Primary and Secondary Processes in normal and dyslexic word identification.

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Abstract

Skilled visual word identification is an effortless component of fluent reading, subserved by a relatively fast, automatic, primary lexical access process. Experimental tasks and neuropsychological conditions that restrict information flow to primary process invoke task specific or secondary process mediated identification. These secondary processes may be alternative routes to identification, used infrequently by skilled readers, but more frequently while acquiring literacy, or when primary process fails. They are sometimes referred to as guessing and meta-linguistic functions. The focus of mainstream research on primary lexical access has meant that they remain relatively unexplored components of normal word recognition.

The thesis proposes a limited set of secondary 'completion' processes, to avoid using the term 'guess'. Completion processes 'complete' degraded input to deliver candidate identifications. Lexical completions are mediated by the orthographic input lexicon, and involve the amplification of sub-threshold representations, either by serial deployment of attention to enhance letter level representations, or by parallel attentional modulation of word level activation. Sublexical completion processes explicitly identify letters, and 'retrieve' or 'assemble' words from letter identities or names. These completions are under constant 'revision' in the normal, motivated, system. In conjunction with primary process, these secondary processes form a broader view of normal word recognition formalised in a flow model call the primary secondary process model

Experimental results indicate that lexical completion is associated with inhibitory effects of neighbourhood size, and that sublexical completion may result in inhibitory or facilitatory effects of neighbourhood size depending on the nature of fragments and procedures used. Neuropsychological results indicate that secondary process deficits may restrict the compensatory strategies open to peripheral dyslexics, and hence, that their performance is best described in terms of both residual primary and residual secondary processes. The explanatory role of secondary processing may extend beyond peripheral dyslexia and fragment completion, to encompass strategic and individual differences in adult performance, and developmental differences in the acquisition of literacy.
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Extended Abstract

Visual word identification involves matching visual representations of words to stored abstract representations of their orthographic structure. This process is referred to as 'the primary process of lexical identification' (Paap & Johansen 1994). However, tasks used in word identification research also invoke task-specific or 'secondary' processes, which are not essential parts of primary process. For instance, subjects often 'guess' or 'deduce' the identity of stimuli in tachistoscopic presentations. Secondary processes also play a role in 'meta-linguistic functions', such as identifying words from oral spelling or solving word fragments. Visual word recognition thus involves both primary and secondary processes. Primary process has been the subject of considerable research, and is described by models such as the interactive activation model of word recognition (McClelland & Rumelhart, 1981; Grainger & Jacobs 1996; Ziegler, Rey & Jacobs 1998). Secondary processes have received less attention to date (Jacobs & Grainger, 1994). The role of secondary processes in the identification of words is explored in two main areas. The first is referred to as 'experimental degradation', and looks at normal performance with word fragments. The second, 'neuropsychological degradation', looks at reading in peripheral dyslexics.

Secondary processes are prominent in the identification of experimentally degraded words by normal subjects. The probability of identifying a degraded word is sensitive to the number of other words that are visually similar to the target, and hence subjects often respond with these 'neighbours' of a target. Research in experimental degradation reports inhibitory effects of neighbourhood size on low frequency words (Snodgrass & Mintzer, 1993; Grainger, O'Regan, Jacobs & Segui, 1989). Andrews, (1997) suggests that inhibitory effects of neighbours are restricted to tasks which invoke 'sophisticated guessing', or secondary processes, such as perceptual identification tasks. In contrast, she reports extensive evidence for facilitatory effects of neighbours when subjects identify intact words. Hence neighbours may be facilitatory in primary process and inhibitory when secondary processes are employed.
Secondary processes produce what have been referred to as ‘sophisticated and unsophisticated guesses’ (Jacobs & Grainger, 1994; Andrews, 1997). Because some of the processes originally referred to as ‘sophisticated guessing’ are now an integral part of many models of primary process, the term ‘completion’ is used in preference to ‘guessing’. The thesis proposes a specific set of completion processes. These are divided into Lexical and Sublexical processes. Lexical completion processes include ‘Cohort completion’ which exploits sub threshold word level activation to produce responses, and ‘Scanned completion’ which employs serial attentional and saccadic letter processing to enhance word level activation. Sublexical processes include ‘Retrieved completion’ and ‘Assembled completion’, which identify individual letters and use knowledge of spelling or visual imagery to identify words, and ‘Revision’ which verifies completions against the visual evidence and amends candidate responses. The secondary processes work in conjunction with primary process in word identification. The thesis goes on to look for evidence for these processes in experimental and neuropsychological degradation.

Two tasks, the Fragmentation task (Snodgrass & Hirshman, 1991) and the Component-letter task (Peynircioglu & Watkins, 1986), use a method of cueing which provides subjects with gradually more informative fragments of a target word (e.g. t _ _ e_ ; t _ r_e_ ; t_rge_ ; targe_). This is referred to as ‘incrementing’. Results indicate that fast incrementing procedures, which only allow scope for some secondary processes to operate, result in inhibitory effects of neighbourhood size (the number of competitors for the target word that share structural features with it). Snodgrass and Mintzer (1993) report however, that slow incrementing, which is thought to allow more scope for both completion and revision, results in facilitatory effects of neighbourhood size. Thus, the effect of incrementing depends on the scope it allows for secondary processes. When relatively fast secondary processes are used, scanned completion for example, high frequency neighbours of low frequency words are likely to be produced as responses. Slower procedures allow more completions, possibly through retrieved completion, and allow revisions. The involvement of these slower secondary processes results in facilitatory effects of neighbourhood size.

Two facilitatory effects of neighbourhood size, the Appreciation effect and the Revision effect are reported with the component-letter task. The results suggest
that the set of secondary processes proposed may be isolated for study with these
tasks, by the combination of different kinds of fragments and different procedures.
Experiments are reported which extend Snodgrass and Mintzer’s findings with the
fragmentation task to the component-letter task, and identify some other factors
relevant to the relationship between secondary processes and neighbourhood
structure. The secondary processes proposed are formalised in a flow model of word
recognition referred to as the **Primary-Secondary Process Model**, or **PSP**.

The significance of experimental degradation to neuropsychological
degradation is that the same set of secondary processes employed in normal word
recognition may be used by peripheral dyslexics. In some instances, the effect of
lesions resulting in impaired primary process may be to place much of the burden of
word identification on secondary processes. However, secondary processes may also
be impaired, and this may limit the compensatory strategies open to particular
patients. Some **Letter-by-letter readers** labour over short words for many seconds,
naming the letters of words in the attempt to read them. An analogy between slow
incrementing and letter-by-letter reading is made, because they may both involve
retrieved and assembled completions, and revision. This would predict facilitatory
effects of neighbourhood for letter-by-letter readers who use the slower completion
processes. On the other hand, peripheral dyslexics who use scanned or cohort
completion might be expected to show inhibitory effects of neighbourhood size.

The second part of the thesis explores the role of secondary processes in the
performance of a new peripheral dyslexic **AC**, who reads letter-by-letter in clinical
confrontation, but not when words are presented at restricted and tachistoscopic rates.
**AC**'s injuries include a parietal infarct, and ischaemic attacks involving the left
occipital lobe resulting in right homonymous hemianopia. Seven experiments and a
computational error analysis assessed **AC**'s residual primary processing, and
identified the secondary processes **AC** employs to identify words.

Several results suggested considerably intact lexical processing. **AC** named
words presented for 100ms as accurately as he named words presented for 3s or in
free vision. Lexical decision to high frequency words presented in his left visual field
was excellent, and there was an inhibitory effect of neighbourhood size on both
accuracy and latency in single word reading. He did not show the linear increase in naming time with word length characteristic of letter-by-letter readers.

However, he was very poor at naming the inner letters in letter strings, and very poor at reading vertically aligned words. Most of the tests failed to produce evidence of effective serial letter processing. These results combined to suggest a **secondary process deficit**. His single word reading depended largely on the parallel completion processes and not on retrieval, assembly, or revision processes. The indications of lexical effects on reading, including an inhibitory effect of neighbourhood size, and the absence of indications of serial letter processing, suggested that many of AC’s completions were cohort completions. The combination of a right field deficit and a letter-processing deficit is also found in neglect patients with attentional dyslexia. This predicted that AC’s performance and error patterns should be similar to those of a right neglect patient with attentional dyslexia, RYT (Warrington, 1991). This was confirmed by a computational error analysis.

The results from neuropsychological testing and experimentation with normal subjects were integrated into the PSP model of word recognition. The model is intended to be comprehensive enough, in terms of both primary process and the secondary processes it describes and tests, to form a bridge between normal and impaired reading. It is intended to allow accurate description of individual differences, experimental procedure, and subject and patient strategy, in terms of primary process and secondary processes.
"Reading is so much simpler to investigate if we assume that we may generalise from this subject to all subjects, and from this reading situation to all reading situations; and it is natural to feel that chaos would ensue if these assumptions were relinquished. The experimental work ........, however shows not only that we must investigate strategic and individual-difference effects in reading tasks, but that we can do so successfully". (Coltheart, 1978 pp. 213).

1.1 The Primary-Secondary distinction

Visual word recognition research has focused largely on the process by which an encoded sensory representation of a word is matched to a stored lexical representation of the word. This mapping between representations of visual features and orthographic representations of the graphemic structure of whole words is referred to as “orthographic lexical access”. The prototypical model of this process is Morton’s (1969) logogen model, which views lexical level representations, or ‘Logogens’, as evidence collecting devices that take on activation values commensurate with the sensory evidence for the word they represent. A more recent model of lexical access, the Interactive Activation Model of word recognition, (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982; Grainger & Jacobs 1996; Ziegler et al. 1998; henceforth IAM), is a development of the logogen model. The IAM uses three processing levels representing features, letters, and words in a hierarchy of facilitative and inhibitory constraints. Activation is passed up the hierarchy by facilitative connections. Mutually inhibitory connections within letter and word levels constrain the selection of a word level representation that best fits the sensory evidence.

This model is a widely accepted description of orthographic lexical access and is used here as a canonical model (Grainger & Jacobs, 1996) of the process. This does not preclude sublexical units larger than letters (Warrington & Shallice 1980; Whitely & Walker 1994), global representations (Howard, 1987), phonological representations
(Jacobs, Rey, Ziegler & Grainger, 1998) or semantic representations (Behrmann, Plaut & Nelson 1998) from being intimately related to orthographic lexical access.

**Lexical access, Lexical decision and perceptual identification**

Much research into lexical access has used a task called lexical decision, in which subjects are shown words and nonwords for brief durations and asked to decide whether the stimulus was a word or not. The motivation for using this task has always been the need to examine what Paap and Johansen (1994) refer to as the 'primary process' of lexical access. Naming a written word involves many other processes besides lexical access. The activated orthographic representation of a word activates phonological representations, which then activate articulatory processes and so on. If, for instance, the question of interest were the time it takes a written word to access the lexicon, naming latency would be an overestimate. Lexical decision seemed to provide the cleanest measure of lexical access, and became the major index of 'the primary process of lexical access'.

This idea has been challenged because lexical decisions may be based on general familiarity or global lexical activity, and hence may not always index lexical access. (Snodgrass & Mintzer, 1993; Balota & Chumbley, 1984; Besner & McCann, 1987; Grainger & Jacobs, 1996). Doubts over the purity of lexical decision, as an index of lexical access, have prompted renewed interest in other tasks. Snodgrass and Mintzer (1993) suggest that perceptual identification tasks can provide useful additional data on word recognition processes.

“It is a peculiar comment on the history of research in word recognition that, although the process was initially studied by use of the perceptual identification task, typically using tachistoscopic recognition thresholds as the dependent variable (e.g., Howes & Solomon (1951)), today the most popular tasks for measuring word recognition are lexical decision and pronunciation. Yet, as the preceding discussion makes clear, questions have been raised about both the lexical decision and pronunciation tasks as viable ways of measuring lexical access. We believe that the two tasks used in this paper perceptual identification and speeded identification can provide important converging evidence about the roles of target frequency, neighbourhood size, and neighbour frequency on the process of word recognition. Although we admit that perceptual identification is not free of response bias effects, the identification technique has the advantage of revealing something about the nature of errors on both the perceptual and response sides.” (Snodgrass & Mintzer, 1993 p. 264)
Examples of the kinds of stimuli used by Snodgrass and Mintzer (1993) in the fragmentation task are reproduced in Figure 1.1. Subjects might be asked to identify the word in fragment 4 for instance. Relationships between accuracy and frequency, or neighbourhood size, might be revealing. Single moderately informative fragment cues are referred to as ‘standard’ cues. Alternatively subjects might be shown fragments 1 to 6 in a sequence, and asked to identify the target word as early in the sequence as possible. Cues made up of a series of progressively more informative fragments are referred to as ‘incremental’ cues. The stage in the sequence at which identification occurs provides a threshold measure that might vary with factors such as the frequency of the target, or neighbourhood size. An immediate objection to the idea of using this task to research lexical access is that degraded stimuli invite guessing, and guessing is not part of the normal process of lexical access. Paap and Johansen (1994) voice these concerns.

“Within this framework, (activation-verification) one argues that the fragmentation task is suspect not because it fails to distinguish what is seen from what is said, but because it fails to distinguish factors important to primary lexical identification from those that are secondary and peculiar to only certain tasks. In this case, the task invites a response bias to guess a common word that is consistent with the visual evidence, but there is no compelling reason to believe that this bias is a ubiquitous part of primary lexical identification.” (Paap & Johansen, 1994, pp. 1142).

A ‘secondary process’ by this reckoning is any process involved in word recognition that is not “a ubiquitous part of primary lexical identification”.

The Primary- Secondary process distinction

This objection implies the view that the process of word recognition consists of a main ‘primary process’, and a variety of secondary processes which vary with the tasks we employ. So for instance, we might consider ‘lexical decision’ as a task that involves primary lexical access, but also tends to invoke a secondary “familiarity assessment process” (Besner & McCann, 1987). Paap and Johansen suggest that the bias to guess a common word invited by perceptual identification tasks, is one of
these secondary processes, and that its involvement renders the task 'suspect' as a research tool for primary lexical access. There is growing awareness that all the tasks used in word recognition research reflect the primary process of lexical access, but in each case, they also bring task-specific processes related more to the task than to lexical access. In this respect, perceptual identification is no different from lexical decision. Both introduce task-specific secondary processes. Jacobs and Grainger (1994) have questioned the apparent reluctance to incorporate so called secondary processes into a broader view of word recognition.

"A word is in order concerning Paap and Johansen's (1994) challenge of the utility of perceptual identification tasks, such as Snodgrass and Mintzer's (1993) fragmentation technique, for distinguishing factors important to "primary lexical identification" (i.e., activation and verification in their model) from those that are "secondary and peculiar to only certain tasks" (pp. 1142-1143). One may wonder whether these authors do not adopt a little-too-narrow, "pure perceptualist" view of the word recognition process. It may well be that threshold tasks, such as Snodgrass and Mintzer's, invite subjects to do sophisticated (unconscious) or even unsophisticated (conscious) guessing and that this "bias" is not a ubiquitous part of primary lexical identification. On the other hand, however, any learner of a language, or imperfect speaker of a foreign language, will agree that all kinds of guessing processes are an integral and central part of everyday word recognition in reading, hearing, and speaking. It is difficult to see what compels researchers not to study the role of such important processes, called "secondary" by Paap and Johansen. It is indeed time to stop arguing away from the models and methods such guessing, decisional, bias, expectational, or strategical processes. Rather, if one wants to achieve any substantial understanding of the reading process "outside the laboratory" (i.e., one in which the distinction between seeing and saying drawn by Paap and Johansen becomes artificial), the models must explain what part these secondary processes play in relation to primary processes (Grainger & Jacobs, 1993b, 1994b; Jacobs, in press; Stone & Van Orden, 1993). Methods for quantifying the part guessing may play in different data limited and resource-limited tasks provide data that can be critical for testing current models and constraining future comprehensive models of word recognition whose validity should go beyond the pure perceptualist's 2AFC task approach to reading (Grainger & Jacobs, 1994a; Jacobs, Grainger & Nazir, 1994). Clearly, word recognition is more than and different from performance in a Reicher, lexical decision, or naming task (Carr & Pollatsek, 1985). Future algorithmic models of word recognition should acknowledge this and specify which structures and processes are task specific and which are not (Grainger & Jacobs, 1993b, 1994b; see also the section on strategies for model construction and Figure 2, presented later).” (Jacobs & Grainger, 1994, pp. 1322)

Secondary processes have been described as "guessing, decisional, bias, expectational, or strategical processes ” (Jacobs & Grainger, 1994), and as any process which is not "a ubiquitous part of primary lexical identification" (Paap &
The descriptions are an indication of a distinction that may prove useful. A more precise distinction between primary and secondary processes may emerge from a better understanding of secondary processes. For instance, longer words are sometimes processed with a number of fixations (Rayner & Pollatsek, 1989). This is not a ubiquitous part of lexical access and none of the current models of lexical access incorporates such a mechanism (cf. Plaut, 1997). This means that the notion of primary process may have to expand as the models are extended to process all word lengths, or that refixation within a word will remain a secondary process.

The primary-secondary distinction makes explicit the observation that few tasks engage only the processes in which we are interested. Jacobs and Grainger (1994) have turned this inconvenience into a virtue by looking at ‘functional overlap’ in tasks and models. Lexical decision, naming, and perceptual identification, all engage the primary process of lexical access, but also engage secondary processes which are peculiar to each task. In neuroimaging studies, methods of cognitive subtraction or conjunction of activity patterns are used with different tasks to identify parts of the brain implicated in particular functional components of the tasks (Price, 1997). In a similar vein, Jacobs and colleagues model primary process separately from secondary processes. In each model of a task, the primary process component of the model remains the same. The only parts that differ from task-model to task-model are the secondary processes. The identical lexical access module (a variant of the interactive activation model), in conjunction with different secondary process modules, should be able to reflect empirical data without having to be modified for each task. This model of the “functional overlap” of tasks allows multiple tasks to be brought to bear on the question of primary lexical access.

Secondary processes become more prominent when representations and processes are degraded by natural variability in stimulus quality, experimental manipulation, developmental processes, or by neurological injury. The use of degraded stimuli with normal subjects will be referred to as experimental degradation. Performance in the fragmentation task has already been linked with secondary processes. Acquired dyslexics (previously literate neurological patients with reading problems), may rely on secondary processes if the primary access process is compromised as a result of injury. Peripheral dyslexia is associated with compromised
processing at relatively early stages of the word recognition process, and includes letter-by-letter readers, who in the course of reading words frequently name their letters. Howard (1991) suggested that a functional, but impaired, primary process may coexist with a serial process.

"Instead it will be argued that the latency data from two letter-by-letter readers can be better accounted for by a primary process of parallel identification of the letters in a word where this process is subject to a significant rate of error; a serial letter-by-letter identification strategy is only resorted to when word recognition on the basis of parallel processing fails." (ibid. pp. 40)

This explicit serial letter identification process is a secondary process mediated route to word identification. This area of research will be referred to as neuropsychological degradation. The thesis will examine the relationship between primary and secondary processes in these two areas.

1.2 Models of word Processing

The Composite Model

![Composite Model of word processing](Ellis & Young, 1988)

Much of the thesis will be set within the confines of particular models of visual word recognition. The broader models, which deal with word processing generally, are described first, followed by a section devoted to orthographic lexical access. The composite model shown in Figure 1.2 provides an overview of word recognition and production processes. Detailed descriptions of the processes specified are given in Ellis and Young (1988) pp. 222. The shaded components are those
involved in understanding and producing spoken words. Under normal circumstances children acquire this system before they learn to read. Several routes from input to output are already evident at this stage. For instance, a word may be repeated without the involvement of semantics via the link between auditory analysis and the phoneme level. The non-shaded components represent the cognitive functions acquired in the course of becoming literate. This system may be viewed as composed of reading and spelling sub-systems. Three routes from the written word to speech output are distinguished. The semantic route connects the visual input lexicon to semantics. The ‘whole-word route’ bypasses semantics and allows reading without understanding, and the grapheme-phoneme route allows unfamiliar letter strings to be decoded piecemeal. The spelling system involves the graphemic output lexicon, which provides the spelling of whole words, and the grapheme level, which decodes these spellings into graphemes (abstract letter identities) ready for output as writing or oral spelling. The oral spelling component is a recent addition (Lesser, 1990; see Cipolotti & Warrington, 1996 for a review) prompted by mounting evidence of dissociation between written and oral spelling.

The processes depicted in Figure 1.2 have been specified over the last half-century by work in two main areas. The first is mainstream word recognition research, which has focussed at early stages of auditory and visual analysis, and the relationship between sensory encodings and graphemic and phonemic lexica. This work has been laboratory based and hence tended to avoid the real world complexities of word recognition in favour of delimiting primary process. The second strand of research has been a painstaking inventory of acquired dysfunction of the processing streams by cognitive neuropsychologists (Coltheart, 1987) resulting in the map of processing shown in Figure 1.2. The importance of secondary processes within this framework will be emphasised in this section by a brief discussion of two points of concern.

These concerns are ‘system level’ concerns. The first is ‘multiple route plasticity’ and strategy, which emphasises the flexibility and adaptability of the system. The second is ‘meta-linguistic functions’, which considers normal functions such as the recognition of orally spelled words, or the retrieval of a word from its first letter name. The term is taken from Hanley and Kay (1992). “Consequently, the compensatory strategies that letter-by-letter readers employ, almost certainly reflect a
normal meta-linguistic function” (ibid. pp. 238). These functions are not as well specified in models of word recognition, perhaps because they are considered ‘secondary’ or ‘meta-linguistic’. Much of the thesis will argue for research into these ‘normal’ processes because, although they may be used infrequently by normal subjects, they become prominent in performance when primary process fails.

Multiple Route Plasticity and Strategy

In emphasising the active response to injury by the brain, Kolk (2000) observes that

“At the behavioural level, there are all sorts of plastic modifications referred to as compensation, adaptation or strategy. The existence of such behavioural plasticity is commonly acknowledged in clinical practice. Although already noted by Wundt (1921, p,77), so far it has not been a topic of extensive study by cognitive neuroscientists. The reason I think is that, when the discussion is about neurocognitive mechanisms, notions like compensation or strategy cannot enter, because they are not specified at that level. This must be remedied. A neurocognitive theory of compensation or strategic adaptation is called for. It is my belief that the conditions for the development of such a theory are very favourable.” (ibid., pp. 129.)

He goes on to point out that ‘behavioural plasticity” could in many instances amount to ‘re-routing’. Many language tasks afford more than a single solution, and plasticity could amount to favouring a different route in case of breakdown in the default route to a response. He distinguishes between ‘automatic selection’ of an alternative route in situations where routes are in competition under normal conditions, and ‘ strategic selection’ in which patients attempt re-routing solutions until they settle on one that works. In placing strategic selection within the ‘Supervisory Processes’ of Shallice and Burgess’s (1996) framework, he suspects

“ ...but this is by no means proven- that most new strategies to cope with a language deficit are “spontaneously generated” as Shallice and Burgess phrase it. As they are part of the normal repertoire, they do not require problem solving. But since they are in competition with processing routes that were typical premorbidly, they – that is to say their corresponding schema units – need an extra boost to be selected. One way of achieving this is by attentional enhancement.” (ibid., pp.130).

Behavioural plasticity, that is, strategic compensation by re-routing, may involve the use of pre-existing secondary processes. Secondary processes might be viewed as coalitions of component processes. Identifying a word from a degraded stimulus may involve aspects of orthographic lexical access, phonological recoding

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and sounding out, and perhaps verification procedures based on the spelling system. The orchestration of various component processes under the control of a supervisory attentional system might be described as a virtual process. This means that secondary processes are not ‘embodied’ in the same way as primary processes. They have no single, simple, anatomical locus (Reichle, Carpenter & Just 2000) Secondary processes might be best characterised as schema controlled virtual processes or supra-modular skills.

Furthermore, secondary processes may be instrumental in modularising primary processes. Polk and Farah (1997) for instance suggest that primary orthographic lexical access is founded on a self-organising abstract letter identification process which develops through experience with written material. Hulme and Snowling (1992) conclude that the relative modularity of adult systems is achieved after an extensive period of development in which interactions between systems are the norm. Bishop (1997) comes to similar conclusions. The long and arduous route to expert reading results in fast and relatively automatic encoding of written material (Cohen, Dunbar & McClelland 1990). However, until the primary system is established, it is reasonable to suggest that the alternative strategies children use to identify words, before primary process comes online, may become schematised to various degrees. The particularly successful ones may remain as troubleshooting routines throughout adulthood, and may become particularly useful in the event of injury to the primary routes. Secondary processes may thus constitute the scaffolding around which primary process is erected, and hence the origins and characteristics of secondary processes may lie in the developmental history of the reader.

