonword targets.

In addition, data were examined as both priming scores (first - second) and second-presentation reaction times alone. Only the former of these measures was discussed in the thesis, but all results were essentially the same when analysed with the latter (means of both are reported in the tables of data included in Chapters 2-5). Given that priming scores might be affected by the order of trials preceding both first and second presentation, while second-presentation scores can be affected by that leading up to the second presentation only, the agreement between the two measures increases confidence in the reported patterns of priming.

Finally, any effects of lexical order would be expected to be quite small in comparison to the size of the ST priming effect (close to 100ms at lag0 in all lexical decision experiments), and more importantly in comparison to the size of the difference between word and nonword targets at lag1 (range of 40-65ms). Even if all trials preceding first presentations, or intervening between first and second presentations, were of the same lexicality (and such an extreme bias never occurred), it would hardly be expected that trial order would produce effects of such magnitude.
There is only one result over which the possibility of order effects casts a real cloud, namely the finding of a "dip" in ST priming for nonwords at intermediate lags. This effect was small (<10ms), and while it was remarkably consistent across a number of experiments, all of these used the same trial order. The only relevant experiment employing a different trial order found no hint of a dip: a single intervening item reduced nonword priming to a completely flat line. The status of the nonword dip, therefore, remains somewhat unclear, although the basic form of the lag × lexicality interaction is not in doubt.

6.0.3 Results pertinent to long term priming

The focus of the empirical work presented in this thesis was ST repetition priming. However, a few incidental findings were obtained regarding standard LT priming. These are summarised below for completeness. Some comment on interpretation and/or agreement with the previous literature is made, but the full implications of these findings for theories of standard LT repetition priming are not considered.

Decay rate of LT priming. The decay rate of standard priming was very slow. Over periods of up to 40 minutes, LT priming decayed at around 1ms per minute (Expt. 3.1). For words, no further decay in LT priming was found over delays of between an hour and a week, with an average value over this time of around 25ms (Expt. 5.2). Gradual decay of priming was apparent over this timescale for nonwords. These results are consistent with previous evidence of the duration and magnitude of standard repetition priming.

No LT priming for very high frequency words. For words of very high frequency (mean Kucera-Francis count = 275 per million), no LT priming was observed (Expt. 3.2). This complete lack of priming is rather unusual: while high frequency words are known to show less LT priming than low frequency words, some positive priming is still generally observed for these items. The "high" frequency words used here, however, were substantially higher in average frequency than the "high" frequency words used in most previous studies (eg. Jacoby & Dallas, 1981; Scarborough, Cortese & Scarborough, 1977). Assuming that there is a continuous negative relationship between word frequency and priming (Kirsner, Dunn & Standen, 1989), words sufficiently high in frequency might be expected to show effectively no priming.

Proportion of close repeats in list. Halving the proportion of items repeated at "close" delays (within 23 items), while maintaining the proportion repeated in the full list, reduced the level of LT priming for both words and nonwords (Expt. 2.1 vs Expt. 4.2). This extends previous reports that the amount of LT priming varies with the total proportion of repeated items in the list (eg.
Jacoby, 1983b), and would seem to suggest that LT priming is at least partially dependent on the motivation that subjects feel to learn/remember individual items.

6.0.4 Results pertinent to general methodological issues

The empirical work presented in this thesis produced concrete data relevant to three general methodological issues which arise in the investigation of both ST and LT priming.

Priming and implicit memory. It is commonly assumed that priming in reaction time tasks (which require no reference to earlier items in the list) is likely to reflect the operation of implicit, rather than explicit, memory. Empirical evidence that explicit recognition (Expt. 4.1) is both slower and less accurate than either lexical decision (Expt. 2.1) or naming (Expt. 2.2), supports the view that priming in these tasks is relatively uncontaminated by explicit influences: an advantage on repeated trials seems unlikely to arise from the use of deliberate recollection when recollection is so much more difficult than simply performing the required task with no overt reference to a prior presentation.

Priming for nonwords and the lexical decision task. A number of authors (Bowers, 1994; Dorfman, 1994; Feustal, Shiffrin & Salasoo, 1983) have pointed out that it is difficult to interpret measures of priming for nonwords in the lexical decision task. Here, prior presentation might be expected to speed processing on repeated trials (tending to help a "no" decision) but simultaneously to increase familiarity (making the nonword appear more word-like and so tending to hinder a "no" decision). The amount of nonword priming actually observed will then depend on the combined effect of these two competing influences. Potentially, then, any of positive, negative or zero observed priming are consistent with a retained "trace" of a nonword target, and differences in observed priming across conditions do not necessarily reflect differences in the surviving strength of target influence.

For short term priming, no evidence of such competing influences was found: decay patterns in naming matched those reported in lexical decision. Long term priming, however, was greater for nonwords than for low frequency real words in naming (Expt. 2.2), while the two showed equal priming in lexical decision (Expt. 2.1). This finding that LT priming for nonwords was proportionally smaller (in comparison to the amount of word priming) in lexical decision than in naming is consistent with the view that long term priming in lexical decision is reduced to some extent by increased familiarity arising from prior presentation of a nonword target.
Faster baseline responses produce less priming. In general, it might be expected that smaller priming scores would be obtained where first-presentation reaction times (ie. the baseline for priming) are faster, simply because the repetition advantage is reduced where there is less "room to improve" on a second presentation. This raises the issue of whether priming should be reported as the absolute speed increase, or as a proportionate speed increase. The conclusions drawn might differ depending on which measure is employed. Suppose, for example, the absolute magnitude of priming was 45ms in one condition and 70ms in another, but the baseline reaction times were 450ms in the first condition and 700ms in the second. In this case, both conditions show a 10% improvement in performance. Do we conclude that performance differs across the two conditions or not? Unfortunately, there is no easy answer to this question.

The present thesis contains a number of examples of variation in priming across tasks or item types which is intrinsically confounded with baseline differences. The most obvious is the difference in priming between the naming and lexical decision tasks: priming in naming was much smaller, but naming responses are also much faster overall. The frequency effect on LT priming could perhaps also be attributed to baseline differences: high frequency words are responded to faster and show a smaller repetition advantage. A final example is the finding of reduced priming for a fixed set of nonwords when they were contrasted in lexical decision with high frequency words (Expt. 3.2), rather than with low frequency words (Expt. 2.1): here, faster overall responses and reduced priming were observed when the easier contrast with HF words was made.

It should be emphasised that baseline differences did not contribute to the primary effects apparent here in short term priming, because the cycling of items across lag conditions ensured that the baseline reaction times were equivalent across all lags. While baseline differences may have contributed to the overall magnitude of priming with various tasks, item types or list structures, differential patterns of decay over lag cannot not be put down to differences in overall speed of response.

6.1 THEORETICAL INTERPRETATIONS OF SHORT TERM PRIMING: INTRODUCTION

The present results have a number of theoretical implications, some pertinent to a "memory" approach to understanding ST repetition effects, and some to a "perceptual" approach. From a memory perspective, it will be argued that ST priming reflects a short term form of implicit memory, and probably
relies on ahistoric rather than historic traces. From a perceptual perspective, it will be argued that ST priming arises from traces left within the word recognition system, most likely taking the form of a transient modification of the state of orthographic representations. Possible decay mechanisms of these state changes and the form of orthographic representation undergoing modification will be discussed briefly, although it will be seen that the present data provide little clarification of these issues. Instead, it will be proposed that the major implication of the present data for word recognition is that the lexical system is able to maintain several words "active" at once, suggesting the existence of a time window of orthographic processing lasting beyond a single trial.

The interpretations proposed within the memory and perceptual frameworks should not be seen as in any way in competition with each other. Rather, the two approaches extant in the literature are seen as providing two different levels of analysis at which the findings can be interpreted. The memory framework provides the more general level of analysis, concentrating on the similarities and differences between ST priming and other manifestations of information retention. The perceptual framework is more specific, and attempts to provide a more detailed explanation of the actual mechanisms that might give rise to the new form of memory proposed.

One or two ST effects? Before considering the theoretical interpretation of ST priming, it may be useful to clarify the argument that ST priming represents a single phenomenon. This clarification is necessary given the finding of (positive) ST priming for nonwords at lag0 only; the patterns of priming across lag could perhaps be interpreted as showing that a) there is a lag0 effect common to both words and nonwords, possibly due to a visual "buffer", b) there is a distinct intermediate-lag priming effect which exists only for real words, perhaps implicating a role for a pre-existing representation of the complete target, and c) there is the standard long-lived repetition priming effect for both words and nonwords (see Ratcliff, Hockley and McKoon, 1985, for a similar idea). In other words, the observed priming over lags 0 through 4 could be interpreted as consisting of two components (lag0 plus lags 1-4), in addition to long term priming.

The strongest argument against this alternative interpretation is that ST priming for nonwords decayed with the same form as that for words when no interfering items were present between repeats. A ST effect lasting 6 or so seconds in the absence of interference hardly seems consistent with temporary buffer storage. A more natural interpretation is that ST priming arises from a single source for both words and nonwords, but that the traces laid down by nonword targets are in some way weaker and more easily damaged by interference.
A second argument is that a number of manipulations affecting LT priming, namely priming task, word frequency and the number of close repeats, maintained the same pattern of decay over all short lags, including lag0 and lags 1-4. If there were two effects, only one of which was lexical, it seems unlikely that such consistency would be observed.

A final argument that lag0 priming for nonwords reflects a more general ST priming phenomenon is the suggestion from four experiments that there is an intermediate-lag effect for nonwords, although it is negative instead of positive, i.e. below rather than above the LT value. However, without further evidence that the nonword dip can be replicated with different trial orders, this particular argument remains somewhat weak.

6.2 INTERPRETATIONS WITHIN A MEMORY FRAMEWORK

6.2.1 Short term implicit memory

The finding that ST priming can be dissociated from both LT implicit memory and explicit working memory suggests that ST repetition effects reflect a distinct short-lasting form of implicit memory. This "memory forms" approach to understanding ST priming implies that the ST/LT distinction and the implicit/explicit distinction might be orthogonal to each other, and that implicit memory, just like explicit memory, can be usefully divided into long and short term components. Furthermore, the duration of short term implicit memory appears to be similar to that found for short term explicit memory, that is, somewhat less than 10 seconds and/or a few intervening items.

There are several reasons for claiming ST priming as manifestation of a new memory form. Short term priming has been distinguished here from LT implicit memory on the basis of four findings, namely the demonstration that ST priming can exist in the absence of LT priming, the demonstration that ST priming decays much more rapidly than does LT priming (of the order of 600 times as fast), and the differential effects of word frequency and of the proportion of close repeats in the list. Implicit and explicit ST memory have been distinguished partly on the basis of the dissociation produced by the manipulation of lexical status on priming and explicit recognition. Additional aspects of the methods used to investigate ST priming, and of the results obtained, are at least consistent with the view that ST priming is not based on deliberate retrieval. These are: that the very large number of trials would be expected to discourage the subjects from using explicit memory when it was not
necessary to do so in order to complete the task; that halving the number of
close repeats (and presumably, therefore, reducing any incentive for subjects to
deliberately learn/retrieve individual items) did not affect ST priming; and finally
that subjects found explicit recognition substantially more difficult than both
lexical decision and naming.

It was proposed in Chapter 1 that a new memory form should be posited
when this will increase, rather than decrease, the degree of conceptual structure
which can be imposed on the empirical data. Some standard criteria for deciding
that reference to a new memory form is warranted include demonstration of: one
memory form in the absence of others; different forms of access (eg. conscious,
nonconscious); specialisation for different types of materials or events; different
learning or decay rates; and experimental dissociations between the new
phenomenon and well-established memory forms (eg. see Roediger, Rajaram &
Srinivas, 1990, and Schacter & Tulving, 1994). Most of these conditions have
been met in the work presented here. Overall, the differences between ST
priming and other manifestations of memory seem sufficient to justify the
conclusion that the effect reflects a novel memory form.\footnote{Recall from
Chapter 1 that new memory forms are usually defined simply when
exemplars of each form of memory share more properties with other exemplars of
the same form than with exemplars of different forms. At this stage there is too little
evidence to say whether ST priming might represent a new memory system, defined as relying on
fundamentally different types of trace or entirely distinct physiological mechanisms or
locations.}

The present data are interpreted as showing that, at short lags, both ST
and LT implicit memory components contribute to the observed priming scores.
It is not that one operates at short lags and the other only at long lags. Findings
that the long term priming level can be altered without affecting the magnitude
or decay of the short-lived priming present over and above this value provide
evidence that ST and LT priming are \textit{independent and additive}, and thus that the
total observed priming at any given lag is given by the sum of the two
components. This interpretation of an implicit memory ST/LT distinction is
therefore somewhat different from at least some views of the explicit memory
ST/LT distinction (for example, views which require that material stored in LT
explicit memory must first "pass through" working memory).

Although ST implicit memory and explicit working memory have been
dissociated, one way in which the two memory forms appear somewhat similar is
in their process of decay. Working memory is believed to decay through the
effects of both spontaneous trace loss and interference (Shiffrin & Nosofsky,
1994), as ST priming has been reported to do. One important difference of detail,
however, is that the critical effects of interference on \textit{nonwords} observed in the
priming tasks were not replicated with explicit recognition.
6.2.2 Historic or ahistoric traces?

A general issue raised by a "memory" interpretation of ST priming is whether such priming arises from historic (context-specific) or ahistoric (abstract) traces. As noted in Chapter 1, the evidence in favour of the view that long term priming is historic comes from two sources. First, such priming lasts far too long to be consistent with persistence of modifications to abstract representations (i.e., buildup from multiple exposures to many words in normal reading would produce catastrophic interference to subsequent processing). Secondly, LT priming is sensitive to mismatches between presentation format at study and test. Importantly, there are some reports of a reduction in priming following within-modality changes in visual appearance, which suggest that maximum LT priming arises from re-use of a complete, context-specific, processing trace.

Short-term priming, in contrast, is short-lived enough to be consistent with transient state changes of abstract representations. Indeed, the magnitude of this effect at lag0, in combination with its rapid decay over a few intervening items, makes ST priming look tantalisingly like an effect arising from the type of short-lived modification (e.g., activation) of pre-existing representations which was at one stage proposed to underlie all priming effects. In terms of duration, then, ST priming is highly consistent with an effect arising from ahistoric modifications of stable representations.

