Short term implicit memory in lexical 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
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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, CREAFL). 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
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& 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 practiced 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; Kersteent-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
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, GENCULE**) 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

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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.
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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,
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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 (e.g. 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 (e.g. 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 (e.g. 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 (e.g. 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 (e.g. 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 (e.g. Jared & Seidenberg, 1991), and whether a grapheme-to-phoneme conversion procedure is really necessary for reading nonwords (e.g. 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.
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) **Wordlikeness 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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reduced when medium and high frequency words are presented in blocks of a single frequency band (plus nonwords), rather than being randomly mixed with low frequency words and nonwords (Glanzer & Ehrenreich, 1979; Gordon, 1983).

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 (e.g. 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 (e.g.
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 (e.g.
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
Background: The time-course of repetition priming

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
Background: The time-course of repetition priming

The time-course of repetition priming 17 magnifying the advantage of the correct word unit WORE over competing units WORK, WORD, WIRE, etc. Soon, 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 WORE active. This "rich-get-richer" followed by "winner-take-all" behaviour is demonstrated in Figure 1.1, which shows the relative activation of WORE and its competing neighbours as a function of the number of processing cycles (ie. 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 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 JGTL is presented to the model, less total word activation results at every cycle number. This is because JGTL 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.² 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

² Despite the recent use of the interactive-activation model as the basis of more complex computational models (eg. see Coltheart et al., 1993; Coltheart & Rastle, 1994), the literature appears to contain no simulations demonstrating how the model might accurately distinguish words from nonwords. Claims that the model reproduces various aspects of human lexical decision data have been made (eg. Grainger & Segui, 1990; Jacobs & Grainger, 1992), but the method of making a "lexical decision" in these simulations has generally been simply recording the number of cycles until a word node reaches some criterion level of activation, allowing a "yes" decision. Given that pseudowords also seem to produce substantial activation levels (eg. see Figure 1.1), albeit more slowly than words, such a simple criterion is clearly inadequate for determining how a decision (ie. "yes" or "no") response is made. Some criterion based on summing activation over cycles, and/or tracking the rate of change of activation, would seem necessary to allow predictions of accuracy or reaction times to say "no" (see Jacobs & Grainger for some preliminary ideas regarding this issue).
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, eg. H- or S-) and "body" units (corresponding to the word ending, eg. -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 (eg. 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
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 \((desired-actual)^2\) 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
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 (eg. 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 (eg. 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.
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
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 rethinking.\footnote{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.}

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.
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 (e.g. 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 (e.g. 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. 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.
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. 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 (ie. when there is strong overlap in processing at study and test). Proponents of the view that such traces underlie long-lived implicit memory (eg. 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 (eg. Jacoby & Hayman, 1987; Kolers, 1979; Roediger & Blaxton, 1987), others have failed to do so (eg. 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 perceptual 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 perceptual 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 (e.g., 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 (eg. 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.\(^7\) 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

\(^7\) 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, i.e. 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, 8, 12, and 20, 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 Kersteen-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
Background: The time-course of repetition priming

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 (e.g. 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 (i.e. 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 (i.e. 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](image-url)

**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)
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 lag 0 than at later lags, but Figure 1.4 shows that, again, there is some disagreement regarding the form of decay post lag 0. (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 lag 0 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.
Background: The time-course of repetition priming

**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 (ie. 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>0,1,3,7,</td>
<td>16</td>
<td>12</td>
<td>5?</td>
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<td>26</td>
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<tr>
<td></td>
<td>7,15</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>SCS 2</td>
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<td>6</td>
<td>5?</td>
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<td></td>
<td>15,31</td>
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<td></td>
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</tr>
<tr>
<td>M 2</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 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>
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<td></td>
</tr>
<tr>
<td>RHM 1</td>
<td>1,2,3,4,6</td>
<td>4</td>
<td>60</td>
<td>5</td>
<td>yes</td>
<td>95</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6,8,12</td>
<td></td>
<td></td>
<td></td>
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<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 lag3 compare reaction time to the final trial of the primed sequence \textit{wt-\textit{wf-nf-wf-wt}} with that to the final trial of the baseline sequence \textit{\textit{wf-wf-nf-wf-wt}}, where \textit{wt} refers to the target word, \textit{wf} is a word filler, and \textit{nf} 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 (i.e. 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.
Background: The time-course of repetition priming

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
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

"Priming" 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
Background: The time-course of repetition priming

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.

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 8 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.)
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 $2 \times 9$ 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: $180 \times 2$ types $\times 2$ presentations, plus fillers: $180$ unrepeated $\times 2$ types $+ 5 \times 2$ types $\times 2$ 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 (i.e. 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 (e.g. 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, i.e. 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 659 ms for words and 704 ms 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 50 ms 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, MS_ε=2126, p<.001), a main effect of target type, such that words showed more priming, on average, than nonwords (F(1,17)=26.1, MS_ε=1726, p<.001), and an interaction between lag and type (F(7,119)=3.6, MS_ε=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>
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<td>53</td>
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<td>52</td>
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<td>5%</td>
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<td>es</td>
<td>1%</td>
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<td>4%</td>
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<td>4%</td>
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<td>5%</td>
<td>6%</td>
<td></td>
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</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:

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

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 ms², and the variance of the actual means (\( MS_{\text{total}} \)) was 949 ms², 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** 59

*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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<tbody>
<tr>
<td><strong>words</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-value</td>
<td>66.3**</td>
<td>11.0**</td>
<td>2.6</td>
<td>5.1*</td>
<td>1.5</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>lag0</td>
<td>82</td>
<td>34</td>
<td>16</td>
<td>24</td>
<td>13</td>
<td>1</td>
<td>-7</td>
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<tr>
<td>nonwords</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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>
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<td>98</td>
<td>-11</td>
<td>1</td>
<td>-15</td>
<td>-1</td>
<td>1</td>
<td>24</td>
</tr>
</tbody>
</table>

Note: ** = \(p<.01\); * = \(p<.05\); \(\text{MS}_e = 1593\) (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

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\(^2\) 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; Kersten-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 (eg. 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.