Kolk (2000) suggests that a “valid theory of behavioural plasticity can be developed in the foreseeable future” (ibid., pp.131). Coltheart (1978) thought “It seems highly likely that the next 20 years of cognitive psychology will be dominated by the concept of ‘strategy’ as the past 20 years have been dominated by the concept of ‘code’ (ibid., pp.199). Jacobs and Grainger’s (1994) observations suggest that this was an optimistic forecast, but there is evidence in the literature that strategic processes are becoming more prominent in both mainstream word recognition research and in the developmental literature on reading.
Zevin and Balota (2000) review mounting evidence that skilled readers have attentional control over the degree to which lexical and sublexical information contributes to naming performance. Stone and Van Orden (1993) review options for modelling and researching strategic effects in word recognition. “Extensive use of sophisticated strategies allows for a system as complex as human cognition seems to be. However, ad hoc appeal to strategy hypotheses undermines the scientific enterprise.” This caution may explain the apparent reluctance of researchers to address strategy, but mounting evidence for strategic effects is now prompting principled attempts to “pursue strategy as a phenomenon to be understood rather than avoided” (ibid., pp.771). Hendriks and Kolk (1997) underline the role of strategy in the symptoms of developmental phonological and surface dyslexia. Whether dyslexic children were classified as surface (many responses with sounding out behaviour) or phonological (many word substitutions) dyslexics, was affected by whether they were asked to read words fast, or to read words accurately. “Thus the different symptoms commonly used as a basis for the classification of developmental dyslexic syndromes do not only reflect underlying deficits, but also strategic choices” (ibid., pp.321).

In an attempt to heed the warning against “ad hoc appeals to strategy hypotheses”, the thesis will propose that strategy be defined in terms of specific and specified secondary processes. This may mean a reappraisal of their status as processes that may contribute to the understanding of ‘normal word recognition’.

Meta-linguistic functions

The processes underlying the recognition of words from oral spelling, and the retrieval of a word given its first letter name are briefly reviewed in this section to illustrate some of the difficulties in specifying meta-linguistic functions. A final section looks at a recent imaging study of systems level functions.

Recognising orally spelled words.

The recognition of words from their spoken letter names, or recognising orally spelled words, is a secondary process in several senses. It is secondary in the sense that it has attracted no mainstream research with normal subjects. “Despite the frequency with which this task is given, the procedures underlying successful
performance have not been studied" (Katz, 1989, pp. 201). It is secondary in the sense that it is a normal process which becomes prominent under neuropsychological degradation, particularly in cases of letter-by-letter reading, and it is secondary in the sense that it is an infrequently used skill. The acquisition of oral spelling recognition is probably related to the processes of developing literacy, and may be one of those skills that serve as the scaffolding around which the primary process based system develops. Recent discussion of the dissociation between written and oral spelling has highlighted a division between two theoretical positions on the manner in which it is accomplished (Cipolotti & Warrington 1996).

Geschwind (1965) proposed that letter names are mentally transformed into written form and then read. This presumably involves listening to a letter name, for example “double U”, and accessing semantics for knowledge of letter shape to guide an imagery-based operation in the visual-spatial component of working memory. Once all the letters were assembled in imagery one could then simply ‘read the word’, because the effect of the operation would be to supply the orthographic input lexicon with bottom up activation. Coltheart (1983) also proposed that the visual input lexicon is accessed by letter names. Current reading theories of oral spelling recognition are depicted in Figure 1.3. They have in common the idea that, in the event of a breakdown in the normal parallel mapping of letter information to the visual input lexicon, explicit single letter identification may intervene and still map to the input lexicon. Patterson and Kay (1982) consider the use of the spelling system as an alternative route. Katz (1989) proposes that spoken letter names are taken directly into a buffer, which also intervenes between visual analysis and the orthographic input lexicon. This allows the recoding of visual letters or spoken letter names into a form suitable for mapping to the visual input lexicon. Rapcsak, Rubens and Laguna (1990) have proposed a very similar model of the process.
An alternative position is the “reverse spelling” hypothesis first proposed by Warrington and Shallice (1980) and elaborated by Shallice and McCarthy (1985).

The reverse spelling hypothesis suggests that letter names, whether recoded from visual letters or encoded from auditory analysis, are accumulated in verbal short-term memory and recognised by the spelling system. The dissociation between written and oral spelling has allowed Cipolotti and Warrington (1996) to elaborate the manner in which ‘reverse spelling’ may be effected. Oral spelling, as shown in their model in Figure 1.4, involves the transcoding of graphemic information from the graphemic output buffer into a letter-name code ready for speech. A synthesiser component of the letter code module is able to accept spoken letter-names and re-engage the orthographic output lexicon via the graphemic buffer hence identifying the target.
The reading-spelling debate on recognising orally spelled words is fuelled entirely by neuropsychological research. This highlights a rather bizarre situation in which a normal secondary process is almost entirely devoid of empirical data from normal subjects. In advocating research on the subject, Katz (1989) observes that “Without such study, the value of the task as a comparison measure or as a clinical tool is limited. Moreover, studying how orally spelled words are recognised may be informative about letter-by-letter reading since patients with this condition attempt to read by naming the letters in words aloud. The present study explores the procedures involved in recognising orally spelled words” (ibid., pp. 202).

The ensuing exploration is however entirely neuropsychological. The first half of the thesis looks into methods by which empirical data from normal subjects might be brought into this debate. However, the important point is that secondary processes tend to be low in research priorities and hence underspecified. They are nonetheless particularly relevant to neuropsychological research and may constitute a barrier to progress in understanding certain conditions.

The controlled oral word association task COWAT.

The controlled oral word association task (COWAT) (Benton & Hamsher 1978; Benton, Hamsher, Varney, & Spreen 1983; Lezak, 1995) requires subjects to name as many words (not proper nouns) as possible beginning with a particular letter without simply altering suffixes. The target letter names are presented to subjects verbally. A model of the component processes involved in this task proposed by Friedman, Kenny, Wise, Wu, Stuve, Miller, Jesberger, and Lewin (1998) is reproduced below in Figure 1.5. The complexity of this simple task required a detailed dissection of all the cognitive functions involved, some of which had to be consigned to the “relatively less-specified constructs” category.

Our main interest is in the initial (relatively well specified construct) task of retrieving a word from a letter name. “We consider that these portions of our model are relatively well specified, in the sense that the nature of the function and its logical inclusion is reasonably self-evident” Friedman et al. (1998, pp 233). They suggest two strategies, one auditory / phonemic, and the other visual / orthographic. Both strategies involve activating appropriate representations and searching the relevant lexicon. Friedman et al. (1998) refer to Howard, Patterson, Wise, Brown, Friston,
Weiller, and Frackowiak (1992) for the process of activating these representations of the target letter and 'searching' the appropriate lexicon. (I failed to find any reference to a process of activating either phonemic representations or visual images of letters from letter names or 'searches' of lexica in Howard et al. (1992).

The auditory-phonemic strategy involves the activation of an auditory representation of a target letter. Thus “subjects form a phonemic representation of the sound of the target letter and search the phonemic lexicon (Howard, Patterson, Wise, Brown, Friston, Weiller, & Frackowiak 1992)” (ibid. 1998 pp. 232). Friedman et al. (1998) refer the reader to Ellis and Young (1988) for the mechanism of lexical search. “We do not specify the structure of the lexicon or the method of search or access to words in the phonemic lexicon. These issues are complex and are addressed elsewhere (Ellis & Young, 1988)” (ibid. 1998 pp. 234). The auditory phonemic strategy involves a further ‘orthographic verification process to avoid producing responses such as “phonemic” with F as the target. Activation found in Brodmann area 21 and 37 was consistent with phonemic analysis and search of the phonemic lexicon.

The visual-orthographic strategy involves the activation of visual orthographic representations of target letter “This process involves the activation of a mental image or memory of the target letter within the visual channel” (ibid.1998 pp. 234). To search the orthographic lexicon, “a visual image of the target letter is compared to
visual word forms in the orthographic lexicon (Howard et al. 1992)” Friedman et al. (1998 pp. 232). “Again we do not specify the structure of the lexicon, or the method of search or access to word in the orthographic lexicon” (ibid. pp. 234). Activation in visual cortex, in the absence of visual stimulation, was consistent with imagery of target letters, and activation in area 37 with the activation of orthographic representations and searching the orthographic lexicon.

Retrieving a word from its first letter name thus involves using one or other strategy, or both. These activate a representation of the letter in the appropriate code, phonemic or visual, use this representation to access the appropriate lexicon, and then conduct a ‘search’, or compare an image to word forms. The main impression from the study was however widespread activation of multiple areas associated with the complexity of this relatively simple task. Much of this was related to the verification checks, sub-vocalisation, and “relatively less-specified constructs”.

Friedman et al.’s conclusions were

“In conclusion we have found evidence from an fMRI study that three brain regions are activated when subjects perform the covert COWAT: (1) an area in the left inferior frontal gyrus, comprised of Brodmann areas 44 and 45 (Broca’s area), (2) an area in the left middle and inferior temporal gyri, comprised of areas 21 and 37, and (3) striate and / or extrastriate cortex in the left occipital lobe near the calcarine sulcus. These areas are implicated in one or more cognitive components of the covert COWAT, and these findings are consistent with prior research. Furthermore, our systematic review of prior research makes evident two principles: a cognitive module can be subserved by several brain areas and each brain area can be involved in multiple cognitive modules.” Friedman et al. (1998 pp. 252)

The previous section suggested that the synthesiser function of the oral spelling module might be another route to words. This module routinely deals in letter-names and has access to the orthographic output lexicon, the main repository of information on spelling. This route may constitute a further strategy option. It may have the advantage of avoiding the further orthographic checks involved in the phonemic strategy, and the extra step of visualising or imaging the letter shape involved in the orthographic strategy. Letter names would access the synthesiser directly, and via the graphemic buffer, activate all word representations beginning with that letter in the orthographic output lexicon.

Note that the notion of ‘searching the lexicon’ is probably one of the least well specified constructs in word recognition research. The debate is reviewed in Jacobs Chapter 1, Page 30
and Grainger (1994), and centres on the mechanism of ‘search’. This is variously described as being ‘serial’ (Forster, 1994), involving lateral inhibitory mechanisms (McClelland & Rumelhart 1981), using activation and verification (Paap & Johansen 1994), or as retrieval from matrix memory models (Humphreys, Bain & Pike 1989). Furthermore, this discussion is concerned, in the main, with the primary process of selection from a cohort of possible targets when the entire stimulus is available. The meta-linguistic functions such as searching with a single letter of the target introduce further complications, which have yet to be addressed within these models.

Several points emerge from the consideration of the recognition of words from oral spelling and COWAT.

- There are probably multiple routes to the simple tasks of retrieving a word from its first letter name, or from its oral spelling.
- The processes engaged in the performance of meta-linguistic tasks are probably the least well specified functions in word recognition research, possibly because they involve multiple components and processes.
- Meta-linguistic functions are highly associated with neuropsychological conditions and much of the existing data on these functions derives from neuropsychological research.
- Research into the meta-linguistic functions with normal subjects is required to specify those functions that are normal secondary processes, and the factors determining the use of these functions in compensating for experimental degradation.

**Plasticity, Routes and Systems**

Both oral spelling recognition and the retrieval of words from first letter names may need systems level explanations. This is becoming apparent in reports of imaging studies of relatively simple tasks. A recent fMRI study of sentence-picture verification highlights the difficulty in characterising meta-linguistic functions. Reichle et al. (2000) taught subjects to read a sentence in two ways before making a decision on a subsequently presented picture. Either just enough to remember it and then wait for the picture, or to imagine the objects and their relations described in the sentence during the wait for the picture. The instructions were based on the idea that
the task could be performed with either linguistic processing, or with visual-spatial matching. The study revealed partially separable cortical systems associated with the two strategies. Activation in these areas was modulated by the skill of the subject. Subjects with better verbal skills showed less activation in the linguistic system when using the verbal strategy. The authors explain this with the idea of minimising cognitive workload. That is, subjects selected a strategy for performing the task that minimised the amount of processing required.

Reichle et al. (2000) concluded that

"The various cortical regions that show activation during each of the two strategies are hypothesised to be parts of the large-scale cortical and sub-cortical networks that subserve linguistic and visual-spatial processing respectively. The hypothesis is that there are multiple regions that participate to a greater or lesser extent depending in part on the properties of the task, rather than a fixed set of regions that constitute each network. Thus the current results are consistent with the hypothesis that language comprehension is subserved by a flexible network of cortical regions and that the degree of involvement of these regions is partially dependent on the processing characteristics of the task. This stands in stark contrast to the implicit assumption that there are fixed networks for cognitive tasks that are as specialised as language comprehension. Thus, previous failures to localise cognitive functions (for a review, see Cabeza & Nyberg, 1997) to specific cortical regions may not be failures per se, but may instead reflect an overly simplistic view of cortical organisation. Instead, our results suggest that high-level cognitive tasks, such as sentence comprehension, are likely to reflect the highly orchestrated processing of several cortical regions." (ibid. pp 286-289)

The authors highlight the involvement of frontal executive function in the performance of the task, and suggest that it has many of the characteristics of problem solving. They distinguish situations in which instructions have a large bearing on strategy, and situations in which the task itself, or the stimuli, determine strategy selection. The orchestration of multiple processes is emphasised, and they suggest that the systems level view of processing may explain how particular strategies (e.g. letter-by-letter reading) may arise with different pathological conditions associated with different neural substrates. "The efficiency of a system depends not only on its components, but also on their interactions, so that, in general, the systems output cannot be reduced to the performance of a single process or a single cortical region" (ibid. pp. 289)

The suggestion is that some meta-linguistic functions and secondary processes may require systems level explanations. This may involve identifying processes at
several levels. For instance, the identification of words from oral spelling may be a high level secondary function of the linguistic system, or the linguistic system in conjunction with the visual-spatial system. This function will fractionate into simpler component processes. The proposal to be developed in the thesis is that the higher level functions can be tackled if they are understood in terms of simpler component secondary processes. Some secondary processes may however be more closely tied to particular primary processes, such as orthographic lexical access. The next section describes this process before the proposed secondary processes are outlined in the final section of this chapter.

1.3 Models of Orthographic Lexical Access

Models of visual word recognition

![Diagram of Models of Lexical Access]

A brief overview of the framework within which both experimental and neuropsychological degradation will be examined is given in this section (see Jacobs & Grainger, 1994 for a review). Recent consensus that the fundamental impairment in letter-by-letter reading is related to the derivation of lexical orthography (Behrmann, Plaut & Nelson, 1998) focuses the thesis at this level. The sections in Figure 1.6 (A, B, C, D) gradually ‘zoom’ in on visual word recognition from its context within word processing generally. Section A of the Figure 1.6 depicts the relations between orthographic, semantic, and phonological representations. This relationship is thought to be “cascaded” (Behrmann et. al, 1998). This means that processing within the
The orthographic system is affected by processing in the other systems. The orthographic system does not complete the processing of a word, and then feed a finished product to the semantic system, for instance. Cascaded relations mean that processing at the orthographic level can be constrained by processing at the semantic (Behrmann et. al, 1998) and phonological levels (Jacobs, Rey, Ziegler & Grainger 1998).

The processing of a written word is the focus of section B, which illustrates the commonly accepted view that written words can be read aloud by three main routes. Questions about the necessity for three routes, and the relative merits of conversion and analogy as the basis for pronouncing unfamiliar letter strings, are still controversial. The relative merits of the different modelling projects underway in visual word recognition are reviewed in Jacobs and Grainger (1994). They argue the need for a canonical model of lexical access, and emphasise the merits of the IAM as a candidate model. Modifications to the original model and extensive research into several controversial aspects of the model have gradually improved its predictive powers with several tasks, including lexical decision and perceptual identification. The need for top-down feedback to the letter level, or the nature and levels of readout from the model, for instance, have been matters of concern. Recent additions to the model include phonological representations, which have enabled it to address questions related to feedforward and feedback consistency (Jacobs, et al. 1998). Multiple criteria on which to base responses (Grainger & Jacobs, 1996), and adjustable parameters allowing strategic effects to be modelled (Ziegler et al., 1998) have been explored.

The general philosophy and research strategy proposed in the Jacobs and Grainger (1994) review is to adopt a canonical base model of primary lexical access. This is then augmented with task specific models in a hierarchy of nested models that subsume earlier ones. This allows the extensive data gathered on primary lexical access to be consolidated in a very well tested base model, while new secondary process models are built and tested in relation to the core process. In combination the core process and secondary process models may come to reflect a broader notion of normal word recognition, and a deeper understanding of the sorts of problems to expect from breakdown and the compensatory strategies adopted to breakdown.
The experiments and discussions to follow will generally assume the architecture of the interactive activation model, and the processing mechanisms it proposes, as a suitable framework for orthographic lexical access. This framework is also adopted by Behrmann, Plaut and Nelson, (1998) in their review of letter-by-letter reading. The model is particularly suitable because of its clear instantiation of the cascaded and interactive processing principles they consider essential to the explanation of several effects in letter-by-letter reading. They point out that several parallel-distributed accounts of word processing (Plaut, McClelland, Seidenberg & Patterson, 1996; Seidenberg & McClelland, 1989; Van Orden, Pennington & Stone, 1990) also embody these principles. The use of ‘attractors’ within these models introduces cascaded and interactive processing to what were initially simple feedforward nets. These models provide essentially the same account of letter-by-letter reading proposed within the interactive activation framework. There is an impressive degree of support for the localist, interactive and cascaded, ‘conservative’ view of word recognition. (e.g. Forster, 1994; Coltheart, Curtis, Atkins & Haller, 1993; Posner & McCandliss, 1993). The interactive activation framework may thus serve as a focal point for research into secondary processes, their relation to primary process, and their role in peripheral dyslexia.

From visual input to lexical orthography

There is substantial agreement on the main stages of processing between visual input and lexical orthography. Caramazza and Hillis (1990) propose a representational framework based on the work of Marr (1982). An initial feature map, corresponding closely to the primal sketch in Marr’s framework, builds a retinocentric description of the edges in the image from discontinuities in light intensities. The second level of representation, the letter shape map, (Figure 1.6C) computes the spatial relations between letter segments with respect to each other. At this stage, the representation is still viewpoint dependent, hence case, font, and orientation dependent. It is still an essentially visual representation. The third stage encodes the visual information as graphemes, that is abstract representations of letter identity, which do not retain information on the case, font or orientation of the stimulus. This representation is a word centred description of constituent graphemes, retains
information about the relative position of graphemes within the word, and accesses lexical orthography. This framework tends to concentrate on the nature of the representations involved in accessing the lexicon rather than the processes.

The IAM explores the mechanisms or processes involved in word recognition in more depth. For instance, it instantiates within level inhibitory connections to explain the manner in which lexical selection takes place, a matter not considered in similar depth in the Caramazza and Hillis framework. The most discussed alternatives to the IAM are the Logogen model (Morton, 1969), The serial search model (Forster, 1976), and the Activation verification model (Becker, 1979). A distributed model of lexical access, Blinet (Mozer, 1987), its extension Morsel (Mozer & Behrmann, 1990), and a recent distributed model of letter-by-letter reading (Mayall & Humphreys, 1996), are particularly relevant to peripheral dyslexia.

The IAM and Parallel Access

One of the most prominent features of the IAM is that information is transferred between levels ‘in parallel’ (Figure 1.7). This is often referred to as multiple constraint satisfaction. Parallel processing between representational levels is a critical aspect of the model, not least because of the role it plays in explaining the word superiority effect. Word level representations are activated in parallel by all activated letter level representations. Letter level representations are thought of as abstract representations of letter identities activated by features. In effect, word level representations monitor letter activation over the visual field, and take on activation values commensurate with the evidence for their constituent letters at lower levels. Note that there is no ‘parallel processing mechanism’ as such. Parallel processing is simply a consequence of all word level representations having access to letter level representations over the visual field, and updating their activation levels synchronously based on the evidence at the lower levels. As depicted in Figure 1.7, because ‘T’ in the final position is also a feature of the word level representation of ‘COT’, cot assumes some moderate level of activation when cat is the stimulus. Word level representations are assumed to compete, and in this scenario, ‘COT’ will have an impact on processing, although the overwhelming evidence for ‘CAT’ should minimise its impact. Primary lexical access is achieved by the simultaneous encoding
of feature and letter level information over all the letter positions of the word, an essential aspect of the model.

Failure of this process to activate word level representations above the threshold for overt identification might be related to various functional deficits. For instance, attentional neglect may result in failure to process perfectly adequate feature or letter level representations, or degraded lower level representations may simply be too impoverished to support adequate activation at the word level. Under these circumstances a set of secondary processes are thought to facilitate identification by, for example, narrowing the focus of processing to letters and employing a serial strategy.

![Interactive Activation Model of word recognition](image)

Figure 1.7: The Interactive Activation Model of word recognition

Processing in the IAM is measured in cycles. These are computational units of time in which all levels of representation update their current activation values in response to the stimulus, and / or to the activation values at other levels. As processing proceeds over cycles, the activation level of the most favoured candidates rises (Figure 1.7B Line 1). Identification is made when the activation value of a unit exceeds a criterion (M). This describes normal word recognition. The criterion M is considered fixed under normal circumstances (Grainger & Jacobs, 1996), because primary lexical access is not under strategic control. Hence, subjects cannot decide to speed up or slow down primary lexical access.
The IAM and Serial Access

The secondary processes often have a serial component. Within the interactive activation framework, serial processing of letter identities should be inhibitory. The reading theories of spelling recognition for example suggest that letter identities are established serially, and fed to the orthographic input lexicon serially. Serial processing in the sense that word level representations receive confirmation of ‘C’, then ‘A’, then ‘P’, would result in an initial word level population of words beginning with ‘C’ becoming activated, with little resistance from any other words (Figure 1.7). Note that the information is not letter names, but activated graphemes. High frequency ‘C’ words would establish a foothold on the cohort. The arrival of ‘A’ would suppress all words without ‘A’ in the second position, but processing would already have taken on a very different dynamic from parallel access. The arrival of ‘P’ meets a cohort populated with high frequency competitors (CAR, CAN) which have had time to build up activation over the preceding cycles of processing. With parallel simultaneous constraints, the presence of ‘P’ would prevent this, and hence improve the probability of correct identification.

The suggestion that serial letter processing within the primary lexical access process should result in inhibition of target identification is one that appears in studies of both experimental and neuropsychological degradation. (Arguin, Bub & Bowers 1998; Snodgrass and Hirshman, 1991). Andrews (1989, 1992) has provided consistent evidence that with intact stimuli in lexical decision and naming tasks, neighbourhood size is facilitatory. There are several strands of evidence suggesting that degraded stimuli incur inhibitory effects of neighbourhood size under circumstances in which a single response is elicited (Grainger & Segui, 1990; Snodgrass & Mintzer, 1993). There is also evidence that when subjects can revise initial responses, neighbourhood size is facilitatory (Snodgrass & Mintzer 1993). This suggests that effects of neighbourhood size may depend largely on experimental procedure. The importance of procedure is that it determines the secondary processing involved in the task.

The IAM and Lexical Decision

Some ‘yes’ responses in lexical decision are based on M. The first word unit to achieve this level of activation is produced as the response, or in the case of lexical
decision, is sometimes the basis for a ‘yes’ response. The model also illustrates the current view on lexical decision, namely that high levels of accuracy may be achieved on the task in the absence of lexical identification. \(\Sigma\) and \(T\), were introduced by Grainger and Jacobs (1996) to explain empirical data from lexical decision and perceptual identification. \(T\) is a time criterion and is used in lexical decision to make ‘no’ responses. That is, if the other two criteria are not exceeded before \(T\), the subject decides the stimulus was a nonword. \(\Sigma\) is a criterion used with an estimate of global activation \(\sigma\) (the sum of activation of all word level units), and enables a ‘yes’ decision on the basis of global activation in the absence of individual word identification. Large numbers of activated word units competing for supremacy would create lexical noise, which is a good indication that the stimulus is a word. Adjustments to \(T\) and \(\Sigma\) are thought to be part of subjects’ strategic accommodation to the particular circumstances of the task. As task specific processes, these adjustments are considered secondary processes. Grainger and Jacobs (1996) account for several effects in lexical decision and perceptual identification by showing how the IAM can produce similar results through adjustments to \(T\) and \(\Sigma\).