At present, only limited evidence is available regarding the within-modality specificity of the ST priming trace. This evidence comes from an experiment presented in Appendix A. The experiment referred to was conducted prior to those presented in the body of the thesis, and was not well controlled, especially for nonword targets (see Appendix A for a complete discussion of possible methodological problems). Priming for words and nonwords was measured at lags 0 and 6, and a very large ST priming effect was found (approximately 150ms). Most interestingly, this lag0 priming a) was completely unaffected by the introduction of a mild visual mismatch between first and second presentation (one presentation clear, the other somewhat degraded), for both word and nonword targets, b) remained completely unaffected by a severe visual mismatch for words (one presentation lower case, the other upper case), and c) was at best slightly reduced by the severe visual mismatch (case change) for nonwords. These findings provide at least preliminary evidence that ST priming is little, if at all, affected by within-modality study-test mismatches.

Both the duration of ST priming and its apparent insensitivity to visual form, therefore, suggest an "ahistoric" interpretation of short term implicit
memory. There are obvious problems with such an explanation of long term priming, but at present it seems highly appropriate for short term priming.

6.2.3 Generality across domains

If ST priming is to be considered as reflecting a form of memory, at least some cross-domain generalisation should be apparent, and ST priming should occur for stimuli other than words and nonwords. In the literature to date, there have been a few studies of priming over short delays for non-lexical stimuli. These studies, summarised below, all provide evidence at least consistent with a non-lexical ST priming effect analogous to the lexical effect reported here, although only one provides convincing evidence for ST priming in another domain.

Bentin and Moscovitch (1988) examined priming for unfamiliar faces and nonfaces, in a face-nonface decision task. Lag0 priming was significantly above zero for both types of stimuli, but neither type showed significant priming at lags 4 or 8. However, no lags between 0 and 4 were employed, making it difficult to know how rapidly the effect decayed.

Kersteen-Tucker (1991) examined priming for symmetrical and non-symmetrical polygons in a symmetry-decision task. For symmetrical polygons, priming at lag0 was greater than that at lags 4 and 8. Lag1 priming fell somewhere between lag0 and longer-lag priming, and was not significantly different from either. This finding suggests a ST priming effect for pictures of objects, although a more powerful test would be needed to determine whether the critical lag1 priming is really above longer-term priming. For nonsymmetrical polygons, priming was significantly above zero only at lag0. No comparisons between lag0 priming and that at later lags were presented for these items.

Smith (1968) presented the numerals 1 or 2, on either a red or green background. Subjects were required to press one key if either a Red 1 or a Green 2 was presented, and another key if either a Green 1 or a Red 2 was presented (the colour refers to the background). A substantial immediate-repetition advantage was found for trials on which the stimulus matched the preceding trial, using a 2 second inter-trial interval. As the time delay between repeats was increased by increasing the intertrial interval to 6 and then 10 seconds, the immediate-repetition advantage was smoothly reduced, consistent with a ST priming effect decaying over time. Unfortunately, priming was not reported as a

\[^2\text{Reduced priming effects for nonsymmetrical stimuli could arise for the same reason as reduced priming effects for nonwords in lexical decision: in both cases, a "no" decision is being repeated (see Gruppuso & Masson, 1994).}\]
function of the number of items intervening between repeats, and so the effects of interference on the repetition advantage are not clear.

More recently, Maljkovic and Nakayama (1994) have provided very powerful measures of non-lexical priming at every lag between lag0 and approximately lag10. They examined priming for the attention-grabbing features of simple visual patterns, using a visual search paradigm. Targets differed from background items in such a way as to always produce "popout" search for the target, usually by the use of a distinguishing colour, ie. a red diamond in a background of green diamonds, or vice versa. Once the differently-coloured target was found, subjects were required to decide if the diamond was missing a corner on the left or the right. A substantial advantage of repeating the same target colour across successive trials was found (in contrast to no effect of maintaining the same response). While a colour match between the target and the immediately preceding trial produced a 50ms advantage, matches with trials further back in the list also independently produced smaller advantages for the same-colour target.

Of most interest for the present discussion is that the same-colour advantage lasted for around five intervening trials and decayed smoothly over intervening serial positions, providing evidence of a short-lived repetition effect similar in duration to that reported here for English words in lexical tasks. In addition to demonstrating a ST priming effect for non-lexical stimuli, Maljkovic and Nakayama also provided evidence that the effect was insensitive to subjects' explicit strategies, by showing that the predictability of the order of target colours across trials did not influence priming. Thus, their ST priming effect appears to represent short term implicit memory in a non-lexical perceptual domain.

6.3 INTERPRETATIONS WITHIN A PERCEPTUAL FRAMEWORK

It has been argued above that ST priming reflects a novel memory form, namely short term implicit memory. This proposal implies that the explanation appropriate for ST priming is unlikely to be the same as those appropriate for either working memory or LT implicit memory. (This is not to say, of course, that there is no relationship between ST priming and other forms of memory.) However, the identification of ST priming with short term implicit memory does not, of itself, provide any clues regarding the factors which give rise to ST priming. Clearly, some explanation of the basis of such priming needs to be considered.
One suggestion which came from considering ST priming in the light of "memory" is that ahistoric traces underlie short term implicit memory. An ahistoric explanation of ST priming is, of course, very much in the tradition of a straightforward "perceptual" explanation of the effect, in which priming is described in terms of changes in the state of a target's internal representation. Under this view, ST priming should arise from "traces" left within the relevant perceptual processing system. For the word and nonword stimuli used here, ST priming would be expected to rely on transient modification of representations within the word recognition system.

6.3.1 A lexical-level effect

Clear evidence that ST priming does, indeed, arise from traces left within the word recognition system comes from the finding of an interaction between lag and lexical status. This interaction locates ST priming as a lexical-level effect: neither a simple visual trace nor a higher-level explicit memory trace (say) would be expected to produce priming effects that differ for words and highly word-like nonwords. The reader should be reminded that the use of the term "lexical" does not mean that ST priming is restricted to real words. As was argued at length in Chapter 1, there are both empirical and theoretical reasons to assume that word-like nonwords are able to access the representations used to process real words.

6.3.2 Locus within the functional architecture of word recognition

The apparently ahistoric nature of ST priming suggests that the lexical "traces" underlying the effect take the form of temporary modification of the state of lexical representations. In this case, the type of lexical representation undergoing modification is at issue: semantic, orthographic, or phonological?

The general view that implicit memory relies on perceptual rather than semantic representations might suggest that the ST priming reported here relied on orthographic and/or phonological representations. One result which is consistent with a non-semantic locus is the finding of ST priming for nonwords. The pseudowords employed as nonword targets should not be able to access semantic representations, as they do not mean anything. However, their construction as legal English strings means that they should be able to access the perceptual representations used to identify real words. In Chapter 1, this point was argued for orthographic access on the basis of evidence that a) human response times to nonwords differ as a function of orthographic similarity to
English, and b) all parallel-access models of word recognition allow nonwords to activate real-word representations, regardless of the form of representation assumed. These arguments apply equally well to phonological representations, and, indeed, there is a strong confounding of orthographic legality with phonological legality in English. Thus, the ST priming for nonwords reported here could be interpreted as arising at either an orthographic or phonological level, with the present data providing no direct evidence distinguishing these two possibilities. The results do, however, show that both real words and pseudowords transiently modify perceptual, rather than semantic, representations to produce repetition effects over short time delays.  

Although the present results provide no empirical basis for distinguishing between an orthographic and phonological basis for ST priming for, there are two reasons for assuming an orthographic locus in the absence of alternative evidence. First, an orthographic locus is supposed given that written, rather than spoken, presentation was employed, and long term priming is generally found to be specific for input modality (Kirsner, Dunn & Standen, 1989).

Secondly, empirical support for an orthographic locus of short term priming for written materials comes from data reported by Kirsner and Smith (1974). Their study apparently shows that ST priming is modality specific, although the data were not originally examined in the light of this issue and so the appropriate analyses to test this conclusion statistically were not presented. A substantial "short term" (lags 0 and 3) advantage over "long term" (lags 15 and 63) priming was present in their study when repeated visual presentations were used. This advantage was 82 ms for words and 61 ms for nonwords, on a comparison of the mean priming for the two short lags with the mean for the two long lags. However, the additional short term priming (along with about half of the long term priming) disappeared when the visual second presentation was preceded by an auditory first presentation: the short term advantage was -2 ms for words, and 14 ms for nonwords. Thus, ST priming for visually-presented targets appears to have relied on modification of representations accessed by visual but not auditory presentations; that is, on orthographic rather than phonological or semantic representations.

6.3.3 Mechanism of lexical state changes

If ST priming for words and nonwords arises from modification of the state of lexical representations, the data imply that these state changes must endure for as long as 10 seconds (or perhaps longer for real words) in the
absence of interference. State changes appear to decay spontaneously over this time, where "spontaneously" means that decay occurs even when no new lexical input arrives, perhaps through some mechanism internal to the representation, or perhaps through the effects of noise within the system.

In terms of the variety of current approaches to word recognition, there are several forms that lexical state changes might take, including (but not limited to) changes in activation, resting-level activation, thresholds or link weights. It is not clear which, if any, of these would be able to endure for 10 seconds without substantially affecting the online processing capability of the model. It should be emphasised, however, that ST priming lasts too long to be explicable in terms of the simple activation mechanism embodied in current models of word recognition. For this reason, the more general terms transient modification of lexical representations or state changes of lexical representations are preferred as labels for the explanation of ST priming put forward here, rather than the potentially confusing activation account which might be suggested by the current implicit memory literature.

6.3.4 Form of orthographic representation

The form of orthographic representation assumed to be modified is also at issue. As described in Chapter 1, possible forms of word-level representation range from completely distributed (e.g. Seidenberg and McClelland, 1989) through partially distributed (e.g. Taft, 1991) to completely localised (e.g. McClelland and Rumelhart, 1981, Morton, 1969, 1979). That is, ST priming could potentially arise from transient modification of hidden units in a completely distributed system, sub-word nodes in a partially distributed system or whole word nodes in a completely localised system.

The present data do not allow any strong conclusions to be drawn regarding this issue. Two aspects of the results, however, seem consistent with the existence of localised whole-word representations (either in addition to, or instead of, distributed representations). First, ST priming (for words at least) can survive interference from three intervening items. One might expect that changes to localised representations, which could be independently modified for each stimulus and thus "store" each word separately, are more likely to be able to survive this degree of interference than distributed representations, in which processing successive items would require different patterns of activation over a shared set of units. With distributed representations, words might be more likely
to "hit" units involved in the representation of other words, thus making traces highly sensitive to interference.4

A second result suggestive of localised representations is the differential decay patterns of ST priming for nonwords, on the one hand, and low frequency words and high frequency words, on the other. In particular, the finding that ST priming decays in exactly the same manner for real words of vastly different frequency, while showing a completely different decay pattern for highly-wordlike nonwords, suggests that whole-word units exist, and that ST priming relies on transient modification of these units.

6.3.5 The process of interference

It is apparent that ST priming decays partially through the effects of interference, and that these effects are much more severe for nonwords than for words. From the present data, it is not clear how these effects are to be conceptualised. One unaddressed issue is whether the effects of interference act proactively or retroactively. In Experiment 5.2, which examined priming as a function of time delay with and without interference, the reduced priming found with intervening lexical items rather than with intervening "blanks" could be attributed to either form of action. For example, compare:

CRET LAKE FROG BEAN MAVE SUNE FROG (interference)

with CRET LAKE FROG :::::: :::::: :::::: FROG (no interference)

On the one hand, the presence or absence of intervening lexical items between the two presentations of FROG changes the nature of the trials following its first presentation. Here, the intervening items might produce retroactive interference by damaging the record of the earlier presentation. On the other hand, the nature of the trials preceding the second presentation also differ across the two conditions. Here, the intervening items might produce proactive interference by leaving traces which somehow slow the processing of successive items, including the second presentation of FROG. (Any proactive effects should affect the first presentations in both conditions equally, as both should have been preceded by lexical items and by blanks equally often.)

4 See McCloskey and Cohen (1989) and Murre (1992) for similar ideas regarding long term learning. These authors emphasise that the standard system producing distributed representations (ie. a three-layer neural network learning via back-propagation), such as that used by Seidenberg & McClelland (1989), shows severe disruption of old knowledge by new learning. This arises because the state of every connection in the system is adjusted in favour of each new stimulus.
A second unaddressed issue concerns whether successive items interfere with one another because their traces interact with each other, or because these simply sum to determine the current starting-state of the system for each new item. Under an *interaction* interpretation of the effects of interference, traces constantly damage, and are damaged by, other traces. This could occur either proactively (eg. reducing a modification that would otherwise have occurred favouring a later target), or retroactively (eg. overwriting a modification which existed favouring a previous target).

An alternative view is that the traces left by each trial coexist peacefully within the lexical system, undergoing spontaneous and independent decay. Under this *noninteraction* interpretation, the effects of interference become apparent only because the sum total of all current modifications determines the starting-state of the system on each new trial: the sum will tend to bias the system in favour of a repeated stimulus to a lesser extent if the total state is also affected by modifications favouring alternative items. If traces do not interact, it becomes difficult to distinguish between proactive and retroactive interference, as intervening items neither "write over" previous items, nor make it more difficult for the next item to be "written in". Instead, the effects of interference arise when the system is *used*, rather than through disruption of stored traces.

An interaction view implies that all representations are competing for a resource that must be shared between them (eg. something like activation). A noninteraction view, in contrast, suggests a mechanism which can operate independently for each representation simultaneously (eg. perhaps a lowered threshold), rather than a limitation on a shared resource.

### 6.3.6 Retention of multiple words: A time window of lexical processing

The preceding discussion indicates that many fundamental questions regarding the explanation of ST priming in terms of lexical processes remain unanswered or at best only partially answered. The implications of the ST priming findings for many key aspects of word recognition are similarly speculative. This is not surprising given the view that priming and perceptual processing are completely intertwined: without a full understanding of the process of word recognition, a full understanding of ST priming for words and nonwords cannot be obtained, and vice versa.