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.
Primming 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 primming 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 primming at lag0 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 primming 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.)

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<tr>
<th></th>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
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<th>lag8</th>
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<td>f</td>
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<td>499</td>
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<td>478</td>
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<td>484</td>
<td>486</td>
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<td></td>
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<tr>
<td>p</td>
<td>27.3</td>
<td>21.1</td>
<td>21.2</td>
<td>15.8</td>
<td>6.7</td>
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<td>509</td>
<td>524</td>
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<td>540</td>
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<td>496</td>
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<td>492</td>
<td>498</td>
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<tr>
<td>p</td>
<td>38.2</td>
<td>15.4</td>
<td>10.4</td>
<td>13.1</td>
<td>11.9</td>
<td>20.6</td>
<td>24.1</td>
<td>20.2</td>
<td>48.4</td>
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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.

<table>
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<tr>
<th></th>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
<th>lag6</th>
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<tr>
<td>13.6</td>
<td>8.6</td>
<td>10.4</td>
<td>6.3</td>
<td>-3.8</td>
<td>-1.0</td>
<td>1.3</td>
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</tr>
<tr>
<td>F-value</td>
<td>10.7**</td>
<td>4.2*</td>
<td>6.0*</td>
<td>2.1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>21.7</td>
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<td>-7.5</td>
<td>-6.1</td>
<td>-9.7</td>
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<td></td>
</tr>
<tr>
<td>F-value</td>
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<td>1.2</td>
<td>2.8†</td>
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<td>&lt;1</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 x 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<sub>e</sub>=1727, p<.001), such that words showed more priming than nonwords, and by delay (F(7,140)=6.9, MS<sub>e</sub>=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 ($F(7,140)=1.9$, $MSE=2204$, $p=.074$). 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 ($F(1,20)=15.4$, $MSE=1986$, $p<.01$) and quadratic components ($F(1,20)=11.4$, $MSE=639$, $p<.01$), 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 (e.g. 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 20 ms, compared to roughly 50 ms). 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

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 lag0. 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 (\(F(7,119)=19.6, \text{MSE}=1662, p<.001\)), no overall effect of target type (\(F<1\)), and an interaction (\(F(7,119)=4.83, \text{MSE}=1216, p<.001\)). Decay patterns were again examined separately for words and nonwords.

![Graph](image)

**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.
### 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).

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

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<td><strong>nonwords</strong></td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>F-value</td>
</tr>
</tbody>
</table>

Note: ** = p<.01; * = p<.05; † = p<.1; MS_e = 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 lag2 priming is not significantly above priming at lags 3 to 23, and that lag3 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

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

was found to provide an excellent fit, with 92% of the variance in the observed means accounted for (\( MS_{fit} = 1001 \), \( MS_{total} = 1087 \)), 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 (97.2ms, s.e.= 7.6 for HF; 93.5ms, 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. = 4.6ms, 95% confidence interval = -8.1 ms to +15.5ms). 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 18ms. 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, MSerror=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 ($\text{Wilks' } \lambda = 0.329$, $F(7,45)=13.1$, $p<.001$); 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.
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 lag 3.

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, lag 3, is significantly below successive lags, the contrasts are somewhat negative at all intermediate lags (i.e. lags 1 to 5), suggesting a general trend upwards from lag 1 onwards. This pattern is consistent with a "dip" following immediate repetition to a minimum at around lag 3 (or possibly earlier), with a return to the LT value by lag 9. In order to investigate the statistical significance of this apparent dip, a "screening" ANOVA was conducted on the nonword priming scores excluding lag 0. There were significant differences amongst the means (\(F(6,318)=2.46, \text{MSE}=.86, p<.025\)), and thus follow up tests were conducted. These revealed that average priming at lags 1, 2, 3, 4 and 5 was lower than at lag 9 and 23 (\(F(1,318)=6.35, p<.025\)), with lag 3 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
Short term priming and long term priming

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>
<th>lag0</th>
<th>lag1</th>
<th>lag2</th>
<th>lag3</th>
<th>lag4</th>
<th>lag5</th>
<th>lag9</th>
</tr>
</thead>
<tbody>
<tr>
<td>words</td>
<td>1.34</td>
<td>.68</td>
<td>.39</td>
<td>.42</td>
<td>.10</td>
<td>.15</td>
<td>.07</td>
</tr>
<tr>
<td>F-value</td>
<td>125**</td>
<td>29.3**</td>
<td>9.1*</td>
<td>8.5*</td>
<td>&lt;1</td>
<td>1.5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>nonwords</td>
<td>1.57</td>
<td>-.23</td>
<td>-.10</td>
<td>-.40</td>
<td>-.12</td>
<td>-.20</td>
<td>.28</td>
</tr>
<tr>
<td>F-value</td>
<td>181**</td>
<td>3.6†</td>
<td>&lt;1</td>
<td>10.1*</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>3.4†</td>
</tr>
</tbody>
</table>

*Note:* ** = p<.01; * = p<.05; † = p<.1; average MSε = .68 (words); average MSε = .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 ($F(7,245)=2.79$, $MS_e=0.69$, $p<.01$), with no main effect of lexicality ($F<1$), and an interaction between the two (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 lag5 (12 seconds).