1.4 Secondary Processes: What is a Guess?

The objection to perceptual identification tasks raised by Paap and Johansen (1994), was that they invite subjects to guess, and guessing is a secondary process. A broad view of what might be considered a ‘guess’, in terms of the processes involved in ‘guessing’ is begun here and developed through the thesis.

Reason (1992) reviews several kinds of what he calls “cognitive underspecification” which includes identifying words from degraded stimuli. This, he suggests induces ‘frequency gambling’. “When cognitive operations are underspecified, they tend to default to contextually appropriate, high frequency responses” (ibid. pp 71). The tendency to better recognition of high frequency words than low frequency words under degradation and the tendency to respond to low frequency words with similar high frequency words are well documented. Guessing has always been considered as an explanation. Neisser (1967) provides a discussion of ‘fragment theory’ which suggests that subjects perceive fragments of the stimulus under tachistoscopic presentation and ‘guess’ a word from this information.
Broadbent (1967) provides an analysis of guesses. He (and Neisser) dismissed the idea of ‘pure’ unconstrained guesses and argued that they are constrained. Broadbent referred to frequency gambling as response bias.

Response Bias

Goldiamond and Hawkins (1958) noticed that on tachistoscopic trials in which no word stimulus had appeared, subjects’ responses were often words they had encountered more frequently in a preliminary experiment. The propensity to produce high frequency responses, even in the absence of a stimulus, became known as the problem of response bias. Broadbent (1967) proposed several ways in which response bias may work. On many trials, the stimulus is assumed to effect an unproblematic identification by primary lexical access. We deal only with those trials on which this process fails and a ‘response bias’ is assumed to contribute to response.

- Pure Guessing. On some trials the stimulus does not activate a candidate and contributes nothing to the response. The subject simply chooses a high frequency response at random. The response is more likely to be correct for high frequency targets.

- Sophisticated Guessing. On some trials, the stimulus does not result in unequivocal target identification but does contribute to response selection. A restricted set of compatible candidates is delimited by the stimulus. Frequency does not determine the probability of inclusion in this set. A response from this restricted set is produced on the basis of frequency.

- Observing response. Unlike the previous schemes, the stimulus is assumed to activate the target more than competitors, and to do so in proportion to the pre-existing frequency of the target. A response is produced from this delimited set. A high frequency distractor thus has the combined advantage of similarity to the target and a higher rate of gain related to frequency.

- Criterion bias. The stimulus is again assumed to preferentially activate the target, but the gain in activation is not proportional to the pre-existing frequency of the target. The propensity to report high frequency words is explained by criterion bias. That is, given equivalent evidence for high and low frequency words, there is a bias to respond with a high frequency word.
In pure guessing, the stimulus has a minimal effect on the response, hence could be produced by a variety of mechanisms. For instance, it could be a word retrieved from the phonological system. The next three schemes all involve a process of cohort delimiting. The idea that the stimulus always has an effect in terms of delimiting a set of candidates based on featural similarity to the target is embodied in all word recognition models. The IAM assumes the ‘observing response’ proposal as the mechanism by which primary lexical access is accomplished. That is, the featural description of the stimulus will always preferentially activate the target under normal conditions. Because of initial higher resting levels and advantages related to competitive processes at the word level, the gain in activation for a high frequency word (given identical neighbourhood constraints) will always be more than for a low frequency word.

The incorporation of frequency and neighbourhood based competitive processes into lexical dynamics blurs the distinction between normal word identification and response bias. It is clear however that response bias effects might be profitably divided into those that rely critically on a lexical delimitation process followed by selection, and those that do not. The term sophisticated guessing will be used to denote responses related to the orthographic input lexicon.

In both experimental and neuropsychological degradation, the reader is confronted with a degraded stimulus. Because the stimulus is degraded, secondary processes referred to as guessing may be involved in ‘completion’. ‘Completion’ will be used in preference to ‘Guess’ for reasons detailed below. Some of the processes hypothesised to be involved in completion are detailed below. Some are processes that have been suggested as compensatory strategies in the peripheral dyslexia literature. The empirical evidence supporting the existence of these processes will be examined throughout the thesis.

The object is to document possible ‘completion’ processes, which may then be investigated in fragment completion tasks with normal subjects and in the performance of peripheral dyslexics. The discussion of the reading-spelling debate in section 1.2 of this chapter suggested that lack of data on secondary processes may, in some instances, constitute a barrier to understanding peripheral dyslexic conditions.
Sophisticated and Unsophisticated Guessing

Paap and Johansen's (1994) view that guessing plays an important part in responding in some experimental procedures is shared by other researchers. Andrews (1997) reviewed recent research on the effects of orthographic neighbours on visual word recognition, and concluded that neighbours are facilitatory in naming and lexical decision, but inhibitory in perceptual identification tasks because degraded material invokes 'sophisticated guessing'. Jacobs and Grainger (1994) distinguish sophisticated-unsconscious guesses, from unsophisticated-conscious ones. Andrews refers the reader to Massaro, Taylor, Venezky, Jastrzembski and Lucas, (1980) for a recent treatment of sophisticated guessing. The Massaro et al. (1980) model referred to by Andrews is reproduced in Figure 1.8 and is discussed in some detail because it makes an explicit distinction between primary and secondary processing, and may be a guide to guessing processes.

![Figure 1.8](image)

Figure 1.8: A model of reading printed text from Massaro et al. (1980).

The model distinguishes between memory systems (shaded boxes) and processes (ellipses). Primary recognition in this model has several factors in common with the interactive activation framework described above. Recognition is based on a process of feature detection, the 'synthesis' of a sequence of letters which can 'utilise information held in long term memory', and words are recognised from these letter strings. Stored knowledge of orthographic structure facilitates letter perception, and the process operates in parallel. It is unconscious, automatic, predicts word superiority effects and resilience to small variations in stimulus quality, because "the orthographic structure of the word simply provides an independent source of
information “. (ibid. pp. 7) This is taken to mean that relatively slight degradation can be overcome by the system, much as it is in the interactive framework, because higher level representations compensate for degraded lower level representations.

The primary recognition process also

“Transmits a sequence of recognised letters to synthesised visual memory ... the secondary recognition process transforms this synthesised visual percept into meaningful form in generated abstract memory ... Generated abstract memory corresponds to the short term or working memory of most information processing models. ... We assume the secondary recognition process attempts to close off the letter string into a word. The secondary recognition process makes this transformation by finding the best match between the letter string and a word in the lexicon in long-term memory. ... Recoding and rehearsal processes build and maintain semantic and syntactic structures at the level of generated abstract memory.” (Massaro et al., 1980, pp 8)

The secondary recognition process works “by finding the best match between the letter string and a word in the lexicon in long term memory”. This is taken to be sophisticated-unconscious guessing. With degraded stimuli, sophisticated guessing may deliver a ‘completed’ word to working memory.

Unsophisticated-conscious guessing uses higher level processes. ‘Synthesised visual memory’ produces percepts, and ‘generated abstract memory’ corresponds to working memory. ‘Rehearsal and recoding’ stores and processes visual percepts and letter identities in working memory, and has access to long term memory, hence presumably the spelling system. Unsophisticated-conscious guessing uses these processes to find completions that fit the constraints of letter identities held in working memory.

The distinction between sophisticated and unsophisticated guessing based on consciousness is likely to be difficult to maintain. Furthermore, both sophisticated and unsophisticated guessing may decompose into several different processes. The distinction adopted in this thesis is that sophisticated guessing may be intimately related to the visual input lexicon while unsophisticated guessing may function by retrieving words from the spelling system, or perhaps from interactions with the phonological system. That is, unsophisticated guessing is not tied to the visual stimulus. (Think of a four-letter word beginning with P and ending in T). Letter constraints held in working memory may be used to find solutions independently of the visual input lexicon. A slightly degraded word or word fragment may thus be read
or completed in several different ways. The normal propensity of primary process to ‘complete’ may cope with the degradation and identify the stimulus. This involves no secondary processes and is parallel. Failing primary identification, sophisticated guessing processes may operate, and these are by definition secondary processes, because they are not a ubiquitous part of the primary process of lexical access.

**Sophisticated guessing and Lexical Facilitation**

The use of the term “sophisticated guessing” will be avoided in the thesis. This is because top-down facilitation of processing by word level representations is often referred to as sophisticated guessing for historical reasons (Jacobs & Grainger 1994). Thus, Patterson and Wilson (1990) refer to this process as guessing. “Guessing in this sense does not necessarily mean the employment of a conscious guessing strategy, but rather that lexical knowledge imposes constraints which will assist word identification when the identity of the second letter largely specifies the identity of letter 1” (ibid. pp. 454). Riddoch, Humphreys, Cleton and Fery (1990) however use the term differently. “These findings may be explained either in terms of sophisticated guessing, following correct identification of right sided letters, or top-down lexical influences on processing” (ibid. pp. 510).

The interactive nature of most current models of orthographic processing (including attractor systems) means that “top-down lexical influences” or “constraints imposed by lexical knowledge” are an integral part of primary process. The “top-down lexical influences on processing” involved in identifying a degraded stimulus will be referred to as lexical facilitation. Primary process does not ‘guess’. It just identifies a candidate word and triggers a response based on that candidate if M is exceeded, otherwise it fails to produce a response. ‘Guessing’ is taken to denote the involvement of secondary processes. The term ‘completion’ will be used instead of guessing to indicate identification aided by secondary processes. This is because some of the processes to be explored, for example serial letter identification and assembly are not very well described by the term ‘guess’.

Lexical facilitation is thus not considered a guess. The seminal achievement of the Reicher-Wheeler paradigm was to demonstrate that the word superiority effect could not be attributed to guessing (Reicher, 1969). Lexical facilitation of letter
processing is thus not a secondary process. The intervention of a secondary process is required to ‘guess’. Lexical access through lexical facilitation may be possible with slightly degraded material (targ_t) such as word stems of short words. The intervention of secondary processes is hypothesised to be required for more degraded material such as fragments with few of the target’s letters (t_ _g_ _). Lexical facilitation is a feature of most models of word recognition. In the framework proposed here it involves no secondary processes and may not be associated with inhibitory effects of neighbourhood size.

**Sophisticated guesses are Lexical completions**

Sophisticated guessing “completes” the stimulus by some additional process that is referred to as a secondary process. No specific mechanisms by which this may be accomplished were proposed in the Massaro et al. (1980) model. That is, some additional process is involved in delivering a completion to working memory but is not specified. The thesis proposes two sophisticated guessing processes, one serial and the other parallel. **Scanned completion** involves enhancing word level activation by the serial deployment of attention, focussed on letters. This is a process which has been suggested in the neuropsychological literature (Behrmann, et al., 1998) in connection with letter-by-letter reading. The second is **Cohort completion**, which does not involve serial secondary processes, and produces completions based on sub threshold lexical activation, by amplifying the effects of letter level activation on word level activation. It is a hypothetical process, but has the merit of allowing completions to be distinguished by whether or not detectable serial processes are involved in producing them. In other words, inhibitory effects of neighbourhood imply sophisticated guessing, and the absence of serial letter processing, in experimental circumstances which produce an inhibitory effect of neighbourhood, imply that the completion process responsible is parallel.

These two completion processes are ‘sophisticated’ but will be referred to as **lexical completions** to emphasise the idea that they are mediated by the visual input lexicon. Both processes drive word level representations over criterion (M), and in the process, may introduce an element of error which may account for the inhibitory effects of neighbourhood associated with lexical completion.
Unsophisticated guesses are Sub-lexical completions

Unsophisticated guessing may produce inhibitory or facilitatory effects of
neighbourhood. Snodgrass and Mintzer (1993) report facilitatory effects of
neighbourhood size in a procedure which allowed subjects to guess completions to
degraded stimuli and revise those guesses on feedback. The thesis also proposes a set
of unsophisticated guessing processes. These are conscious strategic processes, but
may be more usefully distinguished from lexical completion processes by their
dependence on explicit letter identification. When primary process and lexical
completion fail to produce a candidate word, the perceptual process delivers a set of
letters identities [F _ _ M _ T] and positions, which may be used to retrieve a
solution from the spelling system. There are several other possible mechanisms by
which a completion might be ‘retrieved’ and these will be elaborated later. Because
these processes may not depend on the visual input lexicon, and do depend on
establishing individual letter identities, they are referred to as sub-lexical completions.

The completion processes proposed are described below and then researched
in the ensuing chapters.

Completion

The word completion is used here to mean any response that is arrived at by
any means other than by primary process alone. Completion is defined by the primary
secondary distinction. Lexical completions are derived from the visual input lexicon
with the participation of a secondary process that does not explicitly identify
individual letters. Sublexical completions may not be derived from the visual input
lexicon. They use secondary processes that operate on individual letter identities.

Lexical completion

Cohort and Scanned completions are referred to as lexical completions to
emphasise their close ties to the lexicon, and to distinguish them from lexical
facilitation. It is possible that both cohort and scanned completion are normal
automatic secondary processes, triggered by primary process when activation levels
are too low to allow identification by primary process. They may also be under
strategic control. For instance, patients with perceptual deficits may rely on lexical completion much more than normal subjects.

Cohort completion

Completions may sometimes be based on low level lexical activation. For example, in lexical decision, Grainger and Jacobs (1994) suggest that 'fast guess' responses in speeded response paradigms might be thought of as adjustments to \( \Sigma \). Setting \( \Sigma \) to a very low value would allow very quick decisions to be made about the 'wordlikeness' of a stimulus. Along similar lines, a completion in perceptual identification might be thought of as a lowering \( M \) under degraded conditions. Thus, identification could be made on very low levels of activation. The problem is that the ability to adjust \( M \) would put primary process under strategic control. An alternative suggested by McClelland and Rumelhart (1981) and recently by Ziegler et al. (1998), is to use the parameters of the interactive activation model. One parameter that affects processing between the letter and word levels, is the word-to-letter excitatory parameter referred to as \( \alpha \). The effect of increasing \( \alpha \) is to feed more activation down to letter units that are compatible with word level units. So for example in Figure 1.7 on page 37, the activation from 'CAT' to C in the first-letter position would be increased. A feedback loop is set up which might be described as amplifying the evidence for the word, at the expense of incompatible evidence. This might be thought of as attentional modulation of word level processing.

The effect would be to speed up the resolution of the cohort, and hence, in a sense, produce a guess or completion. This may only be possible when a relatively high level of lexical activation is achieved, hence may only be used with relatively intact stimuli which fail to achieve criterion. The effect of parameter adjustment is to drive the most active representation over criterion. The resulting candidate will be referred to as a 'cohort completion'. Because cohort completions are likely to be the most active member of the cohort, higher frequency neighbours of targets are likely to be identified, and hence the process may produce inhibitory effects of neighbourhood size or frequency.

Scanned completion

A second process that might intervene at points where a candidate fails to emerge from primary process, is serial scanning. The idea here, is that an attentional
scan over the stimulus which focuses processing at the letter level may boost the activation of a cohort member over criterion (Behrmann et al., 1998). Behrmann et al.'s view of letter-by-letter reading is an example of compromised parallel lexical access leading to access aided by serial processes.

“We claim that the fundamental impairment in LBL reading, following an occipital lesion, is a general perceptual deficit that degrades the quality of visual input. In the IAM, this deficit can be conceptualised as damage to the letter feature level or between this level and the letter level. The impact of this perceptual impairment on word recognition is that it permits only weak or partial parallel activation of the letters in a word. This weak activation does not suffice for explicit identification of the word (i.e. no word unit achieves a sufficiently high level of activation to exceed the response threshold) and the system must resort to sequential processing to enhance the activation of individual letters. Critically, this type of sequential processing is not an abnormal strategy only employed following brain damage, but is the manifestation of the normal reading strategy of making additional fixations when encountering difficulty in reading text (Just & Carpenter, 1987; Rayner & Pollatsek, 1989). For example, normal subjects fixate more frequently in a long word than in a short word in order to enhance the quality of the stimulus (O'Regan & Levy-Schoen, 1989). LBL readers also fixate more frequently; in fact, given the very poor quality of the visual input, they fixate almost every letter (Behrmann, Barton, & Black, 1998), giving rise to the hallmark word length effect. Presumably these fixations aid performance by permitting the increased spatial resolution of the fovea to be applied to multiple locations within the word. In fact, even in the absence of overt saccades, a word length effect would be expected, given that LBL readers can improve perceptual processing by rescaling covert attention from the entire word to apply successively to letters within the word.” (Behrmann et al., 1998, pp 14).

This serial process of enhancing word level activation is considered secondary under the guidelines suggested by Paap and Johansen (1994). It is a normal process employed intermittently by normal readers “when encountering difficulty in text”. It is not incorporated in current models of primary lexical access because it is considered ‘secondary’. Note that letter identities are not established by the process. Its effect is to enhance letter level activation. A second parameter in the interactive activation model, $\gamma$, controls the strength with which letter units inhibit the words with which they are incompatible. ‘P’ in the third letter position in Figure 1.7 (pp. 37) for instance, is incompatible with ‘COT’ and ‘CAT’ and hence evidence for ‘P’ in the third letter position will inhibit ‘COT’ and ‘CAT’. Increasing this parameter might be thought of as being attentive to letter level information, or adopting a conservative attitude to the task (Ziegler et al., 1998). A sequential application of a higher level of
this parameter over the sequence of letter positions might be thought of as a serial
scan of the stimulus which would inhibit competing incompatible neighbours. A
simultaneous raising of \( \alpha \) would boost words compatible with the evidence.

A response based on serial scanning will be referred to as a ‘scanned
completion’. Note that it is also possible to enhance grapheme activation by refixating
on each letter, but in general, it will be assumed that series of refixations are aimed at
establishing letter or sublexical component identities.

Separating lexical completions

Lexical completions should be sensitive to lexical variables and to
cascaded relations with the semantic system. Behrmann et al. (1998) suggest that
factors such as frequency and imageability intensify with processing duration. Serial
processes take longer to process longer words, and so these factors should interact
with word length. However, because they are mediated by lexical processing they
would not be expected to have as marked an effect in sublexical completions. It may
be possible to show for instance that scanned completions produce larger effects of
frequency and imageability with length, and that cohort completions and primary
identification produce smaller effects or no effects.

Detectable serial components of processing would isolate scanned completion
from cohort completion and primary identification. Because cohort completion
involves no serial secondary processes, it may be difficult to distinguish from lexical
facilitation. It may be possible however to detect the intervention of cohort
completion by intensified effects of frequency and neighbourhood size on accuracy, in
latency to identification, or in the pattern of errors produced. Primary identification
should not be associated with inhibitory effects of neighbourhood size (Andrews,
1997). Howard (1991) points out that serial letter processing should not be affected
by case alternation in print (aLtErNaTe) because the global features, such as shape or
transitional features between letters that alternation disrupts, should not be relevant.
Several methods of dissociating parallel and serial processing are thus available, but
eye-tracking equipment may also be used.
Sub-lexical completion

A second category of secondary processes is referred to as sub-lexical completion to emphasise the idea that they may not be directly mediated by the orthographic input lexicon, and are based on letter identities. They identify words by first identifying letters in fragments or intact words. Sub-lexical completions are either retrieved or assembled.

Retrieved completion

There is a very different sense of completion, which is illustrated by verbal instructions such as, “think of a four-letter word beginning with p and ending in t”. Visual and orthographic processes are not necessarily involved, and the process of coming up with candidates may involve consulting knowledge of spelling (the orthographic output lexicon). Perhaps by sounding out the initial letter, imaging the letter, using working memory to construct and verify candidate solutions and so on. The possible routes were aired in the discussion of COWAT (pp.29). The various possible routes will be mentioned at various times in the thesis with the understanding that none of the routes is excluded as a possibility. They are all empirical questions and may all be used under particular circumstances.

This sort of completion is taken to be a more complex process and will be referred to as a retrieved completion, to denote the idea that a process of retrieval based on letter identities is involved. The visual word fragment [R _ _ _ _ P] for instance, may activate orthographic representations to some extent. However, it may be completed by consulting our knowledge of spelling (Warrington & Shallice, 1980), or by sounding out the first letter (Nelson, Keelan & Nagraro1989). Retrieval may be based on a few letters in the fragment. First and last letters for instance may be easier than middle letters. (e.g. think of a 6 letter word with e in the third place, may be more difficult than, think of a 6 letter word ending in t). A tendency to base retrievals on initial letters for example, may be apparent in errors which match the target at the beginning but not the end. When solutions to fragments are attempted by retrieval, it is assumed that primary process failed to produce a response, and that activation levels are too low for the parallel perceptual process to support identification. Retrieval is thus focussed on letters or sublexical segments.
Assembled completion

Another form of completion is referred to as assembly. This is based on suggested explanations of letter-by-letter reading in the peripheral dyslexia literature. Letter by letter readers labour over even short words, and often name the letters of words. They seem unable to access the pronunciation or the meaning of words without identifying each individual letter. This means that in some cases, they take many seconds to read a single word, and they generally take longer to read longer words. The time course of this strategy allows refixation on letters. Assembled completion is taken to be a qualitatively different process from scanned completion. Letter identities seem to be accumulated and finally assembled into a word response. An analogue of this might be to present all the letters of a word, one a time over a period of say 10 seconds, the task being to produce the word.

The debate on the manner in which a set of letter identities or names may be used to access a word was introduced in section 1.2 of this chapter. Unlike lexical completion, sublexical completion is based on letter identification and implies that letter-by-letter readers identify all the letters of the word. Unlike retrieved completion, assembly implies a systematic accumulation of letter identities, and hence the association between letter-by-letter reading and a linear increase in reading time with word length. In principle, this process of assembly implies that if letter identification were intact then a high accuracy rate would be expected. Scanned completion, as suggested by Behrmann et al. (1998), may also produce linear length functions, but the time frame of scanning and refixation is likely to allow these two functions to be distinguished.

Assembly will be used to refer to the general view of letter-by-letter reading, which is that all the letters of the word are identified, or at least attempted, in the course of identifying the word. There is evidence to suggest that the assembly process may be independently damaged. Dickerson (1999) reports a patient YD, with a right hemisphere lesion who is unable to name words which have “+” symbols inserted between their letters (w + o + r + d). The effect of this distortion was significantly worse than simply increasing the spacing between letters, or alternating case. YD was able to retrieve orthographic and phonological information about the letters, but could not amalgamate this information in a way that allowed him to identify the word. This
would make assembly impossible. YD also illustrates the point that establishing letter names is not sufficient for word identification. The processes by which those names afford identification have yet to be documented. The assembly process is considered a conscious strategy that requires the orchestration of a number of different cognitive processes. The component processes involved, such as serial letter identification by sequential refixation, working memory storage, and spelling retrieval, may be relatively automatic processes, but their orchestration requires conscious processing.

Hofstadter (1995) suggests that with practice, 'jumble' (anagram) enthusiasts develop automaticity in the ability to juggle and assemble letters into words.

"Sometimes, solutions to jumbles in the newspaper just pop into my mind in no time flat – blindingly fast... And it’s even more interesting when it takes ten or twenty seconds, because then you get little glimmers of the shuffling taking place somewhere in there. But it's not you who's directing the show. You’re just a passive observer, at least most of the time. Only when those artificial rut-breaking techniques are needed do you actually play a role in the process. But that's the boring part. The neat part is when you just sit back and watch." (ibid. pp.85)

Revision

The final secondary process introduced at this point is 'revision'. Having completed, and with enough time, subjects may verify the completion against the visual evidence and revise their response. This is likely to be a complex process involving many of the same component processes as assembly. Lexical and sublexical completions may be revised. Snodgrass and Mintzer (1993) reported some results that implicate a revision process in perceptual identification tasks. Two procedures were used with the fragmentation task (Figure 1.1 pp. 18). In one procedure, subjects were shown fragments 1-6 in a series, with each fragment displayed for 1 second. Responses were taken at the end of the sequence. They found an inhibitory effect of neighbourhood size for low frequency words. Subjects were likely to produce high frequency neighbours of the target as responses.