However, the simple observation that ST priming endures across a number of trials has one strong implication for word recognition. This is that the system can maintain multiple fully-identified words "active" at once, in the sense that the recent presentation of these items is coded in some way and then
retained for a few seconds and/or a few trials. (The use of the term "active" here is not necessarily meant to imply that this coding relies on leftover target-representation activation as the particular mechanism for retaining multiple words.) This is true of real words, although the situation regarding nonwords is less clear due to the ambiguity surrounding the finding of a "nonword dip." If ST priming for nonwords does dip below the LT level at intermediate lags, then there is evidence that the system can retain multiple nonwords. If, on the other hand, ST priming for nonwords exists only at lag0, then the severe effects of interference on nonwords would appear to limit the "capacity" of short term implicit memory for these targets to only one item.

The proposal that the lexical system has the ability to retain several words at once sees word recognition as operating within a time window of several seconds 5, during which the processing of any one target is influenced by all of the others currently "active", as well as by the incoming stimulus information. This view implies that all word recognition proceeds in the context of leftover effects of a number of preceding items. While it is well-accepted that sentence processing requires the temporary retention of some trace of recently-processed words, the possibility that the orthographic word recognition system might be one locus of such retention has not been considered in the literature. Current theories of written-word recognition consider processing of isolated words or nonwords only. The time window view of orthographic processing, however, argues that the process of visual word recognition needs to be considered for each item within a continuous series of trials. That is, the dynamic aspect of word recognition must be considered in addition to static, one-item-at-a-time, processing.

Consideration of dynamic processes is likely to raise two important questions about orthographic processing which will need to be addressed in the future. The first regards the process by which continuing traces of previous items are "overcome" without being completely destroyed. These traces must be at least partially replaced to allow successful processing of subsequent items, but must also remain partially active to produce ST priming effects, and it is not clear how such a state might be achieved. The second question is how the system determines which of various partially-active alternatives represents the current stimulus, and not one presented on a previous trial. It will be argued shortly (Section 6.3.8) that our views of the process of orthographic word recognition may need substantial rethinking in order to provide answers to these questions.

5 It is not clear whether or not this temporary "store" could be thought of as a serial-position window of a few items, rather than a time window of several seconds. The decay of short term priming through both interference from successive items and time alone suggests that some combination of time and serial position is probably coded.
6.3.7 Prediction of generalised proactive influences.

In addition to providing an explanation of post-lag0 ST repetition priming, a time window of orthographic processing greater than one trial predicts at least one novel form of empirical effect. This prediction is that a range of proactive non-repetition "priming" effects should emerge, in which particular items interfere with, or perhaps facilitate, the processing of various targets presented on subsequent trials. A post-hoc examination of data collected for this thesis, presented in Appendix C, produced preliminary evidence of such generalised proactive influences, based on the effects of target lexicality.

This examination of proactive effects ignored the repetition involved in all experiments, and, instead, evaluated reaction times to unrepeated items, or to first presentations of items that would later be repeated, as a function of the type of item(s) preceding the one of interest. Two forms of proactive influence of lexicality were uncovered. For both of these, processing a nonword slowed down subsequent responses to both words and nonwords, relative to processing a word. In a new experiment (reported in Appendix C), naming times gradually altered within sequences of up to eight words or eight nonwords presented in a row such that, in a sequence of real words, each word was named slightly faster that the one before it, while, in a sequence of nonwords, each was named slightly more slowly than the one before it. These effects were small (1-2 ms per item) but consistent. In addition, an examination of first-presentation reaction times across all experiments reported in this thesis showed that both words and nonwords were responded to faster if the immediately-preceding item was a word (by an average of 10-20 ms across experiments).

This post-hoc evidence of proactive influences is consistent with the general framework of a lexical modification interpretation of ST repetition priming, and the view that word recognition proceeds in the context of a variety of leftover influences of previous trials. If the time window proposal regarding orthographic processing is correct, it might be possible to identify additional proactive influences of a number of lexical properties, including word frequency, neighbourhood size, number of neighbours in common between "prime" and target, and so on. Given the observed duration of ST priming, effects of these variables might be expected to survive at least 1-3 intervening trials, although generalised effects of stimulus class might well be rather smaller than the effects of exact stimulus repetition.

6.3.8 Implementing a time window in computational models.

It was claimed above that a time window view of lexical processing is likely to require rethinking of a number of key assumptions about the process of
word recognition, in order to cope with the problem of dynamic, continuous,
processing. The potential difficulties with the current approaches emerge most
clearly when the operation of computational models of word recognition is
considered in the light of an extended time window of processing. Therefore,
issues arising from possible implementations of a time window within
computational models are now briefly discussed.

Current models of visual word recognition do not consider the possibility
of a time window longer than one trial. Instead, successive stimuli are assumed
to be processed in isolation, with the system "zeroed" between one trial and the
next. Such models, therefore, have not been evaluated for generalisability to the
case of multiple stimuli. It remains to be seen whether any current approaches
to lexical access can be adapted to successfully recognise new stimuli with a
relatively high degree of influence remaining from previous trials.

Most models assume that activation is the only mechanism by which
knowledge of a recently-presented stimulus can be retained, and this is
hypothesised to decay very rapidly (within 1 second) and/or to be immediately
replaced by the next item. It was suggested in Chapter 1 that perhaps the
assumption of very rapid decay/replacement of activation may be able to be
relaxed somewhat, or that other longer-lasting transient modifications may be
permitted, in order to allow short term priming effects to emerge. Given that the
present data suggest a transient state modification lasting perhaps 10 seconds
and a number of trials, this proposition is now investigated more closely.
Simulations of McClelland and Rumelhart's (1981) interactive-activation model
are used as an example to argue that, in fact, the "winner take all" assumption
common to all computational models of word recognition makes it very difficult
for these models to permit longer-lasting modifications to the state of lexical
units.

The interactive-activation model allows multiple candidate words to be
under consideration in the early stages of identifying a target, namely all those
which are at least partially consistent with the stimulus information. However,
the model employs strong word-to-word inhibition to eventually allow only one
"winner" - the representation corresponding to the target word (or the closest
word if the stimulus is a nonword). This "winner take all" approach means that
only masked priming effects (which arise when the target replaces the prime
before prime processing is complete) and lagO repetition priming (in which the
completely-processed "prime" has not yet been replaced by another item) can be
produced by leftover activation. With the parameters selected by McClelland
and Rumelhart (1981), post-lagO repetition priming cannot be explained in this

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6 Morton (1969) also assumed a temporary threshold lowering with somewhat slower
decay. However, he did not demonstrate via mathematical proof or simulation that his
model actually worked with successively-presented stimuli, or that it demonstrated
priming effects.
way. The survival of priming through intervening items is not allowed for
because, in order for the interactive-activation model to successfully identify a
new word, it must allow the new target to win completely over all other words,
including one which is left activated from the preceding trial: all activation of the
previous item must be destroyed in order to allow the new target to be identified
(see Chapter 1, Section 1.1.7).

Is it possible to find some set of parameters for the interactive-activation
model that will allow activation to survive through an intervening item and so
produce a post-lag0 repetition effect, while still allowing correct identification
of all targets? Limited simulations of the model, which I have conducted using
software provided by Rumelhart and McClelland (McClelland & Rumelhart,
1988), suggest not. By slowing the decay of activation, decreasing the strength of
word-to-word inhibition and playing with the strengths of letter-to-word
excitation and inhibition, it was possible (with at least a few different parameter
combinations) to produce retained activation of an earlier trial after what would
normally be enough cycles of the model to process the intervening item. Indeed,
when the repeated target and the intervening item were orthographically
distinct (eg. CAVE - FROG - CAVE), parameter combinations could be found
which allowed successful identification of all three items and a small lag1
priming effect due to leftover activation. However, such parameter combinations
seemed always to have one catastrophic side-effect: the model could not
successfully process new items which had substantial orthographic overlap with
the preceding item (eg. CAVE - SAVE), because the evidence for the new item
was never considered strong enough to overcome the leftover activation of the
previous target (ie. CAVE remained strongly activated, and was never replaced
by SAVE).

While no simulations of other models have been conducted, it would be
expected that these would be equally unsuccessful in reproducing lag1 priming
by an activation mechanism, since they share the winner-take-all assumption
that target identification entails the destruction of all activations inconsistent
with that target. It is possible that models could do better in explaining ST
priming with some non-activation mechanism. For example, the role of
activation could be to determine which stimulus is currently being shown, while
threshold-lowering might serve to tag recently-presented items. An alternative,
of course, might be a model which replaces the winner-take-all assumption for
activation with a "winner-take-most" assumption. In this case, multiple stimuli
from the recent past would be active at once, in addition to the target, and some
new method of tagging the current stimulus would need to be found.

Whether or not any of these particular proposals is feasible, it is clear
that explaining ST priming effects within current models is likely to require
changes to their basic computational assumptions. The implication of the
present data, however, is that this needs to be done – a model which provides a reasonable simulation of human performance when stimuli are presented in isolation is worth little if a fundamental aspect of its style of operation is incompatible with the processing of multiple words in succession.

6.4 FUTURE RESEARCH

There are a number of directions in which the present work could fruitfully be extended to address further both the "memory" and "perceptual" interpretations of ST priming.

From a memory perspective, additional research might look for further reasons to distinguish ST priming from manifestations of other forms of memory. Of particular value would be: a) evidence that ST priming patterns can be changed by the manipulation of some experimental variable which has no influence on LT priming levels; b) evidence that a variable which influences ST explicit memory does not influence ST priming\(^7\) (phonological similarity of interfering items to the target might be one such variable); and c) further demonstrations of ST priming in the absence of other memory forms and vice versa (eg. finding neuropsychological patients who have impaired working memory but show normal ST priming, or who show LT but not ST priming).

In addition, more convincing tests of the proposal that ST priming relies on ahistoric modifications of pre-existing representations should also be provided. Two critical experiments here are: a) a better-controlled study of the effects of the overlap in visual format between first and second presentation (no effect of study-test mismatch should be found); and b) an examination of ST priming for items expected to have various degrees of access to stable lexical representations (very little ST priming should be found for random letter strings which, unlike pseudowords, should cause little lexical activation).

From a perceptual perspective, ST priming would be expected to vary as a function of lexical properties in addition to lexical status. Details of the effects of all lexical variables might inform various views of orthographic representations, the modifications they undergo, and the method by which multiple modifications are able to coexist and still allow online processing. A number of possible ST priming investigations seem likely to provide interesting data bearing on these issues, including: a) crossing target lexicality with the

\(^7\) For both a) and b), the opposite dissociations have already been demonstrated.
lexicality of intervening items (one intervening item type may provide more interference to one target type); b) determining the effects of interference which appears at particular times and/or serial positions between target repeats (items occurring at particular times/positions may cause particularly severe interference); and c) determining the effects of manipulating other lexical variables such as neighbourhood size, body frequency, and word frequency in both target and interference positions.

This proposed empirical work is based on the assumption that ST priming can, in fact, be explained in terms of transient modifications of stable lexical representations, specifically orthographic representations. This view of ST priming appears consistent with such data as have been collected to date, and findings of further effects of lexical variables on ST priming would, in themselves, strengthen this conclusion. However, two relatively critical experimental tests of this hypothesis need to be carried out. These include (as with the "memory" perspective) providing further tests of the proposal that modification of pre-existing, abstract representations underlies ST priming. In addition, the supposed orthographic locus of ST priming requires more support, such as a demonstration of no cross-modality ST priming, or of no ST priming between synonyms.

In addition to further human experimentation, future research needs to more clearly assess various models of word recognition for their ability to produce ST priming. Given the current complexity of word recognition models, and the difficulty of predicting their behaviour by simply "eyeballing" them, computer simulations of different models will be required. This simulation should be addressed at relatively general questions, such as the types of state change which can be allowed with various representational assumptions, how long these modifications can endure to produce priming, whether the ability to successfully identify new stimuli collapses if particular modification/representation combinations are employed, and what alternative approaches might work if this occurs.

A final way in which the present work merits extension is based on both memory and perceptual approaches to ST priming, namely an investigation of the extent to which the properties of lexical ST priming generalise to other domains. The memory approach suggests that a priming effect of similar duration should be apparent in other domains, while the perceptual approach

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8 See Appendix C for an unsuccessful attempt to do this.
9 This is a vast task, and there are certain logical difficulties associated with demonstrating that a model with 20 or more parameters can not, under any parameter combination, achieve the desired behaviour. Therefore, it may be best to begin with a set of "toy" models, with limited numbers of nodes, restricted connections, and simple stimulus sets (such as vectors of unspecified but partially overlapping "features"). By constraining the systems in this way, it should be easier to determine which aspects of a given model are responsible for which aspects of its ST priming performance.
suggests that any such effect may not generalise completely. It seems likely that the exact details of ST priming within any one domain will depend on an interaction between the type of stimuli employed and the nature of the identification system which is available to process those stimuli.

6.5 CONCLUDING REMARKS

The present thesis provides an illustration that the integration of the perception and memory traditions of research into priming can prove useful. In this case, reviews of the literature in each area suggested a new phenomenon, and investigation of this phenomenon produced results with implications for both the structure of memory and the operation of the relevant perceptual system.

The interpretations of ST priming which have been proposed here have relied, in many cases, on the integration of both traditions. For example, the finding of ST priming for pseudowords was not interpreted as showing that priming relies on episodic, newly-formed traces (as might have been concluded by many memory researchers), because there is evidence from the word recognition literature that word-like nonwords access preexisting real-word representations. On the other hand, conclusions from ST priming regarding the nature of the word recognition system were not drawn until reasonable evidence was found that the effect arises automatically and implicitly. These observations make the general point that it is not sufficient to claim that implicit memory is perceptual in nature without making reference to the current state of knowledge about the relevant perceptual system (see Coltheart, 1989, for a similar view). Nor is it appropriate use priming to draw conclusions about a perceptual system if the observed priming arises through memorial processes which are unlikely to be based within this system.

The implications of ST priming for memory and word recognition have been discussed at some length and in detail. Two more general issues remain which have not yet been considered. These are, first, the possible functional role of short term implicit memory and, secondly, the potential use of ST priming as an experimental technique for investigating perceptual processing in general.
6.5.1 The functional role of short term implicit memory

One general question regarding the theoretical interpretation of ST priming has not yet been addressed, namely, What is it for? In fact, this thesis suggests that this is not quite the right question to ask: short term priming is seen simply as a side-effect of the operation of the lexical processing system and thus, in itself, has no functional role. Instead, it is the function of the orthographic time window posited to underlie short term implicit memory for lexical stimuli which is at issue.