In a second procedure, subjects were required to complete at each fragment in an incremental cue, and were given feedback on accuracy. A facilitatory effect of neighbourhood size was found which did not interact with frequency. Snodgrass and Mintzer explained the absence of inhibition in the second procedure with the idea that feedback allowed subjects to eliminate high frequency neighbours of the target, in other words their completions, and this allowed new and more accurate attempts. This
implies that inappropriate completions can be suppressed and revised. Feedback may not be a necessary component of revision. That is, given the opportunity to complete, subjects may verify their completion against the visual evidence and revise it spontaneously. In a procedure that allows enough time for both completion and revision in the course of an incremental cue, there may be a facilitatory effect of neighbourhood size. This may be related to retrieved completion and revision processes. With enough time on each fragment, retrieval and revision may happen covertly several times over the course of an incremental cue. This might be thought of as a process of elimination. Overt revisions would be committed responses that matched an early cue, and are then eliminated by later evidence, or may be responses that passed verification checks. Neighbours may be eliminated in much the same way as suggested by Snodgrass and Mintzer, but the process would be spontaneous. Facilitatory effects of neighbourhood would thus be expected. This is a complex sequence of sub-processes and may involve multiple systems such as working memory, the spelling system, and phonological processing.

The completion processes proposed above are simply the most prominent ones gleaned from both the experimental and neuropsychological literature, and are meant to be neither exhaustive nor established. On the contrary, they are expected to fractionate into sub-processes, and some may not survive testing. They are however reasonably explicit, and the object of the thesis is to establish how well some of them stand up to scrutiny.

**Conclusions: Chapter 1. Introduction**

A broader view of visual word recognition is proposed, which considers word recognition to be predominantly achieved by a Primary process of lexical access usefully described by the interactive activation model of word recognition. This model is used in both mainstream and neuropsychological research, and may be a suitable focus for discussion and the transfer of results between the research domains. A set of Secondary processes is also used under various conditions determined by text, task requirements, and impairments to primary process. These processes are divided into those which aid lexical access within primary process and are referred to as Lexical completion processes, and those which achieve word identification through
the explicit identification of letters, referred to as Sublexical completion processes. The integration of secondary processes and primary process in a broader view of word recognition renews interest in questions of behavioural strategy, the specification of meta-linguistic functions, and the relationship between secondary processes used by normal and impaired readers.

Secondary processes may be specified by the simultaneous consideration of research with degraded words and normal subjects (experimental degradation), research with peripheral dyslexics (neuropsychological degradation), and research with connectionist systems. A limited set of secondary processes is proposed as the focus of this research. These are processes often discussed in the context of neuropsychological conditions, and in the context of task specific elements of performance, but seldom the specific target of research. This chapter began the task of delimiting the secondary processes most often discussed, with a view to exploring their role in experimental and neuropsychological degradation.

**Objectives of the thesis**

The thesis has three main objectives.

- The first is to focus specifically on secondary process involvement in the performance of normal subjects identifying words from fragmented stimuli. This is referred to as experimental degradation. Experimental degradation is explored by looking at two tasks, the fragmentation and component-letter tasks. Both tasks use incremental cues. The dynamic nature of these cues allows variations in procedure to alter the balance of primary and secondary processes involved in word identification. The fragmentation and component-letter tasks may provide a test ground for theories of peripheral dyslexia, and serve to specify secondary processes suggested above.
- The second is to explore the role of secondary processes in peripheral dyslexia. This revolves around AC, a stroke patient, who has severe problems reading even short single words. He often takes seconds to identify them, and when not pressured by procedure, names the letters of the words before making an identification.
- The third is to explore experimental and neuropsychological degradation within a common framework that recognises and emphasises the interplay between primary and secondary processes in the identification and recognition of written words.
"I have often wondered just what is going on in my mind when it carries out these tricks for me. (Hofstadter, 1995, pp. 85)

2.1 Fragments

The processes involved in completing fragments of words are important because they may also be used by peripheral dyslexics. If they are, then specifying these secondary processes with normal subjects will allow more accurate assessment and description of the compensatory strategies adopted when primary process fails.

Fragment Completion

The contribution of secondary processes to identifying words from fragments was more prominent in early fragment studies than it is currently. Warrington and Weiskrantz (1970) used words photographed through patchwork filters of increasing density to produce series of graduated incomplete words shown in Figure 2.1. This produces a series of progressively more informative fragments, or an ‘incremental’ cue. After a conventional learning session, (reading a list of words three times) they tested amnesics and controls with recall, recognition, incremental cues, and stems (e.g. MET for metal). Performance on incremental cues was measured by the fragment at which identification occurred.

Figure 2.1: The results of Experiment 2 from Warrington and Weiskrantz (1970).
Their results were, very low recall and recognition scores for amnesics compared to controls, but comparable incremental cue and stem scores (Figure 2.1). Warrington and Weiskrantz noted the high level of performance in amnesic patients on incremental cue and stem completion performance (“methods of partial information”) compared to recall and recognition. For amnesics, incremental cue performance was barely better than recognition but better than recall. Stems were the best measure of retention. For controls, recognition was best, and stems were better than recall. An equally interesting observation is that incremental cues not only failed to improve on recall scores (after all they are cues which do provide a certain amount of information) but actually managed to score less than recall with controls. Thinking that the solution is ‘medal’ might prevent ‘seeing’ that it is ‘metal’.

Basing their discussion on the difference between “methods of partial information” and “conventional methods”, they suggested “that long term memory can be demonstrated in the patients if methods are used that eliminate incorrect and interfering responses.” In other words, amnesics are prone to “false hypotheses” or “false retrievals”, which show themselves when tested using partial information. This initial explanation of implicit memory with fragment completion relied largely on the involvement of secondary processes in the task. That is, the process of finding the correct solution involved entertaining alternatives (neighbours or distractors), assessing those alternatives, rejecting some and generating others. Much of subsequent research using word fragments has been in implicit memory research where ‘completion’ facilitated by previous encounter is described predominantly in terms of primary process.

Primary processes theories of fragment completion

The observation that a word can be identified without complete identification of its constituent letters has been a matter of interest to psychologists since Pillsbury. He reported that, with tachistoscopic presentation, subjects will report ‘fovery’ as forever or ‘danxe’ as danger (Pillsbury, 1897). Subjects were often adamant that they had ‘seen’ the g in danger for instance. There seemed to be a process of ‘filling in’ missing information. Cattell (1886) observed that, with brief presentation, subjects were better able to report words than isolated letters. Reicher (1969) established that
letters in words are identified more accurately than letters in isolation (the word superiority effect) and that this could not involve guessing. If words were identified by their constituent letters, the conclusions were that word identification involved processing letters in parallel, and that this process could enhance the perceptibility of letters.

An activation account of the word superiority effect proposed by McClelland and Rumelhart (1981) involved feedback of activation from word level representations to letter level representations. Embodied in the interactive activation model, this feedback mechanism explained the observations of Cattell, Pillsbury, and Reicher, quite literally by ‘filling in’. Other models ‘restore’ missing information and explain the word superiority effect without feedback mechanisms (Humphreys, Bain & Pike 1989; Grainger & Jacobs 1994; Paap, Newsome, McDonald & Schvaneveldt 1982).

The ‘filling in’ process has also been described in terms of schemas (Mandler, 1979, 1980). Mental representations of objects, or schemas, consist of perceptual and conceptual components and the relations among them. These relations are strengthened each time an object is perceived. Given some of the components of a representation, the relations between the activated subset and the other components activates the entire schema. Some of the letters of a word will activate that word’s schema, and any other word schema containing those components, and recent encounters with a word intensify this ‘filling in’ process. Fragment completion with almost complete stimuli may be accomplished by processes built into the perceptual system to cope with natural variations in stimulus quality and content or slightly noisy parallel access. This is ‘lexical facilitation’. Explanations of facilitated word fragment completion in indirect memory tasks (Richardson-Klavehn & Bjork, 1988) by facilitated perceptual processing in a “Perceptual Representation System” (Tulving & Schacter. 1990) for instance, in so far as they do not refer to secondary processes, imply that fragment completion is mediated by primary process. This view of fragment completion may not apply to all fragmented stimuli however.
Variety of processes in fragment completion

The idea that different cues invoke different strategies has been raised in the implicit memory literature. Tulving, Schacter and Stark (1982) used standard component-letter fragment cues to investigate differences between direct memory tasks (recall and recognition) and indirect word fragment completion. They used unique fragments of long words like A__A__IN which have single solutions. Graf and Mandler (1984) used word stems of shorter words (ONI__ for ONION), all of which had 10 possible solutions. To explain differences in the effects of delayed testing between their own results and Tulving et al.’s, Graf and Mandler argued that unique fragments of large words induce a problem solving strategy. They suggested that completions to stems of recently encountered short words “come to mind”. The implication is that ‘coming to mind’ might be thought of as facilitated lexical access, enhanced by a previous encounter. They suggested that unique fragments of longer words changed the nature of the task. Attempts at retrieving solutions from study lists were more likely and the process takes much longer than stem completion. Furthermore, the effects of a previous encounter with the solution last longer (Tulving, et al. reported 1 week, Graf and Mandler reported 2 hours).

Completions of stems to short words “come to mind”, but several secondary processes are recruited in the process of identifying the longer unique fragments. The difference amounts to a different task. This difference is more likely to be taken into account, when comparing results in experimental degradation, if the processes involved in tasks are explicit within a framework of primary and secondary processes. It might be suggested for example, that word stems are solved by primary process perhaps with the co-operation of cohort or scanned completion. Larger fragments may involve processes such as retrieved completion and revision. Assembly might be expected to be involved in the verification of candidate completions by matching them to the visual stimulus. The effect of previous encounter, or priming, in the ‘two tasks’ may be mediated by different processes.

The complexity of these results is compounded not just by the variety of fragments used, but by the terminology. Nelson et al. (1989) found differences between word stems and word fragments. Word stems according to this group, do not
inform the subject about word length, and so [ONI] is a word stem. On the other hand [ONI__] is a word fragment because it indicates missing letters and their positions, and [O_N_ _ N] is a word frame because it has letters missing from various parts of the word. Note that Graf and Mandler call [ONI_] a word stem while Nelson et al. call it a fragment. The difference is important because Nelson et al. reported very different results for stems [ONI] and fragments [ONI_ _]. According to their research, stems and fragments are sensitive to lexical sets (the number of legal completions given to stems and fragments in norming studies hence probably neighbours in primary process). However, only word stems are sensitive to meaning sets (the number of words associatively linked to the target word in norming studies). Their conclusions were that stems invite pronunciation, and through strong links between phonology and semantics, activate semantic sets. In contrast fragments only invite lexical-orthographic searches and hence are not sensitive to meaning set size.

Furthermore, they found that stems engaged meaning sets and fragments didn’t, whether the instructions were direct or indirect. They also found that performance with fragments was generally better if subjects were encouraged to search for solutions at the word level, rather than focusing on the letters and trying to find solutions by guessing letters for missing spaces. In the language of secondary processes, lexical completions may be more accurate than sublexical ones. Most of the Nelson results were in the context of implicit memory research. Since implicit memory instructions generally disguise the study phase of the experiment, the assumption is that subjects are simply completing word fragments in the same way they might complete unstudied fragments. In this sense, the strategies they adopt are assumed to be the same as strategies adopted to non-studied fragments.

Nelson et al. (1989) report inhibitory effects of lexical set size for primed word stem and word fragment completion. The stimuli used were almost-complete stems and fragments of short words, which may be identified by primary process and lexical facilitation (Graf & Mandler, 1984). Lexical set size is the number of completions given to the stems and fragments in norming studies and hence might be considered equivalent to neighbourhood size. This effect of lexical sets suggests that primary process is subject to inhibitory effects of neighbourhood size. However, the stimuli used had many possible completions. This would be expected to produce
effects of lexical set size because all possible completions are legal. The tasks looked at in this thesis use unique fragments. A substantially complete unique fragment of a word may be completed by primary process with no interference from neighbours.

Nelson et al.’s results suggest not only that different sorts of fragments engage different sorts of processes, but underline the observation that different secondary processes are involved in most fragment completion. None of the models of primed fragment completion currently includes mechanisms that acknowledge the interaction between primary and secondary processes in completion. (e.g., Humphreys et al., 1989; McClelland & Rumelhart, 1985; Murre, 1992; Rueckl, 1990; Wolters & Phaf, 1990) Current thinking would describe implicit memory, demonstrated with stem or fragment completion in several ways. As subserved by a primary perceptual representation system (Tulving & Schacter 1990), facilitated by repetition of component primary processes (Roediger, Weldon & Challis 1989), or as episodic memory (Jacoby & Dallas, 1981). This may mean with fragments which Graf and Mandler suggest invoke ‘problem solving’ processes, primary process is taking the explanatory strain for what may be as much an accomplishment of secondary processes as of primary process. A better understanding of secondary process involvement in these tasks may prompt a re-evaluation of some to the implicit memory results and the explanations offered for them.

In a recent treatment of word recognition theories and repetition priming, Tenpenny (1995), excluded word fragment (and stem) completion from the review. “These tasks have been excluded because, although word identification processes probably contribute to their performance, it seems likely that they also invoke problem solving processes that are seldom used in reading.” (ibid. pp. 341).

Perceptual identification tasks usually involve tachistoscopic presentation of words followed by masks in sequences of trials aimed at measuring the threshold of identification. Postle and Corkin (1998) report that HM shows impaired priming on word stem completion, but robust priming on perceptual identification. They suggest that word stem completion uses ‘lexical retrieval’ which involves deliberate searches for target words, whereas perceptual identification indexes a perceptual component of priming.
“Thus, in our conception of the requirements of the WSC and PI tasks, subjects follow different procedures in order to perform successfully, and the priming that can be observed in each task arises from the biasing of two different processes.” (ibid. pp. 434)

The focus of word fragment completion theories on primary process means that they fail to explain the secondary process component of repetition priming. Postle and Corkin (1998) also adopt a component process view of tasks, and the argument here is that secondary component processes are as important as primary component processes.

Primary process models cannot be used to explain the interaction between primary and secondary processes in letter-by-letter reading, or the involvement of secondary processes in word fragment completion by normal subjects. As such, they are unlikely to be useful to neuropsychologists and developmental psychologists dealing with clients whose staple route to word identification involves secondary processes. The first half of the thesis will examine the role of secondary processes in experimental degradation. The investigation of secondary processes is likely to require the assessment of new tasks and the reassessment of old ones.

**Incremental cue tasks**

Tasks that involve ‘incrementing’ the information in cues evoke secondary processing. Two such tasks and a model are examined in this review and the following experimental chapter, the ‘Fragmentation task’, and the ‘Component-letter task’. Both tasks use two sorts of cues. A ‘standard’ cue is a single moderately informative cue, for example fragment 5 in Figure 2.2. An ‘incremental cue’ is a series of progressively more informative fragments, for example fragments 1–5 in Figure 2.2. Though standard cue completion probably involves secondary processes, incremental cues enable us to study their involvement in more detail. There are several good reasons for researchers in word recognition to be interested in these tasks.

- They may be particularly suitable as tasks with which to research secondary processes involved in word and object recognition. Most tasks used in word recognition research are aimed at primary process.
• It may be possible to develop some of the tasks as normal analogues of peripheral dyslexic reading. The serial inspection of letter positions induced by this fragment for instance may simulate letter-by-letter reading to some extent. Terry, Samuels and LaBerge (1976) however failed to find a word length effect with normal subjects using similar materials.

• Research using such tasks allows us to delimit two inhibitory factors in a broader model of word recognition.

  • The first is the idea that serial letter processing is inhibitory. Incremental cueing tasks suggest that identification from series of gradually more informative cues, is generally inhibitory compared to single moderately informative cues. (Bruner & Potter 1964; Snodgrass & Hirshman 1991; Luo & Snodgrass 1994; Thapar 1992) The idea also appears in the neuropsychological literature (Arguin et al., 1998). The suggestion is that because parallel processing of simultaneously present constraints eliminates distractors early in processing, encoding the same constraints serially must be inhibitory. The implication is that the propensity of letter-by-letter readers to encode information serially should result in inhibited performance. For instance, it predicts that the scanned completion process, suggested by Behrmann et al. (1998) as a description of what might be involved in letter-by-letter reading, should be inhibitory. More generally, the importance of understanding the effects of serial information intake is that secondary processes are often serial. An analogy is made between the serial encoding behaviour of letter-by-letter readers, and cueing procedures involving series of gradually more informative fragments or ‘incremental cues’. Both involve the accumulation of piecemeal information. This procedure will be referred to as incrementing.

  • The second factor is neighbourhoods. A prominent feature of research with degraded words is that performance is sensitive to the structure of a target’s neighbourhood. (Snodgrass & Mintzer 1993, Ziegler et al., 1998, Andrews 1997). The number of other words similar to the target in terms of the number of letters they share, and their frequency, has an impact on the probability of
target identification. Neighbourhood size has been reported to be inhibitory with one incremental procedure and facilitatory with another. (Snodgrass & Mintzer 1993). The understanding of these processes is important in broadening our view of word recognition.

The fragmentation task uses fragments produced by random deletions of pixels in images. This task has been used with both words and pictures (Figure 2.2A and B). The fragmentation task stimuli will be referred to as holistic fragments to emphasise the observation that the method of degradation is applied indiscriminately over the entire object. Inhibited performance on incremental cues compared to standard cues of pictures of objects is referred to as the Bruner-Potter effect (Bruner & Potter, 1964). Luo and Snodgrass (1994) report results with the fragmentation task suggesting that the effect is essentially the same for words.

![Fragmentation Task Example]

The component-letter task has been used in a number of investigations on the inhibitory effects of incremental cueing (Peynircioglu & Watkins, 1986; Peynircioglu 1987, 1990a, 1990b; Thapar, 1992; Thapar & Greene, 1995). In the component-letter task, incremental and standard word fragments are made up of letters and space markers (underscores Figure 2.2C). These stimuli will be described as component fragments to emphasise the loss of discrete meaningful component parts of the object in the degraded cue. Inhibitory effects of incremental cues with the component-letter task are referred to as the ‘Cue depreciation’ effect in the literature. The Cue Depreciation literature will be reviewed in the next chapter where some experiments using the component-letter task are reported.
A note on Procedures

Procedures using incremental cues can be very different and vary from experiment to experiment. Some of the important variations are described and named here. Examples of incremental cues are shown in Figure 2.2 above.

- **Self-paced**: Subjects are asked to identify the target as early as possible, do not have to make a response at each fragment, and move on to more informative cues when they wish to by pressing a key. A response terminates the series.
- **Forced completion**: Subjects must produce a completion to each fragment in the incremental cue. The display of each fragment may or may not be time limited, but subjects have unlimited time in which to form a hypothesis about the cue. A correct response terminates the series.
- **Continuous run**: Each fragment in the incremental cue is displayed for a fixed length of time. The final cue may also be time limited, but may be displayed until a response is made. Two variants of this procedure were used in the paradigms described later. The fragmentation task uses a fast version of continuous run. Fragments are displayed for 1 second until the final one, which is unlimited. Responses are only required to the final fragment. The component-letter task uses a slower version, which is to display all fragments including the last one for 4 seconds, and because responses are written, allows a response to be made at any point in the procedure. Subjects are encouraged to complete early in the series.

The different procedures may encourage different strategies and use different completion processes. With the self-paced and forced completion procedures, subjects may spend time on each cue in the series. Holistic and component fragments pose different problems. Fragment 2.2A-1 for instance, poses a time consuming letter identification problem. Fragment 2.2C-1 provides the letters, and with enough time, might be expected to produce a completion. Retrieved and assembled completion may play a role in these relatively slow incrementing procedures. The fast continuous run procedure (1s per fragment, unlimited on last) might be expected to restrict completion opportunities before the last cue. On using this procedure with words, Snodgrass and Mintzer (1993) noted that “This procedure rules out the possibility of eliminating high frequency competitors of the target by judicious use of guessing.”

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This rules out revision before the last fragment, but may also rule out completions before the last fragment. It is doubtful that many letter identifications could be made with fragment 2.2A-1 for instance in 1 second. There may not be enough time for hypotheses to develop at initial fragments of series 2.2A, but early completion may be possible with intact letters in 2.2C. The slow continuous run procedure (4s per fragment including the last), may allow more comprehensive completion at each level of the cue, and may allow revision of completions. Combinations of fragment type and procedure may allow particular secondary processes to be isolated for study.

2.2 The Fragmentation task with Pictures.

The fragmentation task with pictures was used by Bruner and Potter (1964), and Snodgrass and Hirshman (1993). They both found inhibitory effects of incremental cues and came to different conclusions on the processes mediating the effect. Bruner and Potter explained the effect with secondary processes, and Snodgrass & Hirshman explained it with primary process. The Bruner-Potter effect is dealt with in some detail because the explanatory framework developed for the effect was also extended to words.

The Bruner Potter Effect. Secondary or Primary inhibition?

The inhibitory effect of incrementing in the identification of degraded pictures was initially explained in terms of secondary processes. Recent investigations have shifted the explanation to primary process. These two positions are evaluated next.

The Secondary Process view

Bruner and Potter (1964) used series of progressively less blurred pictures. They found that the probability of identifying an object at a moderate level of blur, was greater than the probability of identifying the object at the same level of blur, if it was preceded by several more blurred versions. Hence, the probability of identifying the object from image 5 in Figure 2.3 is reduced if subjects are shown image 1 then 2 and so on before seeing image 5. Note that the first blurred picture affords unlimited
possibilities, as do the first fragments in the fragmented line drawings and words shown in Figure 2.2A & B.

![Figure 2.3: A series of progressively less blurred pictures.](image)

The pictures were unstudied, and subjects were encouraged to identify the object as early in the series as possible. The information contained in the final fragment of an incremental cue, is somehow less effective in eliciting its target by virtue of having been preceded by lesser versions of itself. Bruner and Potter thought that early fragments of an incremental cue evoke hypotheses, which then persist in the face of contradictory evidence in later fragments. They meant this in the sense of consciously held hypotheses. The conviction that it is a penguin obscures information pointing to a kitten. Bruner and Potter varied the starting level of blur and gradually brought the image into focus over periods of 13, 35, and 122 seconds. They found greater inhibitory effects with more blurred starting points, and less inhibition with longer focussing times.

Snodgrass and Hirshman, (1991) explored the effect in depth using fragmented line drawings (Figure 2.2B). Their first experiment used a fast continuous run procedure (1s per fragment unlimited on the last, respond on last), and replicated the effect on an item analysis but not on a subject analysis. The incremental cues consisted of 4 fragments and so the entire incrementing procedure took 3 seconds. (The fastest time used by Bruner and Potter was 13 seconds, and so might be considered a slow continuous run procedure) Experiments 2 and 3 used the forced completion procedure (1s per fragment with unlimited completion time, unlimited on last). Feedback on accuracy of completion in experiment 3, compared to no feedback in experiment 2, failed to remove the effect. Their conclusion was that, the cause of inhibited performance with incremental cues could not be consciously held hypotheses.
This conclusion is based on a procedure that allowed unlimited time in which to develop hypotheses, the forced completion procedure. The procedure was to wait for a completion and then either give or not give feedback. Being told that fragment 1 in Figure 2.3 is not a penguin, may not remove the penguin hypothesis, and may not provide much help in finding a better hypothesis. It is possible that the forced completion procedure with the fragmentation task, and the relatively slow incrementing used by Bruner and Potter, allowed the formation of conscious hypotheses. The failure of feedback to remove the effect may be related to the pictorial material used. Note that Snodgrass & Mintzer (1993) reported facilitatory effect of neighbourhood size with words in a forced completion procedure, and explained the absence of inhibition with the idea that feedback removed high frequency neighbours.

Neisser (1967) had suggested a fundamental difference between pictures and words based on the results of tachistoscopic pre-exposure experiments.

"On the basis of limited experimentation so far, then, it appears that pre-exposure of pictures tends to be inhibitory, while pre-exposure of letters is often helpful. This is not difficult to understand. A string of letters consists of relatively independent and well defined units. Focal attention can work to identify each of them individually in the limited time which the fading iconic memory leaves available. Once it has been identified a letter is easy to reconstruct. What persists between trials is not a pictorial or iconic image but a conviction that certain letters are present at certain positions in the display, leading the subject to construct them there again on subsequent exposures. For this reason, the time interval between trials is not a critical factor, as Haselrud (1964) has shown. In other words the beneficial effect of previous exposures appears with words because they consist of independent parts, each of known size and position, drawn from a known repertoire. The pictures used by Bruner and Potter (1964) or Wyatt and Campbell (1951) do not have these properties. A fragment perceived on the first trial will not be so easily constructed: on subsequent trials the subject may synthesise it incorrectly or in the wrong place. Moreover, the fragments may lead to unjustified hypotheses and expectancies about the remainder of the picture which can prevent a more adequate synthesis from appearing. Thus the nature of successive and cumulative exposures depend on the nature of the material, and on the subject's expectations concerning it." Neisser (1967, pp126).

Farah and Wallace (1991) suggest that two fundamentally different perceptual systems are involved in object and word recognition, and that computational differences related to processing in componential and holistic domains is the basis for their differentiation. These observations may explain the contradiction in Snodgrass...
and Mintzer's (1993) report that feedback is effective at removing inhibitory effects of neighbours with words and forced completion, and the observation that feedback does not remove false hypotheses with pictures here. The inhibitory effect of consciously held hypotheses is referred to as secondary inhibition. Secondary inhibition is not mediated by primary process. Note that secondary inhibition depends on procedures that allow completion at early stages of incremental cues. The suggestion is not that secondary processing inhibits or interferes with primary process. Under circumstances in which it might be more productive to direct attention at the products of primary process, the revision process might not take advantage of them. Perhaps because it is focused at the letter level, busy comparing a hypothesis with the stimulus, or because verification checks have been terminated early.

The Primary process view

Having concluded that the effect was not due to conscious hypotheses, Snodgrass and Hirshman (1991) went on to look at a primary process explanation. The fifth and sixth experiments examined the idea that inhibited performance with incremental cues was related not to conscious hypotheses but to perceptual noise in perceptual structures. Simple arithmetic sums were interpolated between levels of the incremental cues to allow ‘perceptual noise to die down’. Both experiment 5 and 6 used three sorts of cues.

- A standard cue displayed for 4 seconds.
- A spaced incremental cue (1s per fragment, interpolated sum, 4s on last, accurate completion terminates cue)
- A massed incremental cue (1s per fragment, 4s on the last, respond on last).

The result of both experiments was that spaced incremental performance was equivalent to standard performance. Massed incremental performance was below standard performance. In other words, the incorporation of the interpolated task in the spaced condition removed the inhibitory effect of incremental cueing in the massed condition. The conclusion was that transient activation in perceptual structures had time to ‘die down’ during the interpolated task, and hence no longer interfered with target identification. The effect was related to the activity of perceptual distractors in perceptual structures.
This conclusion is based on the difference between the massed and spaced procedures. The massed procedure was thought to preclude the formation of conscious false hypotheses in the course of an incremental cue, and to have an effect by creating noise within perceptual structures. Early fragments in the spaced procedure are processed as single events, not as members of a series of fragments. An interpolated task allows activation associated with the current fragment to die down. The interpolated task may also have the effect of preventing the development of a conscious hypothesis on that fragment. Because inhibition in the massed procedure is mediated by distractor activity within primary process, and is related to serial information encoding, it is referred to as serial primary inhibition. Primary inhibition may be caused by secondary processes, but is mediated by primary process. Hence, there may be inhibitory effects of neighbourhood size related to cohort completion and these would be referred to as parallel primary inhibition.

The Bruner-Potter and fragmentation task results with pictures are quite clear. Incremental cues are less likely to be identified than standard cues. The Competitive Activation Model (CAM) was proposed as a simulation of the effect and moved the explanation from one based on secondary processes (Bruner & Potter 1964), to one based on primary process (perceptual noise within perceptual structures). Luo and Snodgrass (1994) provided more results on the Bruner-Potter effect and explored some of the implications of CAM for what they call “Perceptual Interference”. Grainger and Segui (1990) report similar results with the Progressive Demasking task, suggesting serial primary inhibition. Intact words are revealed, through a gradual reduction in the ratio of mask to stimulus duration in a tachistoscopic task. They report larger inhibitory effects of frequency and neighbourhood frequency with this task compared to lexical decision. They suggest that because information intake is slowed by the procedure, competitive processes intensify and result in more marked inhibitory effects of frequency and neighbourhood. Words with a single higher frequency neighbour are inhibited relative to words that have no such neighbour. They explain this process in terms of the interactive activation model. The speed of the procedure suggests that the effect is due to competitive processes within primary process.
Conclusion

The demonstration of serial primary inhibition with a fast massed procedure does not preclude the possibility that with a different procedure the effect may be mediated by the persistence of consciously held hypotheses, or secondary inhibition. It is still possible that there are two effects. The first is mediated by primary process but related to a fast incrementing procedure. The second is mediated by conscious false hypotheses developed during the course of a slow procedure. The effect encountered depends on experimental procedure. Serial primary inhibition is related to the process of making a single identification and the effects of slowing this process down by restricting the flow of information. The process of attentional scanning or rapid serial refixation might similarly result in serial primary inhibition by raising noise levels in perceptual structures. It is also possible however that target identification in procedures which allow time for completion on early fragments may be inhibited, not by noise in perceptual structures, but by persistent inappropriate secondary processing. The interpretation of results using incremental cues with very different procedures, words and pictures, and different methods of degradation, requires that this distinction be clear.

2.3 The Fragmentation task with Words.

Extending The Fragmentation task to words

Luo and Snodgrass (1994) used the fragmentation task, with both studied and unstudied words and a fast continuous run procedure (1s per fragment, unlimited on the last, respond on last). Peynircioglu and Watkins (1986) had found inhibited incremental performance, compared to standard, restricted to studied sets of words using the component-letter task. Remember that this task uses a very different procedure (4s per fragment including the last, respond at any time). Luo and Snodgrass replicated the restriction of the effect to studied words in their first experiment, and failed to replicate in their second. Reasoning that low performance levels on the second experiment might be responsible for the null effect, they took steps to boost performance in the third experiment, where the effect emerged in both studied and unstudied sets. Their conclusion was that the effect was perceptual and
could be found in both studied and unstudied words, depending on the level of overall performance on the task. The ‘level of performance’ explanation is that a certain minimum level of distractor activity in perceptual structures is required for inhibition. If overall performance level could be taken to reflect distractor activity on any one trial, higher overall performance levels will produce the effect. This argues that high levels of performance should always show an effect. They extended the conclusion by suggesting that CAM also explains the Cue Depreciation results with the component-letter task.

As we will see when reviewing the Cue Depreciation literature, this prediction is not confirmed with the component-letter task. This may be related to the different scope allowed for secondary processes by the two procedures, and the use of holistic and component-letter fragments. In other words, the performance level factor may be appropriate with serial primary inhibition but not with secondary inhibition. It is argued below that CAM is a model of serial primary inhibition. The attempt to extend it to the Cue Depreciation results, and to the Bruner-Potter effect, where slower completion processes are possible, overlooks the possibility that different secondary processes may operate in the different procedures.

**2.4 The Competitive Activation Model**

The competitive activation Model

The Competitive Activation Model offers an explanation of the inhibitory effects of incremental cueing (Snodgrass & Hirshman 1991; Luo & Snodgrass, 1994). The model is important because it implies that scanned completion may be inhibitory, and that this inhibition is related to neighbours, and hence may be one of the sources of neighbourhood effects in lexical completion and letter-by-letter reading. The model maps activation from picteme units to semantics, and then on to phonology (Figure 2.4). Between each of these levels are mapping units, the PS units between pictemes and semantics, and the SP units between semantics and phonology. Mapping units compete with each other, and there is feedback from SP units to semantics. This variant of the IAM is unusual in two respects. The first is that unit activation is unbounded, and the second is that the model incorporates Hebbian learning.
An incremental cue presentation involves two input and cycle phases. In the first phase, input is clamped onto the common picteme unit. After 4 cycles, this input is cut off and the model is allowed to cycle a further 10 times. In the second phase input is clamped to the unique and common picteme units for 4 cycles, input is cut off, and the model allowed to run for 10 cycles. An incremental presentation thus has two phases. A standard cue presentation involves input to the unique and common picteme units from the outset, cutting off input after 4 cycles, and then running for 10 cycles. The standard cue is identical to the second phase of the incremental cue.

On each cycle, units compute weighted sums of input and their activations are set to activations on the previous cycle scaled by a decay term plus the new input value (which includes the negative lateral inhibition value). On all cycles, positive weights between units are modified by a value equal to the product of the activation of the two units linked by the weight, scaled by a learning rate parameter. The decay term is set at .65 and so the effects of previous cycles are very influential on subsequent cycles. This tendency to maintain previous activations is referred to as the ‘Carry-over Effect’. Processing the common features of target and distractor in the early stages of an incremental series elevates the activation of both. The decay factor maintains the activation of distractors at later stages of the incremental series thus producing the effect. The learning factor in the model would also tend to enhance distractor activation in the face of increasingly target-specific information. Hence, both factors contribute to the effect.
The main result of interest is the probability of target identification under incremental and standard cueing simulations. Probability of target identification is calculated as the activation of the target SP unit, divided by the sum of the target and distractor SP units. Snodgrass and Hirshman (1991) show that probability of target identification is on average 11% higher for standard presentations compared to incremental presentations. The first phase of the incremental cue raises activation of all target and distractor related units by the same amount, and the second phase of the incremental cue is identical to the standard cue. This is a counter intuitive result, which Snodgrass and Hirshman explain with the carry over effect.

**Testing the Competitive activation model**

The model was implemented for the thesis to produce graphs of processing profiles for the various conditions of interest. The graph in Figure 2.5A shows a standard cue (input unique and common for 4 cycles, remove input and cycle for 10) being processed. The preponderance of target information means that there is a gradual rise in the probability of target identification. The graph shows the probability of target identification, which is calculated thus. The result of standard processing is SP unit activation for the target = 0.176 and distractor =0.006. The actual values of these results depend on the size of input to the system, but their relative values do not. The probability of target identification using the Luce choice axiom (Luce, 1959) in this instance is \( \frac{0.176}{(0.176 + .006)} = .887 \).

Figure 2.5B shows an incremental cue being processed. The lower line culminating in .5 is the first phase of an incremental cue, where the common unit only is activated. This simply results in both target and distractor accumulating the same level of activation, and hence being equally likely as a response. The second phase is the upper line and shows the input to the unique unit gradually pulling the probability of target identification away from the distractor. The results of the incremental session are activation values of 0.214 for target and 0.037 for distractor. The probability of target identification is 0.789, about 10% lower than the standard cue. The standard-incremental completion rate difference, in both the Cue Depreciation Effect and the Bruner-Potter Effect experimental reports, is usually of the order of 5 –10%.
The Carry-over effect.

The initial phase of an incremental cue results in equal (.5) probabilities for both target and distractor identification, and identical activation levels at the SP level. The second phase is identical to the standard cue. Identification probability is lower for the incremental cue. This is a direct result of the Luce choice rule (target activation divided by the sum of target and distractor activation). If we start with target activation of 10 and distractor activation of 5, the probability of target identification is $10 / 15 = 0.66$. If we now add 10 to both target and distractor activation, we have activation levels of 20 and 15 respectively. Although we have raised both by the same amount the probability of target identification falls ($20 / 35 = 0.57$). The effect of the first phase of incremental cueing is to raise target and distractor levels, the equivalent of adding 10 to both levels in the example above.

In general, this means that any factor that conspires to raise target and distractor activation levels will reduce the probability of target identification. Snodgrass and Hirshman (1991) showed that the Hebbian learning rule alone could not account for the effect by setting activation levels to zero between the first and second phases of incremental cues. This abolished the difference between the two cueing conditions. Hence the conclusion that the effect is mediated by transient perceptual noise in perceptual structures. The zeroing out of activation during the incremental cue might be thought of as a simulation of the spaced incremental cue procedure.
Note that in the simulation of incremental cueing there are no points at which processing is allowed to come to some sort of conclusion between the first and last fragment of the cue. The inhibitory effects of distractors are related to 'noise within perceptual structures', and in the extension of CAM to words this is taken to imply that inhibitory effects are mediated by word level representations in primary process. Furthermore the simulation involves a serial process of information encoding which might be likened to an attentional letter level scan of a standard fragment, or a fast continuous run procedure, but not for instance to a forced completion procedure. With 4 seconds allowed on each level of an incremental cue in the component-letter task, lexical level processing would be expected to come to a resolution. That is, although completion is not forced, subjects are encouraged to complete as early as possible and completions would be expected based on early fragments in the incremental cue.

These considerations suggest that CAM is only appropriate as a simulation of fast continuous run procedures and not of the procedure used in the component-letter task. The extension of the CAM framework to the Cue depreciation effect extends a model of serial primary inhibition to a task that may evoke secondary inhibition.

The Carry-over effect in the Component-letter task.

![Figure 2.6: Processing component-letter fragments](image)

The first fragments of incremental cues in the component-letter task always uniquely specify the target (Figure 2.2C-1). They contain two of the letters of the target, which are incompatible with all other 8-letter words. Simply changing the order of inputs in the incremental simulation from common-then-unique, to unique-then-common, allows us to simulate this difference. The graph in Figure 2.6 illustrates
the results of unique-then-common incrementing. The initial restriction of information to target features results in high activation levels for the target. Because the target and distractor units are competitive, distractor activation is driven below zero allowing the probability of target identification to exceed 1 and reach 1.6. This is because activation values in the model as it stands are unbounded.

In the second phase of the incremental cue, the addition of common features drives the distractor activation upwards reducing the probability of target identification, but in essence not affecting the outcome of processing (Figure 2.6). This suggests that under certain circumstances incremental performance should outstrip standard performance, which might be appropriately termed an ‘Appreciation’ effect. That is, with component-letter incremental cues, where unique information is provided at the outset of incremental series, the model predicts that incremental performance could be higher than standard performance, a reversal of the usual effect. It will be argued that component-letter fragments are completed with different secondary processes and so this result only really illustrates the unsuitability of the CAM framework as a model of the component-letter task. The predictions of the competitive activation model rest heavily on the conception of incremental processing as exposure to common then unique features of targets and distractors. In the case of the component-letter task, this is the opposite of the actual procedure adopted.

Interpretation of CAM

Neighbours or distractors exert an inhibitory effect on perceptual identification performance in fast procedures that require only a single response. When subjects are allowed to make multiple responses with feedback, the effect may be facilitatory (Snodgrass & Mintzer 1993). When unique information is provided at the outset, incrementing may not be inhibitory, and may be facilitated compared to standard cues. The conception of incrementing as providing unique then common information ties the simulation to the fragmentation task; to particular methods of degradation. The failure to consider the intervention of processes outside primary process restricts its explanatory scope to fast incremental procedures.
2.5 Effects of Neighbourhood Size

The concept of distractors is central to the CAM explanation of the effect of incremental cueing. It is surprising therefore, that none of the experiments specifically designed to compare the effects of incremental with standard cueing with words manipulated or controlled for neighbourhood size.

Neighbourhood size is associated with facilitation in naming (Peereman & Content, 1995), and inhibition in perceptual identification of words (Grainger & Jacobs, 1996; Grainger et al. 1989, Grainger, O’Regan, Jacobs & Segui 1992). Effects of neighbourhood can be inhibitory or facilitatory in lexical decision depending on such factors as the nonwords used, the list composition, and subject strategy (see Andrews 1997 for a review). Snodgrass and Mintzer (1993) were concerned to address conflicting results in the word recognition literature on the effects of neighbourhood size and frequency, on lexical decision. They suggested that conflicting results might be related to the nature of the lexical decision task. The paper concludes that the fragmentation task and perceptual identification tasks in general may be better tasks for understanding some aspects of the word recognition system. A similar conclusion by Jacobs and Grainger (1994) places more emphasis on their suitability for investigating secondary processes.

Snodgrass and Mintzer (1993) used the fragmentation task with unstudied words. The first experiment used incremental cues of the Snodgrass and Vanderwart (1980) picture names with a self-paced procedure. They found no overall effect of neighbourhood size on identification thresholds. They did find that with low neighbourhood words subjects tended to make “errors of omission” by just pressing the enter key to move on. High neighbourhood words tended to produce “errors of commission” or completions. An orthogonally manipulated set of 4 letter words (high and low frequency and neighbourhoods) was used in Experiment 2 with incremental cues and a forced completion procedure. Thresholds were lower and accuracy higher for high neighbourhood and high frequency words and the two factors did not interact. Experiment 3 used a fast continuous run procedure (1s per fragment, unlimited on last, and respond on last) with incremental and standard cues. This was an opportunity to examine the difference between incremental and standard cueing (the cue
depreciation effect). No difference was found between incremental and standard cues. This was a failure to replicate the effect reported in Luo and Snodgrass (1994). However, neighbourhood size was inhibitory for low frequency words. That is, fewer low frequency words with many neighbours were identified compared to low frequency words with few neighbours, for both standard and incremental cues. This inhibitory effect of neighbourhood size was replicated in experiment 4.

The absence of an inhibitory effect of neighbourhood size in experiment 2 was explained by the elimination of high frequency neighbours of targets through forced completion and feedback. These eliminated completions on earlier fragments were thus not present to pose a threat to identification on subsequent fragments of the incremental cue. With the fast continuous run procedure however, they remain available to inhibit identification at the last fragment. The facilitation found may be because high neighbourhood words provide many alternatives, and the forced completion procedure provides many more completion opportunities than the continuous run procedure. In general, the results from Snodgrass and Mintzer were that perceptual identification of low frequency screen fragmented words is sensitive to neighbourhood size with both standard and incremental cues. Furthermore, neighbours are inhibitory unless secondary processes are allowed to eliminate them. The secondary processes involved depended on the procedures used with incremental cues, and could produce inhibitory or facilitatory effects.

Other variables affecting completion

Ziegler et al. (1998) investigated the effects of several linguistic variables in regression analyses on thresholds and errors to incremental cues with the fragmentation task, using a self-paced procedure. With this procedure, subjects may move on to the next fragment as they wish, and a response terminates the incremental cue. Note that although the procedure allows unlimited time for formulating completions, there are no opportunities for revision once a response is made. Subjects identified 580 four letter French words. The variables measured were threshold (level at which fragments were completed) and errors. Regression analyses used frequency, logarithmic frequency, neighbourhood size, number of higher frequency neighbours, summed positional letter frequency, summed positional bigram frequency, and letter confusability (thresholds determined for single letters were summed for words).
The results were

- Logarithmic frequency was correlated with thresholds (-.22) and not with error rates.
- Error rates were not correlated with frequency but were with neighbourhood size (.31), number of higher frequency neighbours (.22) and summed positional letter frequency (.24).

Frequency was associated with the speed of completion, while neighbourhood variables were associated with the probability of errors.

- Reliable partial correlation coefficients with thresholds were reported for log Frequency (-.31), and letter confusability (.449).

This indicated that a large proportion of the variance in thresholds could be uniquely explained by the letter confusability measure in particular. This was largely due to the holistic nature of degradation in the fragmentation task and would not be expected to apply to the component-letter task. The effect of frequency on thresholds is however marked and would apply to both tasks.

- Reliable partial coefficients with error rates were reported for neighbourhood size (.164), letter frequency (.151), and confusability (.160).

A similar analysis for component-letter fragment cues is presented later in the next chapter where similar correlation coefficients are reported. In general the results support inhibitory effects of neighbourhood in the fragmentation task. Strategies adopted by subjects in the self-paced procedure were reported and are discussed later.

2.6 Summary and Conclusions

- The initial inhibitory effect of incremental cues compared to standard cues was found with pictures by Bruner and Potter (1964). They explained it with the idea that consciously held false hypotheses, developed in the course of an incremental cue, inhibited identification.
- Snodgrass and Hirshman (1991) replicated the effect with forced completion and found that feedback aimed at removing consciously held hypotheses did not remove the effect. This led them to conclude that the effect was not mediated by conscious false hypotheses.
Snodgrass and Hirshman (1991) found the effect with a fast continuous run procedure. A second procedure, which involved asking subjects to do simple arithmetic sums after exposure to each fragment in the incremental series, abolished the effect. This led to the conclusion that it was mediated by perceptual structures. They implemented the explanation in the Competitive Activation Model CAM of ‘perceptual interference’.

Peynircioglu and Watkins (1986) had found the effect in words with the component-letter task and a slow continuous run procedure. This is the Cue Depreciation effect.

Luo and Snodgrass (1994) extended the fragmentation task to words with a fast continuous run procedure. They concluded that the effect in words was also mediated by perceptual interference and suggested the CAM as an explanation. They extended the CAM explanation to the Cue Depreciation effect although the procedures used were different in the Fragmentation task and Component-letter paradigms.

In the course of looking at the effects of neighbours on the fragmentation task with words Snodgrass and Mintzer (1993) used the forced completion procedure (with feedback), and a fast continuous run procedure. The absence of an inhibitory effect of neighbours with forced completion compared to continuous run, was explained by the opportunity to discard false hypotheses afforded by the forced completion procedure. The completions on early cues are likely to be mediated by secondary processes, and on feedback, likely to be revised by secondary processes.

The opposite effects of feedback with pictures and words may mean that revision is more effective with words than with pictures. This may be related to the componential structure of words. It suggests however that the dismissal of secondary inhibition may have been premature.

### Inhibitory and Facilitatory effects of Neighbourhood size

The review suggests three inhibitory effects and a facilitatory one.

- The first inhibitory effect may involve fast secondary processes such as serial scanning or rapid refixation which are simulated by the fast continuous run procedure. This effect is embodied in CAM and is explained by the propensity of serial degraded information to activate competitors within primary process. This effect is mediated by primary process. Note that it may be caused by a secondary process. That is, the normal processes in word identification which best approximate fast continuous run procedures are serial scanning and rapid...
refixation. The analogy between these processes and the fast continuous run procedure suggested they might be inhibitory. Scanned completion may be associated with inhibitory effects of neighbourhood size.

- The second inhibitory effect is mediated by sub-lexical completion. With forced completion procedures and slow continuous run procedures, which are likely to produce completions during the course of an incremental cue, inhibition may not be related to noise in perceptual structures. It was suggested that the relatively slow deblurring procedure used in the Bruner-Potter (1964) experiments meant that conscious false hypotheses could not be ruled out as an explanation. The Snodgrass and Mintzer (1993) results showed that subjects can complete on early fragments, and with feedback, can eliminate these completions. With procedures that do not force completion, but allow time for completion and encourage it, the effect of these completions on subsequent identification will depend on how well they are revised in the light of subsequent information. If they are not revised, they may remain to reduce the probability of target identification. Results from the cue depreciation effect will be used to substantiate this argument. Hence, retrieved and assembled completion may show inhibitory effects of neighbours.

- The facilitatory effect is mediated by sub-lexical completions and revision processes. Secondary facilitation involves a cycle of completion and revision that may only be possible with a conscious strategy. The revision process may mediate facilitatory effects of neighbourhood size when used in conjunction with completion processes.

- A third inhibitory effect was suggested in the introduction related to cohort completion. Demonstration of inhibitory effects of neighbourhood size in the absence of evidence of serial letter processing will be used later in the thesis to establish the plausibility of this process. Cohort completion may be associated with inhibitory effects of neighbourhood size.

The nature of the inhibition incurred by incremental cueing depends on the procedure used. The 'perceptual interference' framework, developed around the fragmentation task and the fast continuous run procedure, suggests that partial information, supplied serially to an essentially parallel primary processes, is
inhibitory. This means that some of the secondary processes, proposed in the first chapter, might be fundamentally inhibitory. Serial letter scans, or rapid refixations (Behrmann et al. 1998) for example, which directly activate the input lexicon, may have the sort of effects described by CAM. Both the IAM and CAM predict that the first letter to arrive will begin to create distractor activity that persists until a discriminating letter enters the lexicon. At that stage, the probability of successful identification may be jeopardised. Several other secondary processes were hypothesised however, including sub-lexical completion processes and revision, which may only be evident in procedures that allow time for them to operate.

The review of the fragmentation task suggested several predictions and questions, which will be addressed in the next chapter with the component-letter task. The slow continuous run procedure used with the component-letter task is taken to mean that, unlike the fast procedure used with the fragmentation task, completion and revision are possible during the course of an incremental cue. The procedure and fragments used suggest that inhibitory and facilitative effects in this task are likely to be mediated by sub-lexical completion. The component-letter task encourages but does not force completion. Subjects are asked to write down responses as they occur and so evidence of spontaneous completion and revision may be found. The guidelines taken from this review to the component-letter task are,

- The revision process may not require feedback and hence may include spontaneous revision of completions.
- Slow incremental cueing may result in facilitatory effects of neighbourhood size.
- Slow incremental cueing may produce a facilitatory effect of incremental cues compared to standard cues.
- Slow incremental cueing may result in inhibition of incremental cues compared to standard cues.