There are apparent functional advantages of a word recognition system organised in such a way that it produces short-lived priming effects as a side-effect. One reason for having the word recognition system maintain multiple words "active" at once might be to assist with sentence and text processing. At the semantic level, it is clear that we maintain information about a number of words at once in order to understand the meaning of a sentence. There are also reasons for a similar ability to be useful at a phonological or orthographic perceptual level.

In the processing of spoken sentences (ie. using phonological knowledge), it is commonly held that a relatively long time window of perceptual processing is necessary in order to correctly identify each word (eg. Marslen-Wilson & Welsh, 1978). This necessity arises because the speech signal is highly ambiguous: there no direct correspondence between aspects of the speech signal and individual phonemes within individual words, and the speech signal for a given word varies depending on what precedes and follows it. In addition, normal speech is slurred so that there are no clear breaks between words. Thus, the phonological system must often use information from previous or later words to successfully identify a target, suggesting a time window of at least three words "active" or partially "active" at once.

In the orthographic processing of type-written words, there is not the same necessity for the ability to retain multiple words at once. Each word is orthographically unambiguous, in that its written form does not vary with the surrounding context. However, additional evidence that multiple type-written words actually are maintained at once (whatever the apparent necessity) comes from studies by McConkie and Rayner (1974) and Rayner (1975). In these studies, the number of letters available in a moving window of text was gradually increased, and effects of orthographic information extracted from up to 10 letters each side of the current fixation point were found, suggesting a time-window including three or so words.
One reason that the orthographic word recognition system might employ a time window of several items is that this system is required to process handwritten, as well as type-written material. Hand-written material has much of the ambiguity of speech, and so we might expect that all available perceptual clues would be employed in the identification each item, including information extracted from surrounding words. Thus, a general ability to maintain several successive stimuli at once might well be of value in orthographic processing. This interpretation sees ST priming for type-written words presented one-at-a-time as a sort of accident of the continued use of an ability which is functionally useful in other contexts.

A more general reason for the existence of time windows is as a mechanism for integrating a sequence of stimuli into a single event. Such mechanisms would be of use in sentence processing, but also have a more general function. Like speech, many single "events" are, in fact, somewhat spread out over time (eg. standing up, catching a ball). Successful processing in these cases therefore requires information from the recent past to be temporarily stored in some form until it can be integrated with information from throughout the rest of the event. Temporal integration, then, may provide a reason for short term implicit memory to be manifest in a variety of domains.

6.5.2 Use of short term priming as an experimental technique

The view that all implicit memory is perceptual in nature (eg. Schacter, 1994) suggests that all forms of priming potentially provide useful insight into the operation of the system being primed. With standard long term priming, however, perceptual implications of priming patterns have received surprisingly little attention in recent times. This may be because many researchers believe that LT priming is episodic in nature (eg. Forster & Davis, 1984), as opposed to relying on modification of the stable representations used in perception, and thus that any perceptual aspects of the trace laid down at study will be very difficult to specify and/or disentangle from the memorial properties.

Masked priming, on the other hand, has always been seen as simply a tool for investigating the properties of the relevant perceptual system (Forster & Davis, 1984), and given the very brief duration of the effect, it is hard to see how it could be interpreted any other way. There is, however, one limitation on the use of masked priming: it investigates only early-stage perceptual processing. In the masked priming paradigm, the prime is presented only briefly (usually 60ms with forward and backward masks), such that it is only partially processed and does not become available to conscious awareness. It is possible, therefore, that
masked priming will miss a number of aspects of complete perceptual processing, that is, any occurring after the first 60ms of processing.

Short term priming appears likely to provide a tool for investigating the process of full perceptual identification. Like masked priming, ST repetition priming has a natural interpretation as a transient modification of the stable representations involved in stimulus identification. Unlike masked priming, however, the ST priming paradigm employs complete processing of the prime. Thus, one might expect ST priming to provide information complementary to that provided by masked priming regarding perceptual processing.

The present thesis has addressed the possible implications of lexical ST priming for the operation of the word recognition system. So far, only one strong claim (that the system in some way processes or retains multiple stimuli at once) has come out of this work. In the future, however, it should be possible to employ ST priming and/or other ST proactive influences to more directly address other important issues to which the present data were only tangentially relevant, including the form of orthographic representations, and the method of access to these representations.

Finally, while the present work has concentrated on demonstrating ST priming for lexical materials, there seems no reason to assume that the effect does not exist for other types of materials. If this is the case, it could be used to investigate perceptual processing in other domains. Thus, the decay of any ST priming for different types of "possible" and "impossible" objects might be of relevance to models of object recognition (see Schacter, Cooper, Delaney, Peterson & Tharan, 1991, and Schacter, 1990, for similar ideas with respect to LT priming), and ST priming for "faces" and "non-faces" might provide information about face recognition (see Bentin & Moscovitch, 1988).

In conclusion, then, short term priming for words and nonwords has usefully been interpreted within both "memory" and "perception" frameworks, and implications for both the structure of human memory and the process of word recognition have been discussed. Some of the interpretations proposed, while in keeping with an overall view of ST priming, are somewhat speculative in the absence of further data. There are, however, three strong conclusions which can be drawn from the findings reported in this thesis. First, ST priming reflects a novel and distinct form of memory, namely short term implicit memory. Secondly, ST priming for words and nonwords arises within the lexical processing system. Thirdly, the duration of this lexical effect indicates that the word recognition system retains more than one fully-identified word at once; that is, there is a time window of lexical processing of several seconds and a number of distinct items.
It has been suggested that short term implicit memory for lexical stimuli might arise because processing of written language requires the integration over time of successively-presented information, and so is likely to benefit from allowing a several-second window for "online" processing. Given that such a feature would also seem likely to benefit many other perceptual processes, short term priming should prove useful in investigations of a wide range of perceptual systems.
References


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Appendix A

Study-test mismatches in visual form

The experiment reported here investigated the effects of mismatch in the visual form of repeated targets. It was not originally designed to look at ST priming, and was intended to provide a strictly-controlled investigation of word priming only. However, both word and nonword targets were presented at one short and one long lag, with the first and second presentation either matched or mismatched. The outcomes of the experiment, therefore, are relevant to the issue of whether ST priming relies on abstract, ahistoric traces, or on historic traces recording all aspects of initial presentation.

Words and nonwords were presented for lexical decision at lags 0 and 6, and also at some additional lags for nonwords. A mild visual mismatch between first and second presentation was introduced by presenting stimuli either clearly or in slightly degraded (but still easily identifiable) form. A more severe visual mismatch was introduced by changing from lower case on first presentation to upper case on second presentation. If such priming relies on historic traces, then ST priming would be smaller where the two target presentations are in different forms than where the two presentations match.

To demonstrate an effect of study-test mismatch on short term priming, as opposed to long term priming, an effect of mismatch at lag0 must be demonstrated over and above any effect at lag6. Given that lag0 priming is assumed to reflect the sum of both ST and LT priming, this requirement is essentially that there be an interaction between lag and mismatch, such that any mismatch effect is more severe at lag0 than at lag6.

Method

Subjects. Twenty-nine subjects participated in return for credit towards an introductory psychology course. All had English as their native language. Of these, five were removed due to high error rates, leaving 24 subjects.

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1 This experiment was conducted prior to all those reported in the body of the thesis, and provided the data allowing selection of the subset of items which were used in the experiments reported in Chapter 2.
Appendix A

Design. A $2 \times 2 \times 2 \times 2$ repeated measures design was employed for word targets. The four independent variables for words were: degradation of first presentation (clear or degraded), degradation of second presentation (clear or degraded), case of second presentation (lower or upper), and lag between prime and target presentations (0 or 6 items). The same four independent variables were manipulated for nonwords, but the design was not strictly controlled: while some nonwords were presented under each of the 16 conditions used for words, trial numbers in each condition were not equal and additional lag conditions were employed (lag range 0 to 10). The dependent measures were lexical decision times to first and second presentations of targets.

Materials. Two hundred and forty singular, four letter, single syllable words, with frequencies of 4 occurrences or less per million, were chosen from the Kucera and Francis (1967) listing. Some of these real words were highly unfamiliar to first-year subjects. The 240 words were divided into 16 lists of 15 words, corresponding to the 16 conditions of interest. The lists were equated on word frequency, with the average frequency being 2.2 occurrences per million. The complete test list consisted of 960 items: these included two presentations of each of the 240 words, and two presentations of each of an additional 240 four-letter nonwords with legal orthography. No filler items were used.

Since lag between the two presentations was included as a variable, the order of the stimuli could not be randomised. Instead, 5 sequence templates of 64 items were chosen: each template included 1 word from each of the sixteen conditions (presented twice), with an equal number of nonwords (also presented twice). Each template was used 3 times in the complete list, thus producing the total of 960 trials ($64 \times 5 \times 3$).

The first presentation of each target was always in lower case (second presentations were upper or lower case). No filler items were included, due to a wish to restrict the experiment to one hour per subject, and so it was impossible to ensure that both words and nonwords always appeared at either lag0 or lag6. Instead, words only appeared at these lags, but nonwords appeared at all lags between 0 and 10. Lags 0 and 6 were employed as often as possible.

Four sets of materials were prepared, such that the sets of 15 words were cycled across subjects through the four most important conditions, namely clear - clear (ie. first and second presentations clear), clear - degraded, degraded - clear, and degraded - degraded. Note that lists were not cycled across the case and lag conditions: a single set of four lists (a total of 60 word targets) always appeared at lag0 with the target in lower case, a different set appeared at lag0 with upper case target, and so on. The 240 nonwords always appeared in the same position in the list, across the four sets of materials.
Procedure. Each subject was tested individually in a single one-hour session. Stimuli were presented on an Apple Macintosh using PsychLab. The subjects were required to decide if each letter string constituted a real English word. They responded via the keyboard, using their preferred hand for "yes", and the other hand for "no". The stimulus remained on the screen until a response had been made, after which a blank screen was presented for 800ms before the next stimulus appeared (i.e. the presentation rate was roughly one item every 1.6 seconds). Due to a limitation in the program used for presentation, stimuli were always presented such that 2 clear stimuli were always followed by 2 degraded, and so on.

A short practice trial of 8 five-letter strings was given. After this, subjects received three experimental blocks of 320 trials, each taking roughly nine minutes to complete. The order of these blocks was counterbalanced across subjects, and a short break was given between each. Subjects were informed that stimuli would appear in upper or lower case, clear or degraded, and that each would appear twice, so that discovering these regularities during the experiment would not distract them from the task.

Lexical decision times for the first and second presentation of each stimulus were recorded.

Results and Discussion

Data were discarded from five subjects who made an excessive number of errors (more than an average of 18% across words and nonwords, or >25% for either set of targets). Mean error rates for the remaining 24 subjects were 15.4% for first presentations of word targets, and 10.1% for second presentations. Error rates for nonwords were 4.0% for first presentations and 3.6% for second presentations. Trials for which subjects responded incorrectly on either presentation, or for which the response time was <300 ms or >1400 ms were discarded. (A relatively long upper cutoff was allowed due to the longer response times expected with degradation of some stimuli and the inclusion of some extremely unfamiliar real words.) On this basis, a total of 2.8% of the word targets and 3.0% of the nonword targets were excluded as outliers.

For words, lexical decision times were analysed in the normal way, that is by taking means for each subject in each condition and then averaging over subjects. For nonwords, however, medians were calculated for each subject in each condition, due to a reduced number of items per condition. As noted earlier, nonwords appeared in all degradation conditions, and at lags 0 and 6, but these presentations were not strictly controlled. In particular, there was no counterbalancing of particular nonwords over different conditions, nonwords
Appendix A

appeared at additional lags, and the number of nonword targets in each degradation condition was not equal. The number of nonwords presented in each condition is shown in Table A.1. From this table, it was apparent that most of the available nonword data could be used by comparing priming across lag0, lag6, and a composite lag1-5 condition which included nonwords repeated at lags 1 through 5.

Table A.1: Number of nonwords which appeared in each condition.

<table>
<thead>
<tr>
<th>Lag</th>
<th>C-C L</th>
<th>C-D L</th>
<th>D-C L</th>
<th>D-D L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8</td>
<td>9</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1-5</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>&gt;6</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: C-D = clear first presentation, degraded second presentation; similarly for C-C, D-C and D-D; L = lower case second presentation; U = upper case second presentation.

Averaged across subjects, decisions to first presentations took 724ms for clear words, 737ms for degraded words, 725ms for clear nonwords and 734ms for degraded nonwords. Reaction times to clear first presentations were significantly faster than for degraded first presentations (F(1,23)=12.15, MSe=1666, p<.01). Given this, it was decided not to calculate priming scores (ie. first - second), since this procedure would artificially inflate the measure of priming when the first presentation was degraded and the second clear, and underestimate priming when the first was clear and the second degraded. Instead, lexical decision times to second presentations were compared, as a function of the form of the first presentation.