**Conclusion Chapter 2 Experimental Degradation**

The main use of degraded words within experimental psychology has been in the demonstration of facilitated word identification by previous encounter in the absence of recollective processes. The most often discussed explanation for this is
facilitated perceptual processing within primary process. Several lines of evidence suggest that secondary processes play a role in fragment completion and that the processes involved vary with the nature of the stimuli. The role of secondary processes in fragment completion may be explored using two tasks, the Fragmentation task and the Component letter task.

Reviewed results on the fragmentation task raised the question of the inhibitory effects of piecemeal information encoding, or perceptual interference. The procedures used in this task were thought to best approximate the scanned completion process, and predicted inhibitory effects of neighbourhood size. This suggested implications for the serial encoding of letter identities in letter-by-letter reading behaviour. The explanatory framework developed with the task, CAM, was examined, and the extension of its domain to the component letter task questioned. The framework seemed to apply to forces operating within primary process and the associated inhibitory effect to be dependent on a view of incrementing, which did not describe the procedure used in the component letter task. However it is a good model of the effects of scanned completion, and is relevant to similar considerations of inhibitory effects of serial encoding in neuropsychology.

The review also suggested that procedure and fragments may determine the effects of neighbourhood size, and that these may be facilitatory or inhibitory. Facilitatory results were associated with the slower secondary processes, which were thought to be engaged by the component letter task, and not the fragmentation task. Facilitatory effects with the fragmentation task using a slow, forced completion procedure predicted similar effects with the component letter task. The implications of this were that some cases of peripheral dyslexia, developmentally delayed reading, and strategy, may produce facilitatory effects of neighbourhood size related not to lexical facilitation, but to secondary processing. A combination of retrieved and revised completions was thought to be a likely explanation. Chapter 3 explores these predictions.
Chapter 3: The Component-letter task

“Empirical phenomena in the corresponding study of normal processes – human experimental psychology – are very slippery things.” (Shallice, 1991, pp.1)

3.1 Introduction: The component-letter task

This chapter reports a review of the Cue Depreciation literature and two experiments using the component-letter task. Unlike the fragmentation task, the procedure here is a slow continuous run procedure (4s per fragment including the last, respond at any time). It was suggested that this may mean that the inhibitory effects of incremental cues derive from fundamentally different secondary processes. The fragmentation task produced inhibition related to the fast continuous run procedure, and this may be an appropriate simulation of the effects of faster serial secondary processes on primary process. The procedure used here may show inhibition and facilitation related to secondary processes which require time to operate, such as retrieved and assembled completion and revision. The fragmentation task and perceptual interference framework produced some insights into the possible effects of scanned completion. The component-letter task is used to illustrate some of the effects of sub-lexical completion.

Survey of existing Cue Depreciation Results

Peynircioglu and Watkins (1986) found that subjects completed fewer incremental cues than standard cues of studied words, but not of unstudied words. With blocked cueing of studied and unstudied words, the possibility of different strategies by subjects, depending on whether or not there had been a study phase, was explored by mixing fragments of studied and unstudied words at test. Given that subjects were blind to the status of cues prior to completing them, they should not be able to adopt different strategies for studied and unstudied words. The effect was found in only studied words with this design, prompting the researchers to conclude that it could not be mediated by strategy. This was followed with evidence that study
was not necessary for the effect. Peynircioglu (1990a; 1990b) found the effect when a set of words was blocked by semantic category and no effect when they weren’t.

Peynircioglu concluded that study was not necessary, but some sort of limited target set was. She subsequently showed that motivation could induce the effect by finding it when subjects were told that the test was an IQ test, but not when they were told it was a practice session. The cue depreciation effect is thus used to refer to all instances of word identification from fragments, in which incremental completions are inhibited compared to standard.

The results are varied and difficult to interpret. All the experiments are based on the same set of words originally provided in Peynircioglu and Watkins (1986), and so although procedures vary, the words are the same. A survey of the Cue depreciation data is reported below. A list of all the experiments and the various manipulations used is included in Tables 1 and 2 of the reviews section of appendix. The survey sorted the experiments on two criteria. The first is whether the target words were primed. Priming in this context could be studying the words or being informed that they were all from the category (e.g. fruit). The second criterion is whether or not fragments of primed and unprimed words were mixed or blocked at test. This allowed some main points to emerge.

- In mixed sets the effect almost always emerges in the primed set and not the unprimed set. The only exceptions to this were two experiments in Peynircioglu (1990b) in which both sets were primed, but one set was ‘stronger’ than the other through more repetitions at study or through deep as opposed to shallow study. That is, when two studied sets were present, the effect emerged in the stronger set. This suggests that the effect is restricted to the set at which retrieval attempts are directed, when there are two studied sets. The third exception was an auditory cue depreciation experiment in Gibson and Watkins (1991), where a 48hr delay between study and test abolished the effect in both studied and unstudied sets. If we assume that retrieval attempts are reduced by a 48hr delay, then the effect may not be present when retrieval is de-emphasised. The abolition of the effect in the weak primed groups suggests an effect of retrieval rather than perceptual facilitation per se. This is supported by the next observation.
De-emphasising retrieval removes the effect in primed blocked sets. Section C of Table 2 (appendix) lists all the experiments in which primed sets were tested in blocks and hence retrieval was directed at a single set. The effect is found in all cases except for 3 cases from Peynircioglu (1990b). In all these cases, retrieval was de-emphasised by instruction. The first used implicit memory instructions (complete with the first word that comes to mind). The second was a set of high frequency words, incremental cues went up to six letters instead of the usual 5, and levels were exposed for 5 seconds instead of the usual 4 seconds. Subjects were told the fragments were easy, and this was reflected in very high scores and no effect. In the third case subjects were told that the fragments were only worth 1 point compared to 5 points for completions from the other blocked set in the experiment. In all these cases direct steps were taken to de-emphasise retrieval, or to devalue attempts at early completion. In the absence of these instructions, the effect is always present in blocked primed sets. The involvement of voluntary secondary processing in the effect is also underlined by the next observation.

Unusual instructions produce the effect in unprimed blocked sets. In most instances where the effect is observed in blocked unprimed sets, some unusual aspect to the procedure can be identified. Peynircioglu (1990b) told subjects they were engaged in an IQ test. Thapar (1992) gave subjects a set of words to study, told them they would be tested on that set and then tested them on a different set of words. A second group also studied a set of words but were tested only on words they had not studied and were aware of this. In one condition, Thapar and Greene (1995) encouraged subjects to think up as many possible solutions to unique incremental cues even if they were not quite right. In another condition, subjects were asked not to attempt any completions until the very last cue. In all these conditions, the unusual manipulations resulted in an effect. These effects may be explained by the scope for instructional and motivational factors to alter the balance of secondary processes involved. Told that it is an IQ test, subjects might well latch on to the first letters from the first incremental fragment, and begin an anxious and elaborate exercise in assembly. The resulting inhibition in unprimed words is the hypothesised secondary inhibition effect, related to unproductive secondary processing. In a practice session, they might be expected.
to wait until the more informative fragments, hope for primary completion, and failing that use lexical or sublexical completion to produce a response.

- There is no effect and a trend to incremental facilitation in normal instruction-unprimed blocked sets.

The last 5 conditions in section C of the Table 2 in the appendix fulfil these criteria and show no effect. On the contrary, they all show slightly higher performance with incremental cueing, though not high enough to be reliable.

The failure to consider neighbourhood size may mean that a facilitatory effect of incremental cueing was masked in the subject analyses used. This secondary facilitatory effect is likely to be restricted to high neighbourhood words.

The experiments

The general aims of these experiments is to extend the Snodgrass and Mintzer (1993) results to the component-letter task and to look more closely at the secondary processes involved in the task.

The first experiment looks at the effects of neighbourhood size. The predictions based on the fragmentation task results were,

- There would be a facilitatory effect of neighbourhood size on incremental completions.
- There would be more correct incremental than standard completions in high neighbourhoods.
- These effects would interact with study.

The second experiment looks more closely at secondary processes. Only unstudied words were used in this experiment. The opportunity to complete and revise was manipulated by introducing a fast condition that cut the usual time on each fragment in an incremental cue, and the time on a standard cue, to 3 seconds instead of 4.

- Time reduction was expected to reduce both completion and revision.
- An analysis of target-error match.
3.2 Experiment 1. Cue Depreciation

Introduction

The component-letter task research has generally used a slow continuous run procedure (4s per fragment, including the last, respond at any time). Completion is encouraged but not forced, responses are written as cues unfold, hence both completions and revisions are evident in responses. The fragmentation task procedure often allowed unlimited time on the last incremental fragment and standard cues. Timing is strictly adhered to in the component-letter task, and so all fragments are allowed the same time for completion. This means that all cues are under the same time pressure to complete. However, the 4 seconds allowed on incremental fragments may allow reasonable completions to be made, even on 2 or 3 letter fragments of eight letter words (I_W_ _D_ _)O_ _ _ _ X). This suggests that several cycles of completion and revision are possible with this task.

No data is available on the effects of neighbourhood size with the component-letter task. This is addressed here by post hoc analyses using two methods of estimating neighbourhood size for eight-letter words, which are discussed below. This allowed the experiments to use the same set of words used in all the results published to date. The implications of Snodgrass and Mintzer’s findings for the component-letter task are drawn out first. Snodgrass and Mintzer (1993) reported a facilitatory effect of neighbourhood size with forced completion that did not interact with frequency. They also reported an inhibitory effect of neighbourhood size for both incremental and standard cues to low frequency words with the fast continuous run procedure.

• The facilitatory effect of neighbourhood size is only found with the forced completion procedure and applied equally to high and low frequency words. The implications were that two processes contributed to this effect.
  • High frequency distractors are eliminated by forced completion and feedback
  • High neighbourhoods provide alternative completions.
If feedback is not required for revision, and if the procedure used in the component-letter task is slow enough to permit completion and revisions in the course of an incremental cue, the implication is that

- A facilitatory effect of neighbourhood size on incremental cueing should be found with the component-letter task. This may be due either to more revisions of high neighbourhood words, more correct non-revised completions, or to a combination of both.
- A facilitatory effect of incremental cueing compared to standard cueing should also be found, and this may be restricted to the high neighbourhood set. The contribution of revision to an incremental advantage should be evident. However, the greater opportunity for completion incorporated into the incremental procedure may mean that more attempts at completion may produce more correct non-revised completions.

Some of the component-letter task experiments reviewed, used a studied set. The restriction of the cue depreciation effect to the studied set has been a persistent enigma in this paradigm. As discussed previously there is no explanation so far for why the effect should be found in only one set when the fragments from studied and unstudied words are mixed at test. A studied set was included in this experiment to establish whether neighbours are implicated in the effect on studied words as well as unstudied words, and to allow the results to be compared to existing data on the effect. A further question addressed by including a studied set was the relationship of primary and secondary processes to priming. The standard explanations for facilitated word fragment completion are facilitation by, a perceptual representation system (Tulving & Schacter 1990), by repetition of component processes (Roediger et al., 1989) or as episodic memory (Jacoby & Dallas, 1981). Studied words are completed with both standard cues and incremental cues. Assuming a larger primary process component in standard cue completion than in incremental cue completion, and assuming that the initial encounter with the studied words involved only primary process, the prediction would be that standard cues should benefit more from study than incremental cues.
Estimating neighbourhood size for 8-letter words

Two methods of estimating neighbourhood size were explored. A word’s neighbourhood size has usually been defined as the number of words that can be constructed by changing one letter of the word (Coltheart, Davelaar, Jonasson, & Besner 1977). BILL is a neighbour of BALL as are BALD and CALL. With large words, this definition of neighbours is unworkable because as words get longer, it rarely produces a neighbour, and when it does, it’s usually an inflection or a derivation. Various ways of defining neighbours for long words have been suggested including defining similarity in terms of larger sublexical units such as syllables (Andrews 1997). The important characteristic of a neighbour is that it functions as a distractor. That is, it appears as an error to a presentation of a target.

One of the most common error types in neuropsychological investigations is associated with visual dyslexia but is common in other conditions. The ‘visual error’ is defined as an error sharing 50% or the target letters in the same positions. Neighbours defined along these lines might thus be called visual neighbours. The first method employed with the eight letter words in this experiment was simply to count all other 8-letter words that shared 5, 6, or 7 letters in the same positions with the target. Note that only words of the same length qualified, and letter positions were strictly preserved. Data presented in the Experiment 2 of this chapter suggests that, at least with longer words, the actual functional distractors (errors produced in response to fragments) involved in fragment completion, very often fall outside the range of this rule. They are often shorter than the target, and letter positions migrate. That is, errors often contain the same letters appearing in the fragment, just not in the same positions. The second method of estimating fragments is in response to this data, and explores a method by which global estimates of similarity might be derived.

Using an the IAM to estimate neighbourhoods

A less conventional and exploratory way of arriving at neighbourhoods for long words is to build an IAM and allow the model to specify neighbours. The IAM was reprogrammed with all the original parameters. Details of the original algorithms, and pseudo-code guidelines on how to program the algorithms are found in McClelland and Rumelhart (1988). The 4-letter model was re-written exactly as
specified in this workbook, and the new program was verified against the original program supplied on floppy with the workbook. The extension of the program to process 3 to 9 letter words was simply a matter of using variable size arrays and loop indexes depending on the length of word being processed. Routines for processing multiple length words were slightly more complex but involved ranges of loop indexes only, and no changes to the core structure or parameters of the original model.

Words and frequency ratings were obtained from the Oxford Psycholinguistic Database (Quinlan 1992). They were first separated by length and then by first letter. Lexicons determined by first letter may be appropriate for the component-letter task, because errors made to these fragments very rarely begin with a different first letter (results of experiments 1 and 2, this chapter). The first letter of the target is always included in the cue. Separate files listing words and their frequencies were stored. This might be compared to the letter bin system proposed by (Forster, 1976). At the presentation of a word, the model determined the length and first letter of the stimulus. Word level representations were then specified using the relevant file for the stimulus exactly as in the original model. The general layout of the model is shown in Figure 3.1A. In effect, a new model was initialised for each stimulus.

The estimates of neighbourhood size used in the analyses to follow were obtained in the following manner. Resting levels were set to zero so that frequency had no effect on processing. Alphabetic letter bins of 7 and 8-letter words were used to set up the lexicons, even though stimulus length was always 8 letters. This was to explore the effects of introducing some flexibility into the definition of neighbours. Data is presented later showing that errors made to component-letter fragments are very often longer or shorter than the target length, and that letter positions often migrate. The word set was then presented to the model and all word level representations with activation values above 0 at the end of a 10 cycle processing period, were designated neighbours of the stimulus. The example of ‘carnival’ is shown in Figure 3.1B. Complex neighbour relations may be captured by this method of estimating neighbours. Under degraded conditions, it is likely that the two words CARDINAL and CANNIBAL would be confused with CARNIVAL. Neighbourhood dynamics in auditory word recognition take account of frequency (Goldinger, Luce &
Pisoni 1989). This method would allow similar considerations to be adopted in visual word recognition.

A further motivation for exploring this method of specifying neighbourhoods is that similarity may need to be defined in relation to the processing employed. For instance, serial secondary processes may not be sensitive to similarity at the ends of words. Hence, estimates of neighbourhood size taken over the length of a word may not index the competitive processes engaged by the serial transfer of letter identities proposed in reading theories of oral spelling recognition. The model would allow the specification of neighbourhoods under various conditions of information encoding.

Figure 3.1 (A): The IA8 Model. (B): Processing episode for ‘carnival’.

**Objectives**

- To investigate the effects of neighbourhood size on the Cue depreciation effect. The original word set and fragments (Peynircioglu & Watkins 1986) included in the corpora section of the appendix) was used.
- To replicate the facilitatory effects of neighbourhood size related to incremental cueing with a different degradation technique, and without forced completion.
- To examine the prediction that completion and revision may result in a facilitatory effect of incremental cues compared to standard.
- To assess the role of completion and revision in these effects.
- To explore two estimates of neighbourhood size for 8-letter words.
Method

Design.

Two factors Cue (incremental and standard), and Study (studied and unstudied), were manipulated in a 2 by 2 within subjects design. The dependent variables were the number of correct completions and the number of incorrect responses in the four conditions. Post hoc analyses were conducted using two measures of frequency. These were frequency (F) taken from Kucera and Francis (1967), and a transformation of this data, log (F+ 1). This is an estimate of frequency found to be a good indicator of completion performance in perceptual identification studies (Ziegler et al 1998), denoted by logF in this report. Neighbourhood size was estimated in two ways. The first, N8, was a simple computation of the number of words sharing 5, 6, or 7 letters in the same positions with the target. The number of higher frequency neighbours based on this count was identified. This is referred to as N8F. A second estimate of neighbourhood size was obtained from an IAM configured to process eight letter words. The neighbour count derived from the model is referred to as modN, and the corresponding higher frequency neighbour count as modNF. Both the computed and model-estimated measures of neighbourhood size and frequency were used in the analyses.

Subjects, materials and apparatus

Subjects were 16 undergraduates (8 men and 8 women) at Goldsmiths College, London, who participated for course credits. The Peynircioglu and Watkins (1986) word and fragment set was used. The 131 eight-letter word set is included in the appendix. No linguistic variables were specified for the words in the source. The published set also specified the two letters of each word (including the first) which uniquely identified it within 8-letter words. Standard and incremental fragments of the words were constructed according to these specifications. Incremental cues were made up of four fragments, containing 2, 3, 4, and 5 of the word's letters. The first fragment of an incremental cue was constructed using the first letter of the word, and another letter specified in the published set. Subsequent fragments were made by choosing from the remaining letters of the word at random. Because the first two-
letter fragment uniquely specified the target word, all subsequent fragments were also unique to the target. Missing letters were indicated by underscores. The final incremental fragment also served as the standard cue for that word. The incremental and standard cues thus constructed were used with all subjects in all conditions.

128 words from the set were used in the experiment, the remaining 3 served as practice words. The words were divided into 4 blocks of 32 words by random selection without replacement. In each block 16 words served as study words, and 16 served as unstudied words. In each block, 16 words were cued with incremental fragments (8 studied and 8 unstudied), and 16 words were cued with standard fragments. Over 16 subjects, each word appeared 4 times in each of the four conditions of the design (Study * Cue). Response sheets were prepared consisting of 4 sheets of paper, one for each block of the experiment. Each sheet had 32 boxes with 4 slots in each block. The 4 slots were used in incremental trials to mark the point in the sequence of fragments at which identification occurred. All stimulus presentation and timing was controlled by computer programs. Experiments were run on IBM computers equipped with SVGA monitors set at 600 by 800 resolution. Stimuli appeared in white on a blue background in 12-point font.

Procedure

Subjects were run individually. Once seated in the normal position at a computer terminal in a quite room, the experimenter supervised an initial instruction and practice session presented by the computer. The instructions informed subjects that each block of the experiment consisted of a study phase and a test phase. All the words studied would be tested, but there would also be fragments of unstudied words in the test sessions. Fragments would be of two sorts, incremental and standard. With standard cues, subjects were simply to attempt a solution. With incremental cues, it was important to attempt a completion as early in the sequence as possible. Subjects were shown the response sheets and asked to write their completions on the sheet. The four slots in the trial boxes on the response sheets were pointed out, and subjects were asked to write their completions to incremental cues in the slot corresponding to the fragment at which identification occurred. The practice session was repeated if any aspect of the procedure was unclear. A keypress initiated the first experimental block.
The first screen presented 16 words for study. The words remained on-screen for 32 seconds, and were then replaced by a screen announcing the test phase. 16 incremental and 16 standard cue trials then followed in a random sequence, separated by 1 second inter trial screens of a fixation point. Standard cues (5 letter fragments) appeared for 4 seconds followed by the inter trial screen. Incremental cues started with a two-letter fragment. Subsequent fragments appeared directly below the previous ones after 4 seconds, until all four fragments were onscreen. Total presentation time was 16 seconds. This procedure was adopted to approximate the procedure used in Peynircioglu and Watkins (1986) as closely as possible. In their experiments, subjects studied a typed list of 16 words. Fragments were written on cue cards one below another and were displayed by lowering a cover held over the fragments. Subjects had no control over the rate of cue presentation and had to keep up with trials. The end of a block was marked by an inter-block screen informing subjects of a 2-minute pause. The next block was announced by a ‘beep’. After completing the four blocks, response sheets were collected and subjects debriefed.

Results

A subject analysis is followed by item analyses looking at neighbourhood size, frequency, and error types. A final analysis looks at the correlations among the linguistic variables used and between these variables and performance.

Subject Analysis

<table>
<thead>
<tr>
<th></th>
<th>Incremental</th>
<th>Standard</th>
<th>Incremental</th>
<th>standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studied</td>
<td>22.9</td>
<td>24.1</td>
<td>75.3%</td>
<td>80.7%</td>
</tr>
<tr>
<td>Unstudied</td>
<td>15.6</td>
<td>15.1</td>
<td>53.1%</td>
<td>49.6%</td>
</tr>
</tbody>
</table>

Table 3.1: Mean and percent correct completions

An analysis of variance using Study (studied and unstudied) and Cue (incremental and standard) as within subject factors, revealed an effect of Study \( F(1,15)=109.01, p<.001 \). More fragments of studied words were completed than of unstudied words. There was no effect of Cue, but there was an interaction of Study and Cue \( F(1,15)=6.77, p<.05 \). With studied words, incremental performance was lower than standard performance (75.3% and 80.7% respectively).
For unstudied words, this trend was reversed. Incremental performance was higher than standard performance (53.1% and 49.6%). Post hoc tests showed that the cue depreciation effect (lower completions in the incremental condition) was marginally reliable for studied words $t(15) = -1.86$, $p = .08$. All tests are 2-tailed. The opposite trend in unstudied words was not reliable $t(15) = 1.50$, $p = .1554$. The interaction between Study and Cue reflects higher completions of standard than incremental cues for studied words, and the opposite in unstudied words. Analysis of variance on the number of errors revealed an effect of Cue $F(1, 15) = 12.97$, $p < .01$, but no effect of study, and no interaction. Overall, incremental cueing resulted in higher error rates (9.6%) compared to standard cues (5.7%). The marginal effect in studied word completions is consistent with results reported by Peynircioglu and Watkins (1986).

**Item Analysis**

Neighbourhood size and frequency are examined in separate analyses, followed by an analysis of error types.

**Neighbourhood Size**

<table>
<thead>
<tr>
<th></th>
<th>Low N8</th>
<th>High N8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incremental</td>
<td>Standard</td>
</tr>
<tr>
<td>Studied</td>
<td>77.3</td>
<td>78.9</td>
</tr>
<tr>
<td>Unstudied</td>
<td>46.9</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 3.2: Percent accuracy by N8, Cue and Study

The word set was arranged in descending order on each of the estimates of neighbourhood size and neighbourhood frequency (N8, N8F, modN, modNF) described above. The lower 50% of the words were assigned to a Low group, and the rest to a High group on each variable. The post hoc nature of the analysis means that some overlap was present in the groups. Given more confidence in the predictive status of N8, N8F, modN and modNF, future experiments could use more motivated orthogonal sets. The first analysis was based on N8. This was the estimate produced by considering all eight-letter words sharing 5, 6, or 7 letters in the same positions, to be neighbours. N8 was used as a between subjects factor (high/low), with Study (studied/unstudied) and Cue (incremental/standard) as within subject factors. An analysis of variance using these factors on completions revealed no main effect of
Neighbours, an effect of Study F(1,126)=148.63, p<.001, and no effect of Cue. N8 did not interact with Study or Cue, but Study interacted with Cue F(1,126)=5.95, p<.05. This reflects the subject data above.

There was a three way interaction of N8, Study, and Cue F(1,126)=5.44, p<.05. (Figure 3.2) The difference between standard and incremental cues for High N8 words was reliable for both studied t(63)=-3.03, p<.01, and unstudied words t(63)=2.17, p<.05. The differences were in opposite directions. For studied words, incremental performance was reliably lower than standard performance. This is the cue depreciation effect. For unstudied words in high neighbourhoods, incremental performance was reliably better than standard performance. This will be referred to as the Appreciation effect. The low N8 differences between incremental and standard cues were not reliable. There was an effect of neighbourhood size on incremental cues to unstudied words (t(126)=-2.09, p<.05.), but not to studied words (t(126)=.85, p=.4). This indicated that incremental cues with unstudied words performed reliably better in high neighbourhoods than in low ones. This will be referred to as the Revision effect. There was no effect of neighbourhood size on standard cues for unstudied (t(126)=.509, p=.6), or studied (t(126)=.79, p=.43) words. There was thus no effect of neighbourhood size on standard cues.