Table A.2 gives mean response times to second presentations of words and nonwords, as a function of the degradation of each presentation, and the case of the second presentation. Figures A.1 and A.2 show the pattern of results graphically for words and nonwords, respectively. These figures include the mean decision time across first presentations in all conditions, to give an indication of the absolute magnitude of the priming effect.
Table A.2: Mean lexical decision times (in ms) and error rates to second presentations as a function of degradation condition and case of second presentations (first presentations were always lower case).

a) Words

<table>
<thead>
<tr>
<th>degradation condition</th>
<th>case condition</th>
<th>lower case (match)</th>
<th>upper case (mismatch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-C lag0 (match)</td>
<td></td>
<td>491 8.1%</td>
<td>516 4.7%</td>
</tr>
<tr>
<td>D-C lag0 (mismatch)</td>
<td></td>
<td>483 7.2%</td>
<td>508 7.8%</td>
</tr>
<tr>
<td>C-C lag6 (match)</td>
<td></td>
<td>644 9.2%</td>
<td>689 14.5%</td>
</tr>
<tr>
<td>D-C lag6 (mismatch)</td>
<td></td>
<td>658 9.5%</td>
<td>679 12.5%</td>
</tr>
<tr>
<td>D-D lag0 (match)</td>
<td></td>
<td>513 8.6%</td>
<td>523 6.9%</td>
</tr>
<tr>
<td>C-D lag0 (mismatch)</td>
<td></td>
<td>512 9.5%</td>
<td>539 10.3%</td>
</tr>
<tr>
<td>D-D lag6 (match)</td>
<td></td>
<td>677 10.5%</td>
<td>663 15.0%</td>
</tr>
<tr>
<td>C-D lag6 (mismatch)</td>
<td></td>
<td>674 12.8%</td>
<td>685 13.9%</td>
</tr>
</tbody>
</table>

b) Nonwords

<table>
<thead>
<tr>
<th>degradation condition</th>
<th>case condition</th>
<th>lower case (match)</th>
<th>upper case (mismatch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-C lag0 (match)</td>
<td></td>
<td>520 2.1%</td>
<td>564 1.7%</td>
</tr>
<tr>
<td>D-C lag0 (mismatch)</td>
<td></td>
<td>528 2.2%</td>
<td>563 2.5%</td>
</tr>
<tr>
<td>C-C lag 1-5 (match)</td>
<td></td>
<td>701 11.0%</td>
<td>708 3.0%</td>
</tr>
<tr>
<td>D-C lag 1-5 (mismatch)</td>
<td></td>
<td>728 9.4%</td>
<td>672 3.3%</td>
</tr>
<tr>
<td>C-C lag6 (match)</td>
<td></td>
<td>673 4.2%</td>
<td>689 3.2%</td>
</tr>
<tr>
<td>D-C lag6 (mismatch)</td>
<td></td>
<td>683 3.6%</td>
<td>692 4.2%</td>
</tr>
<tr>
<td>D-D lag0 (match)</td>
<td></td>
<td>538 3.5%</td>
<td>567 1.9%</td>
</tr>
<tr>
<td>C-D lag0 (mismatch)</td>
<td></td>
<td>527 3.7%</td>
<td>561 3.8%</td>
</tr>
<tr>
<td>D-D lag 1-5 (match)</td>
<td></td>
<td>714 5.6%</td>
<td>695 2.8%</td>
</tr>
<tr>
<td>C-D lag 1-5 (mismatch)</td>
<td></td>
<td>689 5.9%</td>
<td>686 4.5%</td>
</tr>
<tr>
<td>D-D lag6 (match)</td>
<td></td>
<td>711 2.6%</td>
<td>702 6.0%</td>
</tr>
<tr>
<td>C-D lag6 (mismatch)</td>
<td></td>
<td>691 3.9%</td>
<td>729 3.6%</td>
</tr>
</tbody>
</table>

Note: Example of interpretation of condition code is: D-C lag6 = first presentation degraded and second clear, with six items intervening between repeats. Mean first presentation decision times were 724ms for clear words and 737ms for degraded words. Mean (of median) first presentation times were 725ms for clear nonwords and 734ms for degraded nonwords.
Figure A.1: Second-presentation lexical decision times to words as a function of lag, case of second presentation ($L =$ lower, $U =$ upper), and degradation condition (eg. D-C = degraded first presentation, clear second presentation), plus the mean first presentation response time across all conditions. The predicted form of interaction for an effect of degradation mismatch is shown as "pred deg": see text for explanation.

The most obvious feature of Figures A.1 and A.2 is that, as would be expected, priming at lag0 (of the order of 200ms) is substantially larger than priming at lag6 (of the order of 50ms), reflecting the additional ST repetition effect at lag0. In comparison to this very large lag0 priming effect (around 150 ms greater than the LT value), it is clear that there is, at best, a trivial effect of the various degradation conditions on the amount of priming observed. This conclusion can be drawn by examining the effect of degradation level within each group of columns in each figure (ie. for each lexicality and each case separately). Further analysis is required to make across-figure comparisons and thus investigate differences due to case or lexicality.
Table A.3 presents the results of two 4-way ANOVAs, one for words and one for nonwords, examining second presentation decision times as a function of lag, case, degradation of first presentation, and degradation of second presentation. It can be seen from this table that there are significant (although small - see Figures A.1 and A.2) effects of these variables on the level of priming, but the pattern of results is very difficult to interpret due to the presence of three 2-way interactions in each case. Rather than attempt to make sense of this mess of interactions, it was decided to restrict further investigation to the questions of most interest.

**Degradation mismatch.** As noted above, any effects of degradation mismatch were tiny in comparison with the magnitude of the ST priming effect. This result suggests that the "trace" underlying ST priming is primarily ahistoric rather than historic. However, we can still usefully ask whether there might be some effect of study-test mismatch on priming levels which, while small, is significant. In other words, while it appears that at least most lag0 priming is due to a relatively abstract (presumably lexical) trace, there might still be some contribution to lag0 priming from an historic trace which records details of the visual form of initial presentation.
**Table A.3:** ANOVAs for second presentation decision times. Significant effects are starred.

**a) Words** (df=1,23 for all tests)

<table>
<thead>
<tr>
<th>Effect</th>
<th>F</th>
<th>df</th>
<th>MSg</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degradation of 1st</td>
<td>2.76</td>
<td>1,23</td>
<td>1138</td>
<td>&gt;.1</td>
</tr>
<tr>
<td>Degradation of 2nd*</td>
<td>19.71</td>
<td>1,23</td>
<td>1051</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Case of 2nd</td>
<td>14.94</td>
<td>1,23</td>
<td>2287</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Lag</td>
<td>168.4</td>
<td>1,23</td>
<td>14619</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Deg 1st x Deg 2nd</td>
<td>1.73</td>
<td>1,23</td>
<td>455</td>
<td>&gt;.2</td>
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**b) Nonwords**

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In fact, however, all but one of the possible degradation mismatch effects were in the wrong direction for any contribution of historic traces, to either ST or LT priming. Figure A.1 shows reaction times to second presentations of repeated words as a function of degradation condition, at each of the four lag/case combinations. This figure also shows the pattern of data which would be consistent with a degradation mismatch effect; essentially, reaction times should be faster if the second presentation had the same level of degradation (ie. clear or degraded) as the first presentation, producing an interaction of the form indicated in the "pred deg" group of columns. It is apparent, however, that none of the four conditions produced an interaction of this form. Figure A.2 shows that all but one of the interactions are again in the wrong direction for nonwords.

Thus, it is clear that the significant effects reported above in the overall ANOVAs cannot be interpreted as showing any reduction in priming with study-test mismatches in level of degradation. This failure to find any effect of a mild change in visual form shows that ST (and LT) priming is abstract and ahistoric at least to the extent of ignoring exact physical appearance.

Case of second presentation. Turning to the effects of the more severe change in visual form, decision times to second presentations as a function of case are shown in Figure A.3 (words) and Figure A.4 (nonwords), collapsed over the four degradation conditions. It is apparent that there is, at best, a small effect (10 or 20 ms) of case on decision times to second presentations of word targets. For nonwords, once again priming is not substantially influenced by case mismatch: there appears to be no case effect at all at the longer lags (1 through 6), and, at most, 35ms of the 150ms or so ST priming (<25%) is destroyed by mismatching the case of first and second presentations.

Unfortunately, a flaw in the design of the experiment means that it is not clear whether overall effects of case were due to study-test mismatch (ie. upper case second presentations were processed more slowly because their visual form differs from the lower case employed on the first presentation), or due simply to lower case words per se having been easier to process than upper case words. Despite this flaw, some useful conclusions can be drawn. For words collapsed over degradation condition, there was a main effect of case (F(1,23)=14.9, MSe=571.7, p<.01), and a main effect of lag (F(1,23)=168.4, MSe=3654.6, p<.001), but no interaction between lag and case (F<1). This lack of any interaction demonstrates that short term priming for words is not influenced by case mismatch. While the main effect of case might reflect a study-test mismatch effect on long term priming, the lack of interaction between lag and case indicates that there is no further effect of case mismatch on ST priming.

---

2 In order to properly evaluate the effects of case mismatch, the case of the first presentation, rather than that of the second, should have been varied.
Figure A.3: Second-presentation lexical decision times for words as a function of lag and case, collapsed over degradation condition.

Figure A.4: Second-presentation lexical decision times for nonwords as a function of lag and case, collapsed over degradation condition.
For nonwords, a different pattern of results emerged. Collapsing over degradation condition revealed a main effect of case ($F(1,23)=8.0$, $MS_e=448$, $p=.01$), a main effect of lag (Wilks’ $\lambda=.139$, $F(2,22)=68.0$, $p<.001$), and a significant interaction between the two (Wilks’ $\lambda=.416$, $F(2,22)=15.4$, $p<.001$). Follow-up t-tests indicated that the interaction reflected a difference between the effect of case on ST and LT priming. For LT priming, the lower- (same-) case advantage at lag 6 approached significance ($t(23)=1.9$, $p=.073$), while the upper- (different-) case advantage at lags 1-5 was just significant ($t(23)=2.1$, $p=.047$). These opposite effects probably indicate an overall null effect of case on LT priming. At lag0, however, there was a clear advantage of lower-case second presentation for nonwords ($t(23)=6.9$, $p<.001$), presumably reflecting a reduction in priming for the upper case condition arising due to study-test mismatch. Thus, it may be that a severe visual mismatch reduces ST priming for nonwords by around 25%.

**Error data.** Table A2 includes the error rates (to second presentations) in each condition. It is apparent from this table that faster reaction times (i.e., greater priming) tend to be correlated with lower error rates, suggesting that differences in reaction times across conditions did not rely on speed-accuracy tradeoffs.

**Conclusions.** This experiment produced very large priming effects for both words and nonwords at lag0, both in absolute terms, and in comparison to the longer-term priming values. Despite this, the introduction of a small visual mismatch between first and second presentation, namely presenting one of the targets in a degraded form, had no effect on the amount of lag0 priming observed, either for words or for nonwords. Even a much more severe visual mismatch, namely changing the case of presentation, left ST priming for words unchanged and caused, at most, around a 25% reduction in the ST priming for nonword targets.

Thus, despite some problems with the design of this experiment, it provides reasonably strong evidence that lag0 priming does not rely simply on a trace of the visual appearance of the target. The data are consistent with the view that the ST priming effect arises, primarily or entirely, at a relatively abstract ("lexical") level of processing, rather than from more specific traces which include information about the visual appearance of the target. That is, the present results suggest that the traces underlying ST priming are ahistoric rather than historic in nature.

---

3 On the other hand, the apparent influence of mismatch may reflect item-specific priming, as nonword targets were not counterbalanced across conditions.
Appendix B

Trial order and items used in Experiment 2.1

The following pages contain the order of items and trial-types for one version of the experimental list used in Experiment 2.1. Note that all versions used the exact order of trial-types (ie. conditions) given in this example, as did all lists in Experiments 2.2, 3.2 and 4.1. What differed between versions was the order in which particular items were inserted into this fixed template. Across experiments, the nature of the inserted items also differed in some cases (ie. low versus high frequency words).

The complete list of 1100 trials has been broken into four, corresponding to the four blocks of trials subjects received. One presentation block is shown per double-page spread. Note that the two middle blocks contained 250 trials each, while the first and last blocks contained 300 trials each. Trials run down the page, in sets of three columns. The trial number is given to demonstrate the order in which trials were presented within each block. Within a set of three columns, the first is the trial number, the second is the item that was presented (in this version) on that trial, and the third is a code for the condition which appeared (always) on that trial. Condition codes are as follows:

- 00w = word repeated at lag0
- 01w = word repeated at lag1
- 02w = word repeated at lag2
- 03w = word repeated at lag3
- 04w = word repeated at lag4
- 05w = word repeated at lag5
- 09w = word repeated at lag9
- 23w = word repeated at lag23
- 99w = word repeated at lag1050
- w = word filler (generally unrepeated)
- 00n = nonword repeated at lag0, and so on.

Some of the items specified as nonwords on the following pages may, in fact, be extremely rare or archaic English words. However, all were selected as being functionally nonwords as far as experimental subjects were concerned. The low lexical-decision error rates for these items supports this selection.
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Trial order and items used in Experiment 2.1

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484 gene w
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486 keek 02n
487 rike 05n
488 reap 05w
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493 rike 05n
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495 vesh 23n
496 cask 03w
497 dife n
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500 cask 03w

501 lapen 02n
502 lard 09w
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522 mang 01n
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524 bind 05w
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| 563 | shun w | 613 | curd 23w | 663 | slat w |
| 564 | dell w | 614 | drab w | 664 | duel w |
| 565 | wrap w | 615 | wike 03n | 665 | bang w |
| 566 | bait 01w | 616 | bail w | 666 | chet 01n |
| 567 | lash w | 617 | lore w | 667 | lump w |
| 568 | bait 01w | 618 | oath w | 668 | chet 01n |
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| 570 | bult n | 620 | sude n | 670 | dalt n |
| 571 | clam 23w | 621 | plod 02w | 671 | zale 23n |
| 572 | bine n | 622 | mosh n | 672 | grut n |
| 573 | vale 04w | 623 | shup 04n | 673 | tuge 04n |
| 574 | frip 23n | 624 | plod 02w | 674 | dunk 23w |
| 575 | bape 04n | 625 | nalf n | 675 | rasp 04w |
| 576 | yolf n | 626 | rimp n | 676 | bint n |
| 577 | keef n | 627 | bish 23n | 677 | oaph n |
| 578 | vale 04w | 628 | shup 04n | 678 | tuge 04n |
| 579 | blid 09n | 629 | duct 05w | 679 | tick 09w |
| 580 | bape 04n | 630 | dine 00w | 680 | rasp 04w |
| 581 | hilt 03w | 631 | dine 00w | 681 | trox 03n |
| 582 | mask w | 632 | buke 05n | 682 | ramp w |
| 583 | pail 02w | 633 | cred 00n | 683 | pelp 02n |
| 584 | stag w | 634 | cred 00n | 684 | poll w |
| 585 | hilt 03w | 635 | duct 05w | 685 | trox 03n |
| 586 | pail 02w | 636 | moap n | 686 | pelp 02n |
| 587 | chop 05w | 637 | curd 23w | 687 | clim 05n |
| 588 | bave 05n | 638 | buke 05n | 688 | flip 05w |
| 589 | woss n | 639 | weld 03w | 689 | raik n |
| 590 | tide w | 640 | moss w | 690 | veil w |
| 591 | blut 00n | 641 | nild 02n | 691 | fowl 00w |
| 592 | blut 00n | 642 | toib n | 692 | fowl 00w |
| 593 | chop 05w | 643 | weld 03w | 693 | clim 05n |
| 594 | bave 05n | 644 | nild 02n | 694 | flip 05w |
| 595 | clam 23w | 645 | brew 01w | 695 | zale 23n |
| 596 | bage 03n | 646 | tomb w | 696 | turf 03w |
| 597 | taig n | 647 | brew 01w | 697 | sked n |
| 598 | weat n | 648 | spal n | 698 | timb n |
| 599 | lamb w | 649 | taut w | 699 | wart w |
| 600 | bage 03n | 650 | swog n | 700 | turf 03w |</p>
<table>
<thead>
<tr>
<th>Trial order and items used in Experiment 2.1</th>
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<tbody>
<tr>
<td>701 rass 02n</td>
<td>751 bolt w</td>
</tr>
<tr>
<td>702 soot 09w</td>
<td>752 snag 03w</td>
</tr>
<tr>
<td>703 hing n</td>
<td>753 jall n</td>
</tr>
<tr>
<td>704 rass 02n</td>
<td>754 lewd w</td>
</tr>
<tr>
<td>705 sove 04n</td>
<td>755 whid n</td>
</tr>
<tr>
<td>706 trag n</td>
<td>756 snag 03w</td>
</tr>
<tr>
<td>707 hone w</td>
<td>757 tote w</td>
</tr>
<tr>
<td>708 pave 04w</td>
<td>758 dube 05n</td>
</tr>
<tr>
<td>709 tang w</td>
<td>759 fern 01w</td>
</tr>
<tr>
<td>710 sove 04n</td>
<td>760 germ 23w</td>
</tr>
<tr>
<td>711 cose 23n</td>
<td>761 fern 01w</td>
</tr>
<tr>
<td>712 soot 09w</td>
<td>762 jild 00n</td>
</tr>
<tr>
<td>713 pave 04w</td>
<td>763 jild 00n</td>
</tr>
<tr>
<td>714 fuse w</td>
<td>764 dube 05n</td>
</tr>
<tr>
<td>715 bout w</td>
<td>765 gark 09n</td>
</tr>
<tr>
<td>716 lure w</td>
<td>766 dest 23n</td>
</tr>
<tr>
<td>717 flop 23w</td>
<td>767 swig 02w</td>
</tr>
<tr>
<td>718 ceam n</td>
<td>768 soof 03n</td>
</tr>
<tr>
<td>719 roam w</td>
<td>769 haul w</td>
</tr>
<tr>
<td>720 crem 01n</td>
<td>770 swig 02w</td>
</tr>
<tr>
<td>721 rack w</td>
<td>771 sock 05w</td>
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<tr>
<td>722 crem 01n</td>
<td>772 soof 03n</td>
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<tr>
<td>723 crob n</td>
<td>773 knob 00w</td>
</tr>
<tr>
<td>724 seep 05w</td>
<td>774 knob 00w</td>
</tr>
<tr>
<td>725 pewt n</td>
<td>775 gark 09n</td>
</tr>
<tr>
<td>726 tomp 09n</td>
<td>776 cime n</td>
</tr>
<tr>
<td>727 harp 00w</td>
<td>777 sock 05w</td>
</tr>
<tr>
<td>728 harp 00w</td>
<td>778 murn n</td>
</tr>
<tr>
<td>729 thit 03n</td>
<td>779 doot 01n</td>
</tr>
<tr>
<td>730 seep 05w</td>
<td>780 bulb w</td>
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<tr>
<td>731 sage 02w</td>
<td>781 doot 01n</td>
</tr>
<tr>
<td>732 roam n</td>
<td>782 mose n</td>
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<tr>
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<tr>
<td>735 cose 23n</td>
<td>785 mint w</td>
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<tr>
<td>736 tomp 09n</td>
<td>786 noll n</td>
</tr>
<tr>
<td>737 dand 05n</td>
<td>787 robe w</td>
</tr>
<tr>
<td>738 glin 00n</td>
<td>788 lull 04w</td>
</tr>
<tr>
<td>739 glin 00n</td>
<td>789 gasp 09w</td>
</tr>
<tr>
<td>740 dire 01w</td>
<td>790 dest 23n</td>
</tr>
<tr>
<td>741 flop 23w</td>
<td>791 phon 04n</td>
</tr>
<tr>
<td>742 dire 01w</td>
<td>792 seam w</td>
</tr>
<tr>
<td>743 dand 05n</td>
<td>793 lull 04w</td>
</tr>
<tr>
<td>744 bite w</td>
<td>794 calf w</td>
</tr>
<tr>
<td>745 tack 03w</td>
<td>795 beal n</td>
</tr>
<tr>
<td>746 grav n</td>
<td>796 phon 04n</td>
</tr>
<tr>
<td>747 stap n</td>
<td>797 sile 02n</td>
</tr>
<tr>
<td>748 dort n</td>
<td>798 bain n</td>
</tr>
<tr>
<td>749 tack 03w</td>
<td>799 gasp 09w</td>
</tr>
<tr>
<td>750 zeal w</td>
<td>800 sile 02n</td>
</tr>
</tbody>
</table>
Appendix B

801 soob 02n 851 lint w 901 cuff 09w
802 flog 09w 852 rash 03w 902 darn 09n
803 ceir n 853 jink n 903 hage 23n
804 soob 02n 854 whir w 904 flex 04w
805 mide 04n 855 woln n 905 herk 01n
806 wiss n 856 rash 03w 906 lope w
807 lilt w 857 isle w 907 herk 01n
808 hush 04w 858 spee 05n 908 itch w
809 tout w 859 glum 01w 909 flex 04w
810 mide 04n 860 hive 23w 910 jank n
811 fanl 23n 861 glum 01w 911 cuff 09w
812 flog 09w 862 noth 00n 912 darn 09n
813 hush 04w 863 noth 00n 913 jest 23w
814 hook w 864 spee 05n 914 mink w
815 burr w 865 duse 09n 915 perf 03n
816 prey w 866 gind 23n 916 cite w
817 gust 23w 867 worm 02w 917 putt w
818 keal n 868 reat 03n 918 swim w
819 slit w 869 bust w 919 perf 03n
820 fing 01n 870 worm 02w 920 zomb n
821 slab w 871 vase 05w 921 mute 02w
822 fing 01n 872 reat 03n 922 lont n
823 nurn n 873 pest 00w 923 flad 04n
824 thug 05w 874 pest 00w 924 mute 02w
825 croi n 875 duse 09n 925 mobe n
826 fosh 09n 876 mest n 926 wate n
827 mend 00w 877 vase 05w 927 hage 23n
828 mend 00w 878 mort n 928 flad 04n
829 sipe 03n 879 fron 01n 929 wick 05w
830 thug 05w 880 prop w 930 rung 00w
831 tack 02w 881 fron 01n 931 rung 00w
832 slir n 882 nask n 932 tilb 05n
833 sipe 03n 883 swem n 933 shul 00n
834 tack 02w 884 hive 23w 934 shul 00n
835 fand 23n 885 slot w 935 wick 05w
836 fosh 09n 886 phin n 936 slor n
837 foin 05n 887 spat w 937 jest 23w
838 maif 00n 888 grub 04w 938 tilb 05n
839 maif 00n 889 dump 09w 939 plum 03w
840 fret 01w 890 gind 23n 940 deed w
841 gust 23w 891 kerm 04n 941 tron 02n
842 fret 01w 892 dash w 942 spab n
843 foin 05n 893 grub 04w 943 plum 03w
844 cult w 894 doll w 944 tron 02n
845 sash 03w 895 dift n 945 hash 01w
846 heam n 896 kerm 04n 946 dose w
847 ralf n 897 tasp 02n 947 hash 01w
848 golt n 898 cild n 948 mult n
849 sash 03w 899 dump 09w 949 fake w
850 coin w 900 tasp 02n 950 foll n
<table>
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<tr>
<td>952  chum  09w</td>
</tr>
<tr>
<td>953  swan  00w</td>
</tr>
<tr>
<td>954  swan  00w</td>
</tr>
<tr>
<td>955  keer  01n</td>
</tr>
<tr>
<td>956  wark  02n</td>
</tr>
<tr>
<td>957  keer  01n</td>
</tr>
<tr>
<td>958  lene  n</td>
</tr>
<tr>
<td>959  wark  02n</td>
</tr>
<tr>
<td>960  glar  n</td>
</tr>
<tr>
<td>961  mead  w</td>
</tr>
<tr>
<td>962  chum  09w</td>
</tr>
<tr>
<td>963  lent  w</td>
</tr>
<tr>
<td>964  pact  w</td>
</tr>
<tr>
<td>965  clad  w</td>
</tr>
<tr>
<td>966  lame  01w</td>
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<td>967  soak  w</td>
</tr>
<tr>
<td>968  lame  01w</td>
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<tr>
<td>969  clon  09n</td>
</tr>
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<td>970  heng  n</td>
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</tr>
<tr>
<td>972  drib  n</td>
</tr>
<tr>
<td>973  crow  04w</td>
</tr>
<tr>
<td>974  hosh  23n</td>
</tr>
<tr>
<td>975  dalk  04n</td>
</tr>
<tr>
<td>976  wutt  n</td>
</tr>
<tr>
<td>977  thas  n</td>
</tr>
<tr>
<td>978  crow  04w</td>
</tr>
<tr>
<td>979  clon  09n</td>
</tr>
<tr>
<td>980  dalk  04n</td>
</tr>
<tr>
<td>981  pane  03w</td>
</tr>
<tr>
<td>982  tact  w</td>
</tr>
<tr>
<td>983  leak  02w</td>
</tr>
<tr>
<td>984  gait  w</td>
</tr>
<tr>
<td>985  pane  03w</td>
</tr>
<tr>
<td>986  leak  02w</td>
</tr>
<tr>
<td>987  curl  05w</td>
</tr>
<tr>
<td>988  wolt  05n</td>
</tr>
<tr>
<td>989  grue  n</td>
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<tr>
<td>990  drum  w</td>
</tr>
<tr>
<td>991  tace  00n</td>
</tr>
<tr>
<td>992  tace  00n</td>
</tr>
<tr>
<td>993  curl  05w</td>
</tr>
<tr>
<td>994  wolt  05n</td>
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<td>997  muke  n</td>
</tr>
<tr>
<td>998  moke  n</td>
</tr>
<tr>
<td>999  gram  w</td>
</tr>
<tr>
<td>1000  nilt  03n</td>
</tr>
</tbody>
</table>
Appendix C

Proactive influences of lexicality

Two forms of proactive influence of trial lexicality are reported, both of which were discovered post hoc in data collected for other purposes. All results indicated a counter-intuitive pattern of proactive influence in lexical tasks: processing a nonword slowed down subsequent responses to both words and nonwords, relative to processing a word. The findings provide preliminary evidence consistent with a "time window" view of orthographic processing, in which each item is processed in the context of leftover effects of a few preceding trials.

SEQUENCES OF WORDS OR NONWORDS

The first form of proactive influence was revealed in an experiment originally designed to extend findings regarding the role of interference in the decay of ST priming (see Chapter 5) to the effects of the type of interference. Specifically, the type of interference lexicality was manipulated, and crossed with the lexicality of the repeated target. As will be seen, the experiment failed to successfully address the role of interference lexicality, because of the unexpected effects of a confounding between lexicality and proactive influences of trial order. The experiment is reported in part to demonstrate the methodological problems which must be overcome in order to properly investigate the effects of interference lexicality, and in part because the proactive effects of trial lexicality uncovered are of interest in their own right.

The effects of interference lexicality were assessed by crossing the lexicality of target items with that of all items intervening between target repeats, at lags 0, 1, 2, 3, 4, 5 and 8. As an example, Table C.1 shows the trial order corresponding to the four conditions of interest at lag3. Table C.1 indicates that the lexical decision task is inappropriate in the present context, as target-interference lexicality condition is necessarily confounded with response order: no change in response is required from the last intervening item to the repeated target presentation in two conditions (ie. yes-yes or no-no), but such a change is required in the other two (ie. yes-no or no-yes). To avoid this confounding, a naming task was chosen. It was felt that the advantage that every item in
naming requires a different response outweighed the disadvantage of the small
priming effects expected with this task.

Table C.1: Trial orders for the various target x interference lexicality
conditions at lag3.

<table>
<thead>
<tr>
<th>Condition code</th>
<th>Trial order (lag3)</th>
</tr>
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<tbody>
<tr>
<td>w (w)w</td>
<td>w  w  w  w  w  w</td>
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<tr>
<td>w (n)w</td>
<td>w  n  n  n  n  w</td>
</tr>
<tr>
<td>n (w)n</td>
<td>n  w  w  w  n  n</td>
</tr>
<tr>
<td>n (n)n</td>
<td>n  n  n  n  n  n</td>
</tr>
</tbody>
</table>

Note: Trials in bold represent first and second presentations of repeated
targets, those in plain text represent intervening items. w=word; n=nonword.

There were several differences between the present experiment and
those reported in the body of the thesis. Due to the difficulty of manipulating
both lag and the lexicality of every trial in a sequence of up to 10 trials (lag8),
lag conditions were not overlapped. That is, items intervening between target
repeats were never other targets, and were instead chosen randomly from a pool
matched to the pool of targets. This use of non-overlapping lags substantially
increased the number of trials required to present all conditions. In total, 3000
trials were needed per subject, in order to present 20 items in each of the four
target-interference conditions at all seven lags.

Of the full 3000 trials, only around 18% were repeats. This meant that a
vastly increased pool of word and nonword items was required. Medium and high
frequency words were selected (to give the best chance of finding lexicality
effects by maximising the contrast with nonwords), of both four and five letters
in length. The pool of four-letter pseudowords used previously was expanded,
and an additional pool of five-letter nonwords sharing the same properties
developed. Finally, in order to keep the time per subject down to 2.5 hours, the
presentation rate was increased to one item per 1.8 seconds.