An identical analysis using ModN instead of N8 produced nearly identical results. There was no effect of ModN, an effect of study F(1,126)=146.4, p<.001, no
effect of Cue, and no interaction between ModN and Study or Cue. Like the N8 analysis, there was an interaction between Study and Cue $F(1,126)=5.85$, $p<.05$. To this point, the results were identical. The only difference was that the three way interaction, ModN by Study by Cue, was marginal $F(1,126)=3.15$, $p=.078$. A similar picture emerged for N8F and for ModNF. The 3 way interaction was reliable with the N8F estimate of higher frequency neighbours ($F(1,126)=4.92$, $p<.05$), but not with the model estimate ($F(1,126)=1.51$, $p=.22$). The exploratory criterion level used in the model estimates was discussed above and may be improved. The pattern of results is however consistent. With all of the measures used, neighbourhood structure emerged as a consistent factor affecting completion rates for Cue and Study conditions.

Frequency

The words were allocated to low and high frequency groups for analysis. An analysis of variance was conducted using Frequency (high and low), Study, (studied and unstudied) and Cue (incremental and standard), with proportion of correct completions. More high frequency words were completed than low frequency words ($F(1,126)=17.38$; $p<.001$) and more studied words were completed than unstudied ($F(1,126)=160.19$; $p<.001$), but there was no main effect of Cue ($F(1,126)=.28$; $p=.59$). Frequency interacted with study ($F(1,126)=13.41$; $p<.001$), but not with Cue ($F(1,126)=.58$; $p=.4$). The effect of frequency was thus equivalent for incremental and standard cues, but different for studied and unstudied words. There was an interaction between Study and Cue ($F(1,126)=5.71$; $p<.05$) which we saw in the subject analysis. The 3 way interaction was not reliable ($F(1,126)=.07$; $p=.79$).

![Figure 3.3: Accuracy by Frequency, Cue and Study](image-url)
<table>
<thead>
<tr>
<th></th>
<th>Studied</th>
<th>Unstudied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incremental</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>HF</td>
</tr>
<tr>
<td>Accuracy</td>
<td>.72</td>
<td>.79</td>
</tr>
</tbody>
</table>

Table 3.3: Proportion accuracy by Frequency, Cue and Study

The interaction between Study and Frequency is shown in Figure 3.4. The priming effect was reliable ($t(164) = 10.95, p<.001$) for low frequency words and for high frequency words (reliable $t(164) = 6.73, p<.001$). The effect was however larger for low frequency words (.38) than for high frequency words (.17). The advantage of high frequency words was reliable in the unstudied ($t(126)=4.81, p<.001$) and studied ($t(126)=2.81, p<.05$) sets, and again was larger in the unstudied set. The results suggest that frequency affects the probability of fragment completion and hence accuracy, and that the effects are larger with unstudied words. This difference is reduced in the studied set, because of a larger effect on low frequency words of previous encounter. MacLeod and Kampe (1996) also found larger effects of priming for low frequency words using unique fragments of 6 to 10 letter words. The results indicate that frequency is an important factor in fragment completion, particularly when the fragments are unstudied.

Figure 3.4: Interaction between Frequency with Study

Within the IAM framework, lexical processing is thought to be frequency sensitive. This is instantiated as resting levels within the model. This does not however preclude the possibility that other, secondary, processes may also be frequency sensitive. The equivalent sensitivity to frequency of standard and
incremental cues may mean that their solution shares a common component, but this need not be a lexical process.

Error analysis

<table>
<thead>
<tr>
<th>Unstudied Revisions</th>
<th>Studied Revisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapeze-theorise</td>
<td>Inwards-inwardly</td>
</tr>
<tr>
<td>Dutiful-downfall</td>
<td>Inquiry-inquirer</td>
</tr>
<tr>
<td>Banquet-boutique</td>
<td>Quality-quantity</td>
</tr>
<tr>
<td>Justice-jaundice</td>
<td>Enu-envelope</td>
</tr>
<tr>
<td>Turquoise-tranquil</td>
<td>Kalogran-kangaroo</td>
</tr>
<tr>
<td>Righteous-rehearse</td>
<td>Unluck-unlikely</td>
</tr>
<tr>
<td>Doubtful-downfall</td>
<td>Acquired-acquaint</td>
</tr>
<tr>
<td>Lullaby-lollipop</td>
<td>Handfull-handcuff</td>
</tr>
<tr>
<td>just-joyfully</td>
<td>Vehi-vehement</td>
</tr>
<tr>
<td>Justice-jaundice</td>
<td>Acqu-acquaint</td>
</tr>
<tr>
<td>Gigline-gigantic</td>
<td>Overlook-overkill</td>
</tr>
<tr>
<td>Justify-joyfully</td>
<td>Quotien-quantity</td>
</tr>
<tr>
<td>Oblivious-oblivion</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.4: Revisions in incremental conditions

Completions were classified as follows. **Hits** were the number of correct solutions. **Revisions** were any initial responses that were changed to the correct response. These will be referred to as **overt revisions** to emphasis the idea that covert revisions may be a factor in incremental cue completion. Examples of these are given in Table 3.4. **Misses** were the total of the following kinds of errors. **List:** errors that were other words on the test list (completed earlier). **Variants:** Inflections or Derivations of the target. **Visual:** bore some relation to the target but not enough to qualify as a neighbour under current definitions. **Nonsense:** was not a word.

The object of this analysis was to establish the role of revisions in the effect of neighbourhood size on standard and incremental cueing. Counts are given in Table 3.5. (Each of the 128 words appeared equally often in the four conditions, and there were 16 subjects, so the maximum in each cell is 512.) The first point to emerge was that overt revisions were confined to the incremental condition. Fewer errors were made in the standard conditions, but none were revised. The 4s allowed may simply not be enough time to revise responses. Five of the 25 revisions in the unstudied incremental condition, and 1 of 13 in the studied set, were revisions of study list

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intrusions. This suggests that mixed set experiments may complicate the data if the object is to study secondary processes per se. The next experiment will examine errors on unstudied words only. There were substantial numbers of variants, visual errors, and nonsense responses, in both standard and incremental conditions.

<table>
<thead>
<tr>
<th></th>
<th>Studied</th>
<th>Unstudied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INC</td>
<td>STAN</td>
</tr>
<tr>
<td>Attempts</td>
<td>432</td>
<td>438</td>
</tr>
<tr>
<td>Hits</td>
<td>386</td>
<td>413</td>
</tr>
<tr>
<td>Revisions</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Misses</td>
<td>46</td>
<td>25</td>
</tr>
<tr>
<td>List</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variants</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Visual</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Nonsense</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3.5: Completion and Error counts
*Variants = Inflections and derivations, INC = incremental, STAN = standard

The results indicate that substantial numbers of revisions were made during the course of incremental cues. The revision process operates spontaneously to correct early errors, which are as likely to be made overtly in high and low frequency neighbourhoods. These early completions are apparent in the thresholds for responses to incremental cues shown in Table 3.6. All incremental condition responses were scored 1 to 4 according to the fragment on which a response was made. Response points were then summed for each category and divided by the number of responses. So for example, the unstudied revision threshold of 1.68 means that, on average, the initial response in overt unstudied revisions was made between the first and second fragment. In other words, overt completions were made based on 2 or 3 letter fragments.

<table>
<thead>
<tr>
<th></th>
<th>Correct</th>
<th>Revisions</th>
<th>Variants</th>
<th>Visual</th>
<th>Nonsense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studied</td>
<td>2.80</td>
<td>1.77</td>
<td>2.85</td>
<td>2.11</td>
<td>3.0</td>
</tr>
<tr>
<td>Unstudied</td>
<td>3.05</td>
<td>1.68</td>
<td>3.4</td>
<td>2.39</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Table 3.6: Thresholds for Incremental conditions

Intrusions from the studied list accounted for 20% of revisions to unstudied fragments. This may implicate retrieval processes in completions. The involvement of neighbourhoods in the revision process is apparent in responses that correct
inflections and derivations (oblivious-oblivion; inwards-inwardly; inquire-inquirer).
The numbers of completions and revisions in the eight conditions of study by N8 and
Cue are given for studied and unstudied words in Table 3.7.

<table>
<thead>
<tr>
<th></th>
<th>Unstudied</th>
<th></th>
<th>Studied</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incremental</td>
<td>Standard</td>
<td>Incremental</td>
<td>Standard</td>
</tr>
<tr>
<td>Revisions</td>
<td>Completions</td>
<td>Completions</td>
<td>Revisions</td>
<td>Completions</td>
</tr>
<tr>
<td>High N8</td>
<td>13</td>
<td>152</td>
<td>128</td>
<td>7</td>
</tr>
<tr>
<td>Low N8</td>
<td>12</td>
<td>120</td>
<td>6</td>
<td>198</td>
</tr>
</tbody>
</table>

Table 3.7: Exp. 1. Correct completions and revisions by Cue and N8.

For incremental cues of unstudied words, the number of overt revisions made
for high and low neighbourhood words were equivalent (13 and 12). However, a
facilitatory effect of neighbourhood on incremental cues was reported in the analysis
of variance earlier. Because overt revisions were equivalent for high and low
neighbourhood words, they cannot account for the effect (152-120=32 completions).
Revision is involved in both high and low neighbourhood completion, but the effect is
due to 31 more completions in the high neighbourhood set. The incremental cue
advantage over standard cues in high neighbourhood words was (152–128=24). Half
of this advantage can be attributed to overt revision, and the rest may be accounted for
by covert revision. The discussion will suggest that covert revisions contribute to both
the appreciation effect, and the revision effect.

Correlational Item Analysis

Simple correlation coefficients for the estimates of frequency (F, logF),
nearhood size (N8, ModN) and neighbourhood frequency (N8F, ModNF) are
shown in Table 3.8.

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>LogF</th>
<th>N8</th>
<th>N8F</th>
<th>ModN</th>
</tr>
</thead>
<tbody>
<tr>
<td>LogF</td>
<td>.51</td>
<td>.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N8</td>
<td>-.07</td>
<td>-.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N8F</td>
<td>-.08</td>
<td>-.27</td>
<td>-.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ModN</td>
<td>-.02</td>
<td>-.01</td>
<td>.56</td>
<td>.49</td>
<td></td>
</tr>
<tr>
<td>ModNF</td>
<td>-.12</td>
<td>-.53</td>
<td>.43</td>
<td>.62</td>
<td>.62</td>
</tr>
</tbody>
</table>

Table 3.8: Correlation coefficients for parameter estimates

Note: * = significant, p<.05, # = significant, p<.01

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The transformed frequency estimate $\log F$ was positively correlated with frequency, and negatively with the estimates of neighbourhood frequency (number of higher frequency neighbours), $N8F$, and $\text{ModNF}$. For the set of words used, low frequency words tended to have more higher-frequency neighbours than high frequency words. The correlations between $N8F$ and $\text{ModNF}$ and the two neighbourhood size estimates $N8$ and $\text{ModN}$ support an observation reported by Snodgrass and Mintzer (1993) that words with many neighbours also tend to have more higher frequency neighbours.

Following Ziegler et al. (1998), simple and partial correlations with the parameter estimates were calculated between the completion measures and the four conditions. Table 3.9 details the significant simple and partial correlation coefficients for correct completions in the four experimental conditions. Simple correlations can tell us which estimates are related to the performance measures. Partial correlation coefficients indicate the degree to which the estimates account for variance not accounted for by the rest of the estimates. Because the set of estimates of frequency, orthographic redundancy, and neighbourhood structure are so interrelated, it is useful to identify variables that account for unique variance.

<table>
<thead>
<tr>
<th>Simple correlations of dependent measures with correct completions</th>
<th>Partial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
</tr>
<tr>
<td>Studied Incremental</td>
<td>.232 #</td>
</tr>
<tr>
<td>Studied Standard</td>
<td>.303 #</td>
</tr>
<tr>
<td>Unstudied Incremental</td>
<td>.175*</td>
</tr>
<tr>
<td>Unstudied Standard</td>
<td>.179*</td>
</tr>
</tbody>
</table>

Table 3.9: Significant Simple and partial Correlation coefficients

Note: * = significant, $p<.05$, # = significant, $p<.01$

Completions were consistently correlated with $\log F$ in all four conditions, and $\log F$ accounted for unique variance in completion rates for unstudied words. This positive relationship is consistent with the relationship between frequency and thresholds reported by the Ziegler et al. (1998). Completion rates in all the conditions of the experiment were significantly related to the number of higher frequency neighbours as estimated by $\text{modNF}$, and studied incremental completions correlated with $N8F$. All these coefficients were negative suggesting that higher frequency
neighbours were inhibitory in all conditions. These relationships indirectly support the notion that large neighbourhoods, and high neighbourhood frequency in particular, constrain word completion performance with both types of cue and in both conditions of study.

Discussion

Main findings

- The subject analysis revealed a marginally reliable cue depreciation effect in studied words but no effect in unstudied words. There was a trend to higher incremental completions in the unstudied set.
- Overall, there were more errors in incremental than standard conditions.
- The item analysis found no effect of Cue in either studied or unstudied sets for low neighbourhood words.
- There was a cue depreciation effect in studied high neighbourhood words.
- Hereafter applies to only unstudied words
- There was an effect of neighbourhood size on incremental cues. More high neighbourhood cues were completed than low (the Revision effect).
- There was a facilitatory effect of incremental cueing in the high neighbourhood set. (the Appreciation effect)
- There were no effects of neighbourhood size on standard cues.
- Revisions were restricted to the incremental conditions and were equally likely for high and low neighbourhood words.
- Overt revisions did not account for the advantage of incremental cues in high neighbourhoods.
- The advantage of incremental cues over standard cues in the high neighbourhood set was accounted for equally by overt revisions and completions. (the Appreciation effect)

Discussion

The results of the subject analysis were quite straightforward. A marginal cue depreciation effect in studied words but no effect in unstudied words. The item analysis was more revealing. The differences in the effects of incremental and standard cueing emerged when the original word set used in the cue depreciation
experiments was divided into groups of high and low neighbourhood words based on N8.

Unstudied words.

Snodgrass and Mintzer (1993) reported a facilitatory effect of neighbourhood size with the forced completion procedure. The presence of overt revisions in this experiment supported the notion of a process of spontaneous revision of initial completions to incremental cues. Two facilitatory effects were found with unstudied words. The first was an effect of neighbourhood on incremental cues. The facilitation of incremental performance by high neighbourhoods will be referred to as the Revision effect. The second effect was higher performance with incremental cues relative to standard cues in high neighbourhoods. The facilitation of incremental performance relative to standard performance in high neighbourhoods will be referred to as the Appreciation effect. The data support the idea that both these effects were sustained by revision and hence indicate the involvement of covert revision. This is a rather complex argument so it is made in list format.

- Two processes are proposed in component-letter cue completions. Initial completions are made based on the cue. These initial completions may be revised in incremental conditions. There is no evidence for revision in the standard condition, probably because of time limitation.
- Because incremental cues in the low neighbourhood set have as much opportunity for revision as incremental cues in the high neighbourhood set, the opportunity for revision cannot account for the revision effect.
- Because incremental conditions in the high and low neighbourhood sets have equivalent numbers of overt revisions, these cannot account for the revision effect.
- Because standard completion rates are the same for high and low neighbourhood sets, neighbourhood size cannot account for the effect.
- If the effect were related to higher levels of accurate initial completions in the high neighbourhood set, then standard cues in the high neighbourhood set would have the same advantage. There would be no appreciation effect in the high neighbourhood set.
• The absence of an appreciation effect in the low neighbourhood set suggests that alternative completions, associated with high neighbourhood size, assist the process of revision.

• The equivalence of standard performance in the high and low neighbourhood sets implies that neighbourhood size has little effect in the generation of initial completions. This may indicate that they are not generated by lexical, but by sub-lexical completion. The next experiment reports some evidence supporting the idea that these initial completions are largely retrieved completions.

• The revision effect is entirely due to covert revision because incremental cues in the low neighbourhood set produced equivalent numbers of overt revisions.

• The appreciation effect is due to both overt and covert revisions.

The results above are taken to support the revision process. Several different completion processes may produce initial completions. With standard cues, the absence of revisions suggests that the process of completion occupies much of the 4 seconds, and the absence of an effect of neighbourhood may indicate sublexical completion. The presence of revisions with incremental cues suggests that some were attempted on early fragments. Completions based on 2-3 letters of an 8-letter word may be retrieved completions Standard and incremental completion rates were equivalent in the low neighbourhood set, though a number of revisions contributed to incremental performance. This may indicate a tendency for initial completions to standard cues to be more accurate than initial completions to incremental cues, related presumably to the number of letters they are based on. The listed results above however make a good case for the involvement of revision in both the revision and appreciation effects The next experiment will explore further the processes implicated in initial completions.

Unlike the forced completion procedure used by Snodgrass and Mintzer (1993), the procedure used here did not force responses, limited the time available for completion, and provided no feedback. This suggests that incremental cues elicit spontaneous early completions, which are verified against subsequent fragments, and suppressed if wrong. Alternative completions are then selected for response. The complexity of this process suggests that it requires time, and that alternative similar
words would facilitate revision within the time allowed. The appreciation effect in the high neighbourhood set supports this. Part of the appreciation effect was accounted for by overt revisions, and the listed argument above suggested that covert revisions account for the remainder. An equivalent number of overt revisions in the low neighbourhood incremental condition, suggested that initial completions were corrected here also, and hence the absence of an effect may be related to the frequency with which immediately apparent alternatives are available. This might be expected to be higher in large neighbourhoods. The component processes thought to underlie revision, that is, verification, suppression, and reselection imply sophisticated comparison processes. For example, a neuropsychological patient who is unable to process single letters within letter strings (attentional dyslexia) might not be expected to be able to compare a completion with the stimulus. This would need to be done by matching letters and letter positions. Thus, abolished revision and appreciation effects may be useful diagnostic effects of the component processes implied by revision. The possibility that these effects are related to the inclusion of an episodic set in this experiment will be examined in the next experiment. Both the revision and appreciation effects are likely to be sensitive to time constraints.

**Studied words**

The survey of cue depreciation results presented in the introduction reported that the cue depreciation effect is found in blocked studied words unless retrieval is discouraged. It is not found in primed sets if there is a stronger set, or testing is delayed. This suggested that retrieval directed at a limited set was required for the effect. The enigma in the reviewed results was that the effect is found restricted to studied sets when fragments are mixed at testing. The results of this experiment deepen the enigma by showing the effect restricted to high neighbourhood words. The performance level explanation (Luo & Snodgrass 1994) does not explain the effect with the component-letter task because CAM is not applicable to this task. The effect is found at low performance levels and absent at high levels, and in this experiment, is both present and absent at much the same level of performance. Priming does not explain the effect because it would be found in the low neighbourhood set. Comparing the effect in high neighbourhood set, and its absence in the low neighbourhood set (see Figure 3.2), suggests the effect is composed of two elements. Compared to the

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low neighbourhood set there seems to be an inhibitory element of incremental cueing and a facilitatory one of standard cueing in the high neighbourhood set.

- The inhibitory element may be related to false familiarity. If early fragments are used to retrieve an episodic candidate, the retrieved candidate is more likely to be a neighbour or variant of the target in the high neighbourhood set. If false familiarity results in the retrieved candidate being accepted as the episodic target, then the revision process may be terminated prematurely.

- The facilitatory element in the standard condition of the high neighbourhood set may indicate a larger involvement of primary process in primed standard cue completion. Primed standard cues are likely to be completed by primary process. That is by virtue of previous encounter, 5 letters of the target word may provide enough word level activation to support identification without secondary process involvement. Andrews (1989) reports facilitatory effect of neighbourhood size on intact word naming and lexical decision. If primed standard fragments in the high neighbourhood set were slightly more likely to be completed than in the low neighbourhood set, the cue depreciation effect would be restricted to the high neighbourhood set in studied words.

Further experimentation to test this possibility was not pursued because the remaining experiments are directed at secondary processes as they operate in word identification and not memory. A study set was included in this experiment to explore the possibility that the Cue depreciation effect was restricted to high neighbourhood sets. This appears to be the case and hence further research into the restriction of the effect in the studied set will need to consider neighbourhood size.

The results are taken to support a role for retrieved completion and revision in the component-letter task. The strategy of delimiting a set of tentative secondary processes and thinking about tasks in terms of these processes has established several points so far.

- The procedures used in the Fragmentation task and Component-letter task recruit different secondary processes.

- The inhibitory effects of incremental cueing, as describe by CAM, are not appropriate to the component-letter task. If they were, the performance level argument would apply, effects of incremental cueing would be seen in low
neighbourhood words, and there would be no facilitatory effects of incremental cueing.

- Incremental cueing with the component-letter task can be facilitatory in high neighbourhood sets. This facilitatory effect is mediated by a revision process, which produces overt revisions, but the results also point to a covert process.

- The Cue depreciation effect may be restricted to high neighbourhood sets.

Some empirical evidence for the revision and appreciation effects was found in this experiment. Both effects are based on the hypothetical secondary process of revision. The demonstration of revision is important for several reasons. It demonstrates that empirical support can be established for secondary processes and that the other hypothetical secondary processes proposed may be similarly researched. The secondary processes are important partly because they play a role in a broader view of normal word recognition, but also because they may constitute the components of strategy. That is, it may be possible to describe strategy and individual differences in terms of the secondary processes used. This applies to normal as well as impaired reading. Laxon, Coltheart and Keating (1988) for example, report facilitatory effects of neighbourhood size on accuracy, in single word reading for children of 8-10 years, with a self-paced procedure. The facilitatory effects were more pronounced in poor readers. The self-paced procedure would have allowed poor readers to make covert revisions, which would account for the facilitatory effect of neighbours in this group. The unlikely alternative would be to suppose that poor readers had better developed primary process, implying an effect in this set based on the lexical effect described by Andrews (1997). Revision is also important because it underlies two tangible effects in the component-letter task, and these effects may be put to good use. The rest of the thesis is concerned with reading, and so focuses on unstudied words. The effects are replicated in the next experiment without the presence of an episodic set.

**Conclusion Experiment 1: Cue Depreciation**

The materials and procedures used with the Component letter task engage different secondary processes and have different effects compared to the Fragmentation task. Standard and incremental component letter cues to unstudied words engage secondary
processes referred to as retrieved completion and revision. The spontaneous deployment of these processes produced two facilitatory effects of incrementing, the Revision and Appreciation effects. The results replicate results from Snodgrass and Mintzer (1993), support the role of secondary processes in fragment completion, and provide a method for studying the sublexical completion processes. The results also address the Cue Depreciation literature, suggest that neighbourhood size be considered in further exploration of the effect, and that the effect is related to strategic use of combinations of secondary completion processes.

3.3 Experiment 2. Cue Appreciation and Revision

Introduction

The term “revision effect” was introduced in the previous chapter to refer to the advantage of incremental cues in high neighbourhoods over incremental cues in low neighbourhoods. The ‘appreciation effect’ was introduced to refer to the advantage of incremental cues over standard cues in the high neighbourhood set. This experiment focuses on these effects to look more closely at the secondary processes involved in incremental and standard cue completion. The involvement of revision in incremental cue completion in the previous experiment was evident for both high and low neighbourhood words, and in both studied and unstudied incremental conditions. This suggests that it is a general, spontaneous process, which is used with all incremental cues, with varying degrees of success, depending on the availability of alternative solutions. The absence of revisions in all the standard conditions was marked. Standard cues may often be identified by primary process or lexical completion, and these may not trigger verification processes. That is, retrieved completions to early incremental fragments may automatically enter a verification and revision process that is not applied to lexical completions. So in the four seconds allowed on a standard fragment, solutions may be found quite quickly but not revised.

On the other hand standard fragment completion may involve time consuming secondary processes such as letter position scans or refixations, and may use retrieved completions and the revision process to check letter positions and so on. If so, standard cues would be under considerable pressure, and an appreciation effect might
be found simply by reducing the time allowed on fragments. If lexical completion mediates standard fragment completion, then reducing the time from 4 to 3 seconds might be expected to have minimal impact on standard completions. However if more time consuming secondary processes are involved, then the time reduction would be expected to have a large impact on standard completions.