Method

Subjects. Twenty-four undergraduate subjects participated in return for course
credit. Data from one of these were discarded due to excessive error rates.

Design. Lag (0, 1, 2, 3, 4, 5 and 8), lexicality of target (word or pseudoword) and
lexicality of interference (word or pseudoword) were all varied within subjects.
At lag0, no items intervened between repeats. For each remaining lag, all items intervening between repeated targets were consistently words, or consistently nonwords. Thus, the 26 conditions of interest could be summarised as shown in Table C.2.

In addition, length of items (four or five letters) was varied (although not completely crossed with the other factors), due to an insufficient number of suitable four-letter items. The dependent measure was naming latency for first and second presentations of repeated targets.

Table C.2: Conditions employed in the experiment crossing lexicality of target and interference.

<table>
<thead>
<tr>
<th>Conditions</th>
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<tbody>
<tr>
<td>w()w0</td>
</tr>
<tr>
<td>w(w)w1</td>
</tr>
<tr>
<td>w(w)w2</td>
</tr>
<tr>
<td>w(w)w3</td>
</tr>
<tr>
<td>w(w)w4</td>
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<tr>
<td>w(w)w5</td>
</tr>
<tr>
<td>w(w)w8</td>
</tr>
<tr>
<td>w(n)w1</td>
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<tr>
<td>w(n)w2</td>
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<td>w(n)w4</td>
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<td>w(n)w5</td>
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<td>w(n)w8</td>
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<td>n(n)n3</td>
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<tr>
<td>n(n)n4</td>
</tr>
<tr>
<td>n(n)n5</td>
</tr>
<tr>
<td>n(n)n8</td>
</tr>
</tbody>
</table>

Note: w=word, n=nonword, and the numeral refers to the lag condition. For example: w()w0 represents a word string repeated immediately with no intervening item, and w(n)w4 represents a word string repeated at lag4, with all four intervening items being nonwords.

Materials. In order to maximise any chance of finding effects of target and/or interference lexicality, medium and high frequency words (approximately 4 - 1000 counts per million) were used instead of very low frequency words. In order to obtain the 1180 word targets, it was necessary to include every four- and five-letter single-syllable word, of these frequencies, appearing in the Kucera and Francis count. (Proper names were excluded.) The full set of words contained 590 four-letter, and 590 five-letter words. To match these, the set of four-letter pseudowords used in the earlier experiments was extended to give 590 such items, and an additional set of 590 five-letter pseudowords was created. All new nonwords were single-syllable, and none were pseudohomophones.

These full lists were split into two pools, one of which would provide 520 (repeated) target items, and the other of which would provide 1840 (unrepeated) interfering items. Each pool contained equal numbers of words, nonwords, four-letter items and five-letter items. The division was initially random, but was tidied up in order to equate target and interference pools on the basis of frequency (for words), and neighbourhood size (for both words and nonwords). An estimate of neighbourhood size was obtained by counting the number of
items present in the Kucera and Francis listing which could be formed by changing one letter in the string. For four-letter words, the mean frequency was 109 counts per million (range 10 – 967) and the mean number of neighbours was 8.38. For four-letter nonwords, mean number of neighbours was 6.39. For five-letter items, mean word frequency was 66 (range 4 – 938), and mean number of neighbours was 3.01 for words and 2.12 for nonwords. Note that the differences between item types here are intrinsic to the items: words have more neighbours than nonwords, four-letter items have more neighbours than five-letter items, and there are fewer five-letter words that occur with higher frequencies.

The pool of 520 target items was split into 26 sets of 20 items, corresponding to the 26 conditions of interest; 13 sets included 10 four-letter words and 10 five-letter words, and 13 sets included 10 four-letter nonwords and 10 five-letter nonwords. (It was necessary to use 20 items per condition because of the reduced magnitude of priming expected with a naming task.) Each set was equated on frequency and neighbourhood size as far as possible.

Lag was manipulated by dividing the full 3000 trials into 20 sequence templates of 150 trials, with each pattern assigned a different order of lag conditions. Each template contained one occurrence of each of the 26 conditions of interest, and was made up as follows: 13 word targets x 2 presentations + 13 nonword targets x 2 presentations + 46 word interfering items + 46 nonword interfering items + 6 fillers. Fillers were words with frequency of 3 counts per million. Target items were cycled through conditions across 13 versions of the complete list. Interfering items were not cycled, but were instead selected randomly from the pool of such items differently for each subject.

The full list was split into 10 blocks of 300 trials for presentation. An individual presentation block did not contain both four-letter and five-letter items. Instead, the first block contained only four-letter items, the second only five-letter items, the third only four-letter items, and so on. Thus, within any one block, length of the target item was confounded with length of the interfering items. (It was impossible to properly cross length of target with length of interference, as there are simply not enough suitable words available in English.)

Rather than overlapping lag conditions, it was decided in this experiment to have no other target items appearing between the two presentations of any given target. By chance rather than design, this approach allowed proactive influences of trial lexicality to be investigated by examining reaction times to sequences of randomly-selected items sharing the same lexicality (ie. the "interfering" items). For example, in the w(w)w3 condition, naming times to unrepeated words could be compared for the first, second and third "intervening" words, thus allowing word naming times to be tracked as a function of the number of preceding items sharing the same lexicality (1, 2 or 3).
Procedure. Subjects were tested individually in two 1 1/4 hour sessions. Trials were presented in 10 blocks of 300 trials (ie. two patterns were used per block), five in the first session and five in the second. Stimuli were presented on a Macintosh using PsychLab, at a rate of one every 1.8 seconds. (This was reduced from the 2 seconds used previously.)

Subjects were required to read each item aloud as quickly as possible into a microphone, and naming latency from onset of the stimulus to triggering of the microphone was recorded. Errors were recorded as for Experiment 2.2, ie. these were defined as including mispronunciations, changes in pronunciation from first to second presentation, stutters, failure to trigger the microphone, and unwanted triggering by an extraneous noise.

A practice trial of 23 six-letter items preceded the experimental blocks in each session.

Results and discussion

One subject made substantially more errors than any other (an average of 9.7% across all conditions), and data from this person were excluded. For the remaining 23 subjects, error rates were low, at 1.3% for words and 2.4% for nonwords across first and second presentations in the conditions of interest. As for the previous naming experiment (Experiment 2.2), errors could not be analysed as they were not fully scored during the experimental session and subjects' responses were not taped. Even if it were possible to do so, there would seem little point in attempting to analyse errors when the total rates were so low.

Naming times were discarded if they were less than 250ms, or if they were more than 2.5 standard deviations above the mean for each subject. These criteria excluded 0.7% of words and 1.4% of nonwords in the conditions of interest. Naming times to all first presentations of repeated targets were 484ms for words and 519ms for nonwords. As expected, four-letter stimuli were slightly faster to name (474ms for words and 512ms for nonwords) than five-letter stimuli (494ms for words and 527ms for nonwords).

Priming data. Priming was calculated with respect to an average of first presentation times across all conditions for each subject. This all-conditions-give-baseline measure of priming did not produce patterns that differed in any important way from an each-item-gives-baseline approach, but the variability across conditions was smaller with the measure employed. The mean priming in each condition is presented in Table C.3. No analysis or interpretation of the patterns of priming apparent in these data is presented, as it will be argued that
the priming scores, and thus the decay patterns of ST priming, are hopelessly entangled with proactive influences of trial order.

Proactive influences: serial position of intervening items. As noted earlier, the fact that the intervening item in each given position in the total list was chosen randomly for each subject allows an evaluation of naming times as a function of the number of preceding items to have had the same lexical status. For example, in the lag4 w(w)w trials, naming times can be examined as a function of the position, 1, 2, 3 or 4, of the intervening words, while in the lag3 n(n)n trials, times can be examined for intervening nonwords in positions 1, 2 or 3. Note that the eventual repetition of the target is irrelevant to this evaluation of proactive influences of trial lexicality.

Naming times to intervening items were examined as a function of their lexical status and of the number of preceding items in a row with that same

### Table C.3: Mean naming times, priming scores, and error rates when target lexicality was crossed with interference lexicality for: first presentations (f), second presentations (s), priming with each-item-gives-baseline (p(eib)), priming with all-conditions-give-baseline (p(acb)), errors to first presentations (ef), and errors to second presentations (es).

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>w(w)w</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
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<td>480</td>
<td>493</td>
<td>488</td>
<td>479</td>
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<td>483</td>
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<tr>
<td>s</td>
<td>463</td>
<td>468</td>
<td>472</td>
<td>467</td>
<td>466</td>
<td>464</td>
<td>460</td>
</tr>
<tr>
<td>p(eib)</td>
<td>18.1</td>
<td>11.8</td>
<td>19.9</td>
<td>20.1</td>
<td>11.9</td>
<td>16.1</td>
<td>22.8</td>
</tr>
<tr>
<td>p(acb)</td>
<td>20.4</td>
<td>15.4</td>
<td>11.1</td>
<td>16.3</td>
<td>17.1</td>
<td>19.7</td>
<td>23.5</td>
</tr>
<tr>
<td>w(n)n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>484</td>
<td>481</td>
<td>488</td>
<td>482</td>
<td>478</td>
<td>478</td>
<td>490</td>
</tr>
<tr>
<td>s</td>
<td>476</td>
<td>485</td>
<td>482</td>
<td>482</td>
<td>483</td>
<td>485</td>
<td></td>
</tr>
<tr>
<td>p(eib)</td>
<td>8.1</td>
<td>-3.5</td>
<td>5.1</td>
<td>0.5</td>
<td>-5.1</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>p(acb)</td>
<td>7.7</td>
<td>-1.3</td>
<td>1.1</td>
<td>2.0</td>
<td>1.0</td>
<td>-1.7</td>
<td></td>
</tr>
<tr>
<td>n(n)n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>513</td>
<td>516</td>
<td>522</td>
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<td>523</td>
<td>522</td>
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<tr>
<td>s</td>
<td>484</td>
<td>506</td>
<td>515</td>
<td>521</td>
<td>516</td>
<td>513</td>
<td>517</td>
</tr>
<tr>
<td>p(eib)</td>
<td>28.7</td>
<td>10.1</td>
<td>6.9</td>
<td>-0.3</td>
<td>6.0</td>
<td>10.0</td>
<td>4.8</td>
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<tr>
<td>p(acb)</td>
<td>35.6</td>
<td>13.5</td>
<td>4.1</td>
<td>-1.8</td>
<td>3.7</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>n(w)n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>521</td>
<td>519</td>
<td>516</td>
<td>517</td>
<td>523</td>
<td>523</td>
<td>514</td>
</tr>
<tr>
<td>s</td>
<td>501</td>
<td>497</td>
<td>489</td>
<td>493</td>
<td>496</td>
<td>496</td>
<td>495</td>
</tr>
<tr>
<td>p(eib)</td>
<td>19.7</td>
<td>21.8</td>
<td>26.7</td>
<td>24.1</td>
<td>26.7</td>
<td>19.2</td>
<td></td>
</tr>
<tr>
<td>p(acb)</td>
<td>18.4</td>
<td>22.0</td>
<td>30.3</td>
<td>26.5</td>
<td>23.1</td>
<td>24.6</td>
<td></td>
</tr>
</tbody>
</table>
Proactive influences of lexicality. A varying number of trials was available in each "preceding-items-with-same-lexicality" condition, as fewer lag conditions included longer sequences of same-lexicality intervening trials. For example, naming times for words with one preceding word were available from the lag 1 through 8 conditions with word targets and word intervening items, and from the lag 2 through 8 conditions with nonword targets and word intervening items, giving a total of 220 trials (11 conditions × 20 trials per condition) per subject from which to estimate naming times in this condition. Each successive value was based on fewer trials, as lag conditions gradually dropped out, so that the estimate of naming times where eight items of the same lexicality preceded the word of interest were based on only 20 trials (from the lag 8 with word targets and words intervening condition). Table C.4 gives the number of trials available per subject in each condition.

Figure C.1 plots the relationship between the number of matched preceding trials and naming times for words and nonwords, averaged over all trials available in each condition, and then over all subjects. (See Table C.5 for means.) A completely unexpected pattern is apparent: words were named faster as they were preceded by more and more words, while nonwords were named slower as they were preceded by more and more nonwords. This differential pattern indicates that the improvement for long strings of words cannot have been simply a generalised practice effect, a conclusion backed up by the magnitude of the effect, which is substantially larger than any practice effect that would be expected over only eight successive trials.

Table C.4: The number of trials available in each preceding-items-with-same-lexicality condition, and the target-interference conditions whose intervening items gave rise to each of these.

<table>
<thead>
<tr>
<th>No. preceding with same lex</th>
<th>No. of trials available</th>
<th>Coming from conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>220</td>
<td>w(w)w 1,2,3,4,5,8 &amp; n(w)n 2,3,4,5,8</td>
</tr>
<tr>
<td>2</td>
<td>180</td>
<td>w(w)w 2,3,4,5,8 &amp; n(w)n 3,4,5,8</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
<td>w(w)w 3,4,5,8 &amp; n(w)n 4,5,8</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>w(w)w 4,5,8 &amp; n(w)n 5,8</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>w(w)w 5,8 &amp; n(w)n 8</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>w(w)w 8 &amp; n(w)n 8</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
<td>w(w)w 8 &amp; n(w)n 8</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>w(w)w 8</td>
</tr>
</tbody>
</table>

Note: Target-interference conditions shown are those leading to strings of words-preceded-by-words only. The equivalent n(n)n and w(n)w conditions were also used to evaluate nonwords-preceded-by-nonwords.
The patterns apparent in Figure C.1 were confirmed statistically. A two-way ANOVA indicated a significant interaction between item lexicality and the number of preceding trials of that lexicality (Wilks' $\lambda=.402$, $F(7,16)=3.40$, $p<.02$). In addition, significant correlations between the number of matched preceding trials and naming times were found for both words ($r=-.71$, $p<.05$) and nonwords ($r=+.77$, $p<.05$). Lines of best fit indicated an average reduction in naming times of 1.34 ms per item for words, and an average increase of 1.13 ms per item for nonwords. Thus, there appears to have been a genuine "proactive" effect.
present, such that word and nonword naming times moved in opposite directions in response to sequences of trials of the same lexical status.

**Implications for the priming data.** The finding of opposite sequence effects for words and nonwords indicates that the priming data do not validly reflect simply the leftover effects of prior presentation. It would appear that second presentation times in at least the w(w)w and n(n)n conditions were influenced not just by the previous presentation of the target item (ie. the priming effect of interest), but also by a more generalised proactive "priming" effect arising due to the fact that the target repeat was the last in a sequence of items of the same lexical status. This problem would be expected to affect each successive lag more severely than the preceding one, and, while it might move naming times by only a tiny 1 or 1.5 ms per trial, this adds up to around 9 to 11 ms by lag8, an important influence in the context of priming effects of between 0 and 30 ms in magnitude.

**Conclusions.** The one interesting result of the present experiment was the unexpected finding that, in the context of a naming task involving both word and nonword stimuli, effects of sequences of items with the same lexical status were apparent. The sequence effects were small in absolute terms (around 1 to 1.5 ms per item), but large in comparison to any general practice/fatigue effects that might be expected over the 3000 trials in the list, and also large in comparison to the size of the repetition priming effects of interest. The proactive influences were in the opposite direction for words and nonwords, with words being named faster as they had been preceded by more words, and nonwords being named slower as they had been preceded by more nonwords. This would seem to indicate some generalised proactive influence of item-type (ie. whether the item was a word or a nonword), in addition to any priming effects based on item-identity. It would seem that processing more nonwords makes it progressively harder to process the next nonword, while processing more words makes it progressively easier to process the next word.

The methodological implication of the present results is that, in order to successfully address the original question of interest regarding the effects of interference lexicality on the decay of ST priming, the confounding influence of trial sequence on second presentations needs to be overcome. One way to do this would be to repeat the experiment with separate baseline conditions: rather than measuring priming against first presentation times, reaction times to repeated presentations would be compared to unprimed presentations preceded by sequences of trials matching those in the target condition. For example, to calculate the influence of prior presentation in the w(n)w3 condition, the two conditions required would be:
where the trials shown in bold present the target, and the other trials present randomly-chosen words or nonwords from a pool of non-repeated items.

**LEXICALITY OF IMMEDIATELY-PRECEDING TRIAL**

The form of proactive influence reported above involved examining sequences of trials with the same lexicality. Here, naming times gradually altered within sequences of up to eight words or eight nonwords presented in a row, such that words sped, and nonwords slowed, the processing of successive trials. One limitation of that experiment, however, was that it was possible to examine the buildup of proactive influences only on those items which matched the preceding sequence in lexicality. An examination of *first-presentation* reaction times across all experiments presented in this thesis allows a more general question to be addressed: What are the effects of maintaining or changing lexicality from one trial to the next?

In lexical decision, where response-matching is an issue, it might be expected that words ("yes") would be faster when preceded by words ("yes"), while nonwords ("no") would be faster when preceded by nonwords ("no"). In fact, this was not the case. Figure C.2 shows naming or lexical decision times in each experiment to first presentations (ie. the later repetition is irrelevant), as a function of the lexicality of the immediately-preceding item. It can be seen that there were consistent proactive influences of the preceding item, such that both words and nonwords were responded to faster if the preceding item was a word. In all experiments, words were processed faster when preceded by a word than when preceded by a nonword (by approximately 20ms). In seven of the eight, nonwords were also processed more quickly when the preceding item was a word (by approximately 10ms). This pattern occurred in both naming and lexical decision, with the size of the effect being reasonably large in comparison to the overall speed difference between word and nonword targets.

Table C.6 shows the magnitude of the advantage when the preceding item was a word. For word targets, there was a significant word advantage in all experiments. For nonword targets, the advantage was highly significant in four experiments, approached significance in two, but was not significant in two others; the pattern of results over all experiments, however, clearly shows a
Proactive influences of lexicality

word advantage (note that the one experiment in which the effect went in the opposite direction had the fewest trials per condition and so would be expected to be the least reliable). Given that word-then-nonword trials might be partially affected by a response-mismatch slowing in lexical decision, some reduction in a word advantage for nonwords might be expected with this task. (Indeed, it is the lexical decision experiments only that produce some mixed results; the two naming studies both show highly significant word advantages.) As with the effects of other manipulations, the absolute magnitudes of the word advantage – for both types of targets – are smaller in naming than in lexical decision, presumably reflecting the faster baseline naming times.

Table C.6 also demonstrates that no effect of preceding-item lexicality was apparent in the one experiment which used an explicit memory task (recognition in Experiment 4.1) rather than a priming task. This is consistent with the view that the proactive influences revealed to date in the lexical decision and naming tasks are lexical in nature.

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**Figure C.2:** Effect of lexicality of immediately-preceding trial on words and nonwords across all experiments.
Thus, a posthoc analysis of all experiments has extended the findings regarding proactive influences of lexicality, by showing that both word and nonword targets are processed more slowly following a nonword, while both are processed more rapidly following a real word. This analysis was able to examine the effect of the immediately-preceding trial only. More recent work conducted in this laboratory has been designed to investigate the duration of proactive influences. So far, equivalent effects of trial lexicality surviving at least one and possibly up to three intervening items have been identified, suggesting that such effects do, indeed, arise from the operation of the lexical processing time window which has been proposed to underlie ST priming.

### Table C.6: Proactive influences of preceding-item lexicality, across all experiments. The number of items available in each combination of word/nonword target and word/nonword preceding trial is shown, plus the task employed, the advantage for each target type if the preceding item was a word (in ms), and the significance level of this advantage (based on t-tests).

<table>
<thead>
<tr>
<th>No. of trials</th>
<th>wW</th>
<th>nW</th>
<th>wN</th>
<th>nN</th>
<th>Word advantage for...</th>
<th>p</th>
<th>Nonwords</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expt 2.1: LF words, lexical decision</td>
<td>68</td>
<td>89</td>
<td>78</td>
<td>78</td>
<td>24.8 ms **</td>
<td>8.8 ms **</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expt 2.2: LF words, naming</td>
<td>68</td>
<td>89</td>
<td>78</td>
<td>78</td>
<td>7.6 ms **</td>
<td>12.8 ms **</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expt 3.1: LF words, LD, long lags</td>
<td>32</td>
<td>36</td>
<td>35</td>
<td>33</td>
<td>17.9 ms *</td>
<td>-7.5 ms ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expt 3.2: HF words, lexical decision</td>
<td>68</td>
<td>89</td>
<td>78</td>
<td>78</td>
<td>29.6 ms **</td>
<td>18.9 ms **</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Expt 4.2: LF words, LD, half repeats  | 68 | 89 | 78 | 78 | 20.9 ms **             | 10.8 ms *  
| Expt 5.1: LF, LD, varied time or items| 67 | 110| 122| 55 | 13.3 ms *              | 8.0 ms ns  
| Expt 5.2: LF, LD, blanks or interference| 86 | 168| 173| 91 | 29.5 ms **             | 14.5 ms **  
| App. C: MF/HF, naming, target x interference| 120| 120| 120| 120| 12.0 ms **             | 6.3 ms **   
| Average, all priming expts:            | 68 | 89 | 78 | 78 | 19.5 ms **             | 9.1 ms **    

| Expt 4.1: Explicit recognition         | 68 | 89 | 78 | 78 | 0.8 ms ns              | -8.1 ms ns  

Note: ** = p<.01; * = p<.05; † = p<.08; ns = p>.08;
Condition codes are: wW= word preceded by word; nW = word preceded by nonword; wN = nonword preceded by word; nN = nonword preceded by nonword. The word advantages were calculated as (nW-wW) and (nN-wN).
Supplementary footnotes

S1. pg 25. Section 1.1.6 Word recognition and priming.

Burt and Humphreys (1993) have previously noted that priming may arise from weight changes in a connectionist network, and that the duration of such changes is potentially longer than the duration of very transient activation.


Word frequency effects can, of course, be as large as the effect of a single repetition when the target words differ vastly in frequency. However, the effect of a single increment in word frequency (eg. a frequency of 101 occurrences per million rather than 100) is very small in comparison to the effect of a single intra-experimental repetition.

S3. pg. 28. Section 1.1.8. Short term priming?

It is acknowledged that one well-known short-lived priming effect exists, namely semantic priming in which one word primes another related to it by meaning or association. This thesis, however, raises the possibility of a short-lived perceptual change (ie. in orthographic and/or phonological representations, as opposed to semantic representations), by which words and wordlike nonwords might demonstrate a short term repetition effect.

S4. pgs. 41, 42 & 44. Section 1.3.2. Directly relevant literature: Short term priming for words and nonwords. Figures 1.2, 1.3 and 1.4.

Part of the discrepancy between the various previous studies of short term priming for words and nonwords is simply in the overall magnitude of priming. Given the many methodological differences between these studies, and the variation in baseline reaction times across studies, a relative rather than absolute measure of priming may be considered more appropriate. However, plotting priming as a percentage decrease in reaction time does not reduce the discrepancy in pattern of decay across the various experiments, which is the feature of the data under consideration.
When a small number of items is used per condition, statistical analysis is often conducted "over items" as well as "over subjects". This is done to evaluate the likely generalisability of the results to items other than the limited set actually used. However, bearing in mind that the experiments in this thesis employed a large set of words and nonwords (at least 180 of each), analyses over items were not considered necessary here.

I have chosen to fit the decay data for words with an exponential function. This is shown to provide a very good fit to the data ($r^2=.98$), but is not compared to any other alternative curves, such as power functions. The strongest justification for selecting an exponential comes from later experiments showing that the ST and LT priming effects appear to be additive. If this is the case, an exponential function (which includes two additive components of priming) must be more appropriate than a power function (which allows only a single component of priming). In addition, Experiment 3.2 revealed that, for very high frequency words, ST priming can exist in the absence of any LT priming. This pattern of data can easily be modelled by an exponential function by setting one of the additive components to zero. A power function, however, would predict that priming would continue to decrease beyond lag 23, thus predicting negative long term priming for some real words, a counter-intuitive finding which has never been observed.

The "nonsensical" finding of substantially less priming at 20 s than at delays of 48 s to 5 min cannot be attributed to an idiosyncratic choice of items, as all items in the full set of targets appeared at each delay, with each subject seeing a different set of items in the 20 s condition. The finding might be more explicable as an order-of-lexical-status effect: all subjects saw the same order of conditions across trials (although with different items appearing in each condition). For example, an imbalance in the number of words and nonwords preceding either first or second presentations of the 20 s condition could have reduced priming by speeding first presentation times or slowing second presentation times.

The reversing of the 2-second list provided an easy way of producing a new trial order while maintaining the correct lag between repeats in the various conditions.
S9. pg. 142. Section 6.2.2 Historic or ahistoric traces?

The extended duration of long term priming has commonly been used to argue that long term priming must be historic in nature (e.g. Schacter, 1987). Technically, however, this extended duration simply rules out activation as an explanation of the effect; it does not provide direct evidence for priming relying on historic traces unless the assumption is made that this is the only theoretical alternative.

S10. pg. 146. Section 6.3.2 Locus within the functional architecture of word recognition.

The results of Kirsner and Smith (1974), showing no cross-modality short term priming, are also consistent with the proposal that short term priming arises in one-way links from orthography to phonology, and vice versa, rather than in priming of the orthographic and phonological representations themselves.

S11. pg. 154. General Discussion. Additional comment on the basis of nonword priming.

The basis of nonword priming, and of the difference between word and nonword decay patterns, deserves more attention than it received in the body of the thesis. I argued there that the difference between the word and nonword decay patterns shows that the short term priming effect is "lexical", rather than relying on, say, a purely visual trace, or on explicit recognition of prior targets. However, I did not provide any concrete examples of how nonword priming might arise within the lexical processing system, and how its decay might differ so noticeably from that for words.

A complete explanation of the pattern of results would require a full knowledge of the representations underlying word recognition, and the methods of producing both lexical decision and naming responses. In the absence of such understanding, however, a number of points can still be made. First, short term priming for nonwords must be explained in terms of access mechanisms, as opposed to response or decision mechanisms. The evidence for this is that the decay patterns for lexical decision and naming were the same. These tasks presumably share the access stage of lexical processing, but differ substantially in their response requirements.

Second, some consideration can be given to the access mechanisms which might lead to priming for nonwords. Assume, for example, that a Seidenberg-and-McClelland-style parallel distributed processing system provides a suitable model of the word recognition system. Here, lexical access corresponds to the pattern of activation over the hidden units falling into a particular pattern. For a
word target, the pattern to which the system stabilises will be close to the stored pattern representing that word. For a nonword target, the pattern to which the system stabilises will be far from that representing any word. Some measure of distance from familiar representations can then be used to support a lexical decision, and the flow-on of activation from the hidden units to the phonological units can be used to support naming. Priming during access within such a system corresponds to the hidden units stabilising to their final activations more rapidly on repeated presentation, thus allowing faster resolution of the stimulus. The mechanism by which this might occur remains unclear, but it can be noted that it is as likely to work for nonwords as for words: in both cases, some leftover influence of prior presentation starts the system somewhat further down the processing track, meaning that fewer processing cycles are required to reach the stable pattern. This should lead to a speed up in "lexical access" for both words and nonwords.

Third, reasons for the difference in word and nonword decay patterns following lag 0 can be considered. As noted in the thesis, the evidence is that this difference in decay patterns arises because nonword priming is more sensitive to interference: in the absence of interference, the decay of nonword priming takes the same basic form as for word priming. One way in which such a finding could be produced is if the word recognition system contains localised whole-word representations, in addition to sublexical or distributed representations. Under this scheme, first presentations of words modify both whole-word and sublexical/distributed representations, while first presentations of nonwords modify the latter only (nonwords, by definition, do not have a representation as a familiar whole). For repeats at lag 0, where no interfering items have disturbed the state of the system, priming should then occur for both words and nonwords; and if only the time delay between repeats is increased, both item types should show a smooth reduction in priming as the initial modifications slowly decay. However, when other items appear between target repeats (ie. from lag 1 onward), initial modifications of sublexical or distributed representations are likely to be overwritten, given that these will participate in the processing of many different words and nonwords. As short term priming for nonwords depends on these representations only, such priming will be catastrophically reduced by even a single intervening item. Priming for words, on the other hand, will survive interference more easily, as part of such priming arises from modification of a representation specific to the target word.