Figure 3.5: Results from Peynircioglu and Watkins (1986) Experiment 5.

Figure 3.5 graphs data from Experiment 5 of Peynircioglu and Watkins (1986). The experiment cut the usual exposure from 4 to 3 seconds, but subjects were monitored by the experimenter for 60 seconds after the final incremental cue, and responses were recorded by time slot. The pattern of slightly higher completions in unstudied incremental conditions is seen at the 3-second mark. At this point incremental cues have been unfolding for 12 seconds but standard cues have only been on display for 3 seconds. The graph could be described as a chart of the time course of the revision process. Standard completions are equivalent by 6 seconds and higher thereafter. Neither the initial incremental advantage nor the eventual standard advantage were significant (neighbourhood was not manipulated), but the graph suggests an initial time disadvantage for standard cues. It also suggests that the processes involved in completing a 5-letter fragment of an 8-letter word are fairly complex and drawn out. This may explain why there were no effects of neighbourhood size on standard cues to unstudied words in the previous experiment.
If standard cues were identified by lexical completion, some effect of lexical neighbours might be expected. Retrieved completions on the other hand may not be subject to neighbourhood effects until they come to be revised. The aim of this experiment was to compare performance at 3 seconds and 4 seconds. The suggestion is that both standard and incremental cues will be affected by the drop in time. The effect on incremental cues should be reflected in their ability to make use of revision. The effect on standard cues should be on the number of completions made, and hence on correct completions.

The previous experiment suggested that both the revision and appreciation effects were related to a cycle of completion and revision and that this was facilitated by neighbourhood size. Cutting the time available for revisions should have an impact on both effects. That is, the appreciation effect may be intensified in the both neighbourhood sets, and the revision effect may be abolished in the high neighbourhood set. The revision effect in the unstudied condition at 4 seconds, depended on both the presence of alternative completions (high neighbourhood) and the opportunity to revise completions (incremental cues). Cutting the time to 3 seconds may prevent enough revisions to abolish the effect. The appreciation effect compares incremental to standard cue performance. In the previous experiment, the effect was confined to high neighbourhood words because of the advantage of alternative completions. Cutting the time to 3 seconds should produce the effect in both high and low neighbourhood sets because of the disadvantage to standard cues of a 3 second cue time.

One of the most important reasons for using perceptual identification tasks is that they produce errors that can be informative about processes. Error analysis is a prominent feature of neuropsychological testing and can play a role in the development of a broader view of word recognition. A more detailed error analysis is undertaken in this experiment because there was no episodic set to influence processing. The patterns observed with unstudied words only may reflect normal secondary processes as they operate in degraded paradigms or peripheral dyslexia. The N8 and ModN estimates of similarity used produced sets of words that reacted differently to the cues used in these experiments. The functional distractors, that is, the distractors that actually appeared as errors, defied any simple definition. The
revision error examples given in the previous experiment were often shorter or longer than the target, and were visually similar to the target (e.g. banquet-boutique, righteous-rehearse, flavour-festival). The example ‘flavour’ was an early completion to the cue \([f_\_\_\_\_ v_\_\_]\) aimed at a studied word ‘festival’. The visual similarity is defined by the two letters the words have in common with the cue (f and v), and their relative positions in the words. By looking at error patterns to cues like this, it may be possible to develop a definition of similarity based on functional distractors to cues. Similarity may be in the eye of the process engaged. Similarity to a serial process may be biased to information at the beginnings of words, while a parallel process might take a more evenly spread view of similarity. Current definitions of similarity assume the parallel view of neighbours, and this may not be appropriate for the serial secondary processes proposed.

**Objectives**

- To replicate the Cue appreciation effect and the Revision effect with unstudied words only, and to explore the time course of completion and revision processes thought to be involved in fragment completion.
- To verify the abolition of the revision effect in high neighbourhoods with reduced time.
- To verify the appreciation effect in low neighbourhoods with reduced time.
- To explore the structural relationship between targets and errors.

**Method**

**Design**

The design used two within subject factors. The first was Time, and refers to the duration of cue presentations. Standard cues and each fragment in an incremental cue were displayed for 4 seconds in the ‘Slow’ condition, and for 3 seconds in the ‘fast’ condition. The second factor was ‘Cue’ with two levels, incremental and standard. The dependent variables were number of correct completions and number of errors.
Subjects, materials and apparatus

32 undergraduates (16 men and 16 women) at Goldsmiths College, London University, participated in the experiment for course credits. The same word set and apparatus used in Experiment 1 was used here. The programs were altered to omit study phases, and to implement changes in timing. Half the cues of each type (incremental and standard) were presented at the fast rate, and the other half at the slow rate. Response sheets were identical to the ones used in experiment 1.

Procedure

The procedure was the same as Experiment 1. The only difference was that the program omitted a study phase. The test phase was identical. 32 trails presented incremental and standard cues for completion in 4 blocks. The same inter trial and inter block screens and timings were used. Response sheets were collected and subjects debriefed after the last experimental block.

Results

Subject Analysis

An analysis of variance using Time and Cue as within subject variables revealed more correct completions in the slow condition than in the fast condition F(1,31)=5.92, p<.05, and more incremental than standard completions F(1,31)=11.14, p<.01. There was a marginal interaction between Time and Cue F(1,31)=3.16, p<.08. Post hoc tests revealed a reliable difference in completion between incremental and standard conditions with fast cues t(31)=3.63, p<.01. The difference in the slow condition was marginal t(31)=1.89, p=.08. This was a trend seen in unstudied conditions in the review, and in the subject analysis of the previous experiment, where completion rates tended to be higher in incremental conditions but not reliably so. The extra second in the slow condition produces a reliable gain in performance for standard cues t(31)=-3.11, p<.01, but not for incremental cues. The results indicate a marginal cue appreciation effect in the slow condition, and a reliable effect in the fast condition caused by a larger drop in performance for standard than for incremental cues. This suggested that the critical factor in standard performance is time. The effect
of time on incremental performance was expected to interact with neighbourhood size. This is examined in the item analysis below.

<table>
<thead>
<tr>
<th></th>
<th>Inc</th>
<th>Stan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>48.6</td>
<td>40.6</td>
</tr>
<tr>
<td>Slow</td>
<td>51.3</td>
<td>47.7</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>44</td>
</tr>
</tbody>
</table>

Table 3.10: Percent Correct completions

Figure 3.6: Marginal Cue by Time Interaction

Item analysis

The N8 estimate of neighbourhood size was used again in this experiment to separate the words into high and low neighbourhood sets. An analysis of variance using N8 as an independent factor with Time (fast and slow) and Cue (incremental and standard) as within subject factors, was conducted on correct completions. There was no effect of N8, an effect of Time (more completions in slow than in fast $F(1,126)=12.48, p<.001$), and an effect of Cue (more completions in incremental than standard conditions $F(1,126)=15.65, p<.001$). The interaction between N8 and Time was not reliable ($F(1,126)=.24, p=.6$), although there was a trend to higher completions in high neighbourhood words for both fast and slow conditions. There was no interaction between N8 and Cue ($F(1,126)=.85, p=.3$) because incremental completions were higher than standard in both high and low neighbourhoods. A marginal interaction between Cue and Time ($F(1,126)=2.78, p=.09$, (see Figure 3.6) mirrored the subject analysis, where the incremental advantage was reliable in the fast but not the slow condition. Although the 3 way interaction ($F(1,126)=1.28, p<.26$),
was not reliable, the results of the previous experiment and the pattern of the interaction shown in Figure 3.6 prompted planned comparisons.

- The appreciation effect was reliable for both high (t(63)=2.68, p<.01), and low (t(63)=2.92, p<.01) neighbourhood words with fast cueing. This was due to a fall in standard completion rates in both sets.
- The appreciation effect was reliable in the high (t(63)=2.07, p<.05 but not the low neighbourhood set with slow cueing. This replicated the pattern in the previous experiment.
- There was no effect of neighbourhood on standard cues in the fast or slow conditions.
- There was no revision effect in the fast condition (t(126)=.44, p=.6). Incremental performance was equivalent in the high and low neighbourhood sets.
- The revision effect was marginal in the slow condition (t(126)=1.38, p=.16. The prediction of revision effect in the high neighbourhood set allows a one tailed value of .08). Completions were however still higher in the high neighbourhood set.

Although the revision effect was marginal, the pattern of results here repeats elements of the results in the previous experiment, including the absence of an appreciation effect in the low neighbourhood set, and its presence in the high set. Two results were replicated in this experiment. The absence of an effect of
neighbourhood on standard completions, and the trend to a revision effect based on higher incremental completions in the high neighbourhood set. The use of two completion times may have introduced an element of uncertainty about time, which may have resulted in premature cessation of revision processes. This might have had the effect of reducing the revision effect in the slow condition in this experiment. The appreciation effect is maintained by falls in standard completion, and uncertainty about time may have reduced slow / incremental completion rates. In this respect, time may have been better employed as an independent factor. Its use as a within subject factor had the advantage of controlling for subject variables such as strategy and individual differences. The general pattern of results pointing to a revision effect is also supported by its absence in the fast condition.

It was suggested in the previous experiment that incremental cues are completed in two phases, a retrieved completion phase and a revision phase. The drop in time was predicted to reduce standard fragment completions through shortening the time available for retrieved completion. The fall in standard completions in both high and low neighbourhood sets supports this. There was fall in incremental cue performance in the high neighbourhood set which was responsible for the abolished revision effect in the fast condition. This suggests that the revision process is also affected by time limitations. The results were taken to support both the appreciation effect and the revision effect and hence the revision process. The results also support the notion that both standard and incremental cue completion involve relatively time consuming processes. This suggests that standard cues may often be completed by sublexical completion and not primary process or lexical completion.

Error Analysis

Errors were categorised as in the previous experiment as list, variants, visual, and nonsense (see page 100). Examples of error types are provided in Table 3.11. Error counts are given in Table 3.12 (Each of 128 words appeared equally often in each of the four conditions and there were 32 subjects, so the maximum count in any of the four cells is 1024). The total number of errors is referred to as ‘misses’. The number of revisions was noted and ‘hits’ refers to correct completions. The total number of correct completions for the two levels of Time and Cue are plotted on
Figure 3.8. The drop in performance in the standard condition with fast presentation was due entirely to a failure to respond. Error levels for slow and fast standard conditions remained unchanged (67 and 73 respectively). There were 78 fewer attempts at completion in the fast standard condition, and 72 fewer hits. This effect did not interact with neighbourhood size, which might have been expected if revision was implicated, and hence suggests that it was due entirely to a failure to complete.

<table>
<thead>
<tr>
<th>Variants</th>
<th>Visual</th>
<th>Revisions</th>
<th>Nonsense</th>
</tr>
</thead>
<tbody>
<tr>
<td>logical--logician</td>
<td>tonight-twilight</td>
<td>Unmoved-unvoiced</td>
<td>quintile-quaintly</td>
</tr>
<tr>
<td>observe-observer</td>
<td>immersion-imprison</td>
<td>Workable-wreckage</td>
<td>amateus-amethyst</td>
</tr>
<tr>
<td>Observant-observer</td>
<td>yawning-yearning</td>
<td>Lateralise-localise</td>
<td>lomiere-loiterer</td>
</tr>
<tr>
<td>atomise-atomiser</td>
<td>oscillate-obstacle</td>
<td>barnowl-bungalow</td>
<td>dedjuised-dejected</td>
</tr>
<tr>
<td>logical--logician</td>
<td>orbitol-oratorio</td>
<td>justice-jaundice</td>
<td>quient-quotient</td>
</tr>
<tr>
<td>joyful--joyfully</td>
<td>cinquest-conquest</td>
<td>vicinity-volcanic</td>
<td>joureal-judicial</td>
</tr>
<tr>
<td>logical--logician</td>
<td>immersion-imprison</td>
<td>europa-euphoria</td>
<td>virding-yielding</td>
</tr>
<tr>
<td>inscribed--inscribe</td>
<td>unloved-unvoiced</td>
<td>nowadays-november</td>
<td>ladeback-lifeboat</td>
</tr>
<tr>
<td>deliver--delivery</td>
<td>ebenezer-embizzle</td>
<td>handover-hangover</td>
<td>unjuly-unjustly</td>
</tr>
</tbody>
</table>

Table 3.11: Examples of Error-Target pairs.

<table>
<thead>
<tr>
<th>Variants</th>
<th>Visual</th>
<th>Revisions</th>
<th>Nonsense</th>
</tr>
</thead>
<tbody>
<tr>
<td>INC STAN</td>
<td>INC STAN</td>
<td>INC STAN</td>
<td>INC STAN</td>
</tr>
<tr>
<td>Attempts</td>
<td>622</td>
<td>561</td>
<td>585</td>
</tr>
<tr>
<td>Hits</td>
<td>526</td>
<td>488</td>
<td>508</td>
</tr>
<tr>
<td>Revisions</td>
<td>17</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Misses</td>
<td>96</td>
<td>73</td>
<td>77</td>
</tr>
<tr>
<td>List</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Variants</td>
<td>33</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Visual</td>
<td>45</td>
<td>36</td>
<td>33</td>
</tr>
<tr>
<td>Nonsense</td>
<td>16</td>
<td>12</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 3.12: Completion and Error counts

* Variants = Inflections and derivations, INC = incremental, STAN = standard

This experiment replicates the absence of overt revisions in the standard condition in the previous experiment. It is possible that covert revisions are involved in standard fragment completion at these durations, but the strong relationship between neighbourhood size and revision would predict some indication of its influence on standard completion rates. None were found in either experiment.

The 50% drop in overt revisions seen in the fast incremental condition supports the conclusion that the abolition of the revision effect in this condition was related to revision opportunities. There were more attempts to complete in the incremental
conditions for both slow ($X^2=7.45$, df=1, p=.01) and fast ($X^2=20.36$, df=1, p<.001) presentation, and the probability of making an error, when initial responses in revisions were included, was higher for incremental cues ($X^2=4$, df=1, p<.05.) than for standard cues. Incremental cues were more likely to be attempted, to result in error, and to be revised.

Figure 3.8: Total completions by Time and Cue.

**Structural analysis**

Snodgrass and Mintzer (1993) provided evidence of both facilitatory and inhibitory effects of neighbourhood for 4-letter words with the fragmentation task. The definition of neighbourhood for 4-letter words is generally accepted. This experiment, and the previous one, used a broad conventional definition of neighbours (any word which shares 5, 6, or 7 letters with the target), and a rather more flexible estimate derived from an interactive activation model. These estimates seem to have replicated some of neighbourhood effects seen with four letter words in the fragmentation task. Ultimately however, a workable definition of ‘neighbours’ of eight letter words (long words generally) will have to come from an understanding of the structural similarity between functional distractors and the targets they inhibit. Although most of the errors involved in revisions bore a visual resemblance to the targets, length was quite often disregarded, and letter positions migrated. Uncertainty about letter positions may be responsible for the range of visual errors seen. For example the response ‘divorce’ to the cue [d _ _ _ _ iv _ _ _] suggests that relative letter positions are important when spaces in cues create uncertainty over letter positions.
A corpus of 403 errors made to unstudied incremental cues, and 271 errors made to unstudied standard cues were collected, pooled, and analysed. The analysis suggested factors that may be important in the definition of neighbourhood size for longer words. The nature of the errors also raised issues related to the processes involved in solving component-letter fragments. The differences between target and errors lengths were counted and are shown in Table 3.13 (Figure 3.9). In both standard and incremental conditions, although the highest number of errors were the same length, there were almost as many errors 1 letter shorter than the target length and substantial numbers of errors 1 letter longer. 62% of errors to incremental cues and 59% of errors to standard cues were non-target length errors. Of these, 76% of standard and 79% of incremental errors were shorter than the target word. The main trend was to produce shorter completions.

Conventional definitions of orthographic neighbourhood do not take account of this effect. Luce (1986), and Grainger and Segui (1990) have observed and commented on this effect, but to date its incorporation into definitions of neighbourhood has been restricted to the auditory domain (Luce 1986). This suggests that conventional definitions of neighbourhood underestimate the real effect of distractors in perceptual identification tasks and in peripheral dyslexic reading, at least with longer words. The method of defining neighbours using IA8 described in the
previous experiment may allow this factor to be considered, because the lexicon implemented in the model can be configured with a range of word lengths. The results above suggest that estimates of the functional distractors involved in identifying longer words from fragments should consider a range of word lengths rather than just target length candidates. One of the interesting points raised by this pattern is why the main trend should be towards producing shorter words. The discussion will pick up on this point and suggest that it may point to sublexical completion.

A second error analysis, took a closer look at the relationship between targets and errors, in terms of the number of matching letters by letter position, and the information content of fragments.

Figure 3.10A shows the percentage of positional letter matches between targets and errors by position. All errors were compared to their targets, and the letter matches by position accumulated. Nearly all errors matched their target in the first position, for both incremental and standard cues. The fragments always specified the first letter. This suggests that the use of first letter bins in the IA8 neighbour estimation method is appropriate, because words with a different first letter rarely appear as errors to fragments which specify the first letter. Percent match falls steadily as we move over the positions in the eight letter words. There was a distinct gradient of accuracy from left to right for both standard and incremental cues. Figure 3.10B shows the percentage of fragments at each level of an incremental cue (level 4 is identical to the standard cue) which provided information at the eight positions of the
eight letter word targets. So for instance, all fragments provided information at the first letter position and 30% of them provided information at the second position in the last fragment of incremental cues, and hence also in standard cues.

The graphs suggest that although errors ‘restore’ information at the beginnings of words, they largely fail to make use of information available at the ends of fragments. This is highlighted if we superimpose the information content of standard cues on the percent positional match of errors to standard cues (Figure 3.11).

The graph indicates that subjects often complete the first half of words accurately, but supply different endings. Remember that standard cues are single entities and so the information is simultaneously available at all letter positions. A plausible assumption when thinking about how the processes involved in completing a standard cue might differ from those involved in completing an incremental cue is that standard cues are more likely to be processed in parallel. They provide letter information over the length of the word, and provide 5 out of the 8 letters of the word. Standard cues may be more likely to be identified by a primary process or cohort completion. However, the pronounced left to right gradients seen in the graphs does not support this. Both standard and incremental cues seem to invoke completions that are disproportionately influenced by the first few letters of the fragment, and tend to lose information at the ends. This suggests that completions are retrieved on the basis of initial letters in fragments. The ready availability of letter information in component-letter fragments may encourage early retrieved completions with
incremental cues. Standard cues may provide too much information on which to base a retrieved completion, and so subjects may use only initial letters.

Discussion

Main findings

• The subject analysis revealed a marginal appreciation effect at 4 seconds and a reliable one at 3 seconds.
• There were no effects of neighbourhood size on standard cues.
• There was a marginal revision effect in the slow condition and no revision effect in the fast condition.
• The abolished revision effect in the fast condition was caused by a drop in incremental completions in the high neighbourhood set.
• There were appreciation effects in both fast and slow conditions in the high neighbourhood set.
• The appreciation effect was only reliable in the fast condition of the low neighbourhood set.
• The fall in standard completions in the fast conditions was due almost entirely to a failure to complete.
• The process of completing both standard and incremental cues results in more than 50% non target length errors suggesting that length information is lost in the process.
• Errors restore early position information, and fail to make use of late position information, consistent with sublexical completion based on the left-most letters in fragments.

Discussion

The subject analysis was again straightforward, with the usual marginal appreciation effect in the slow condition which as we saw in the previous experiment masks a reliable one restricted to high neighbourhood sets. The reliable appreciation effect in the fast condition was expected on the grounds that standard cues invoke secondary processes that would be sensitive to time.

The abolished revision effect in the fast incremental condition supported the conclusion of the previous experiment. It was argued there that because there was no
effect of neighbourhood on unstudied standard completions (which is repeated here in the slow condition), neighbourhood size alone could not account for the revision effect in the unstudied set. The effect could not be ascribed to incrementing alone because incremental cue performance was no higher than standard cue performance in the low neighbourhood set. If the effect was based on non-revised completions then there would be no appreciation effect in the high neighbourhood set. This seemed to be good evidence that the revision effect was largely mediated by the revision process and hence the name. The same arguments apply in this experiment and are supported by the abolished effect in the fast condition. The suggestion is that incremental cues are completed in two phases. The first phase retrieves a completion based on some letters in the fragment. This is then revised in the second phase, and the advantage of high neighbourhoods is that alternatives are readily available. Fewer alternatives in the low neighbourhood set removes the advantage of incremental cues because revision is less successful, and hence because both standard and incremental cues use the retrieval phase, they have equivalent levels of performance. Because standard cues only use the retrieval phase, they have no advantage in the high neighbourhood set. The effect of fast cueing is to remove the advantage of high neighbourhood by curtailing the revision phase.

The absence of an effect of neighbourhood on standard cueing was noted in both experiments. If standard cues were identified by lexical completion some effect of lexical competitive processes related to neighbours might be expected. Snodgrass and Mintzer (1993) reported inhibitory effect of neighbours for standard and incremental cues but only for low frequency words. It was suggested that holistic fragments may pose letter identification problems which may emphasise perceptual processing in their completion. Component-letter task fragments provide the letters and hence may not be as tied to primary process. It is possible that such an effect is masked here by frequency. This would require a more motivated orthogonal set of words to establish. However, results suggest that standard cues are on the whole not completed by primary process. When the advantage of revision is removed by fast cueing, incremental and standard performance was equivalent. The drop in time with fast cueing resulted in a large fall in standard completions, almost entirely due to a failure
to complete. This suggested that the process of completion was interrupted at 3 seconds, and this is probably too long to be mediated by even slow primary process.

The large range of error lengths produced by both incremental and standard cues suggested that the process involved in producing the initial completion discards target length information. That is, parallel access by the entire standard cue might be expected to maintain a more accurate specification of the length of cohort candidates. This suggested that standard completions are retrieved on the basis of a few letters and relative letter position information. The analysis of structural similarity between errors and targets identified a gradient of error from left to right. Information available at the ends of fragments was relatively less effective in specifying completion than the information at the beginning. The same pattern was evident for both incremental and standard cues, although all the letter information is simultaneously available in standard cues. These observations suggested that initial completions to both standard and incremental cues are retrieved completions based on the initial letters and letters towards the beginning of the fragment. With slow presentation, incremental cues are revised, particularly in high neighbourhoods, but standard cues are not. With fast presentation, the revision phase is affected in incremental conditions, and the retrieval phase is affected in standard conditions.

The fast condition still produces 35% completion rates in low neighbourhood sets. The view of secondary processing proposed is not that cues determine a single mode of completion, but that there is a hierarchy of processes through which attempts descend. Some standard cues may be distinctive enough or frequent enough to reach criterion in primary process. This may be possible with distinctive 2 letter cues to eight letter words such as [O _ _ _ _ _ _ X], and probable with five letter cues such as [SM _ _ _ _ LP _ _ X]. Failing primary identification, lexical completions may succeed, and failing those, a retrieved completion may be the next option. High neighbourhoods may facilitate fast revision, but with time, the assembly process may be needed to fix letter positions and compare completions to the stimulus. This hierarchy of processes is formalised into a flow model of word recognition processes in the general discussion. Overall, the results support the involvement of retrieved completion and revision in word identification with the component-letter task.
Conclusion Experiment 2: Cue Appreciation and Revision

The results of the first experiment were replicated without the influence of an episodic set. The Appreciation effect was found in both neighbourhood sets with fast cues, and was related to failure to complete in the standard condition. This and the absence of an effect of neighbourhood size on standard cues at both speeds suggested that they are not revised, and that the facilitatory effect of neighbours is mediated by the revision process. The restriction of the appreciation effect to the slow / high neighbourhood set replicated previous results. The Revision effect was absent in the fast condition and marginal in the slow condition, but substantially supported by convergent results. Uncertainty over time for revisions was thought to account for this. The results confirmed the effects in the previous experiment and lent credence to the view of retrieved and revised completions as the mechanisms of the effects. The error analysis provided direct evidence of the involvement of revisions, and the effects of time restrictions on the error patterns. Structural analysis of the errors revealed several aspects of performance. Information at the beginnings of fragments is disproportionately influential on completions at the expense of end information, and length information is discarded. These factors suggest that the functional distractors in fragment completion are not captured by conventional definitions of neighbourhood. With a better understanding of the repertoire of secondary processes available to the normal reader, similarity may have to be defined with respect to the process engaged.
3.4 General discussion and the PSP model

Summary of Experiments 1 and two (this chapter).

Table 3.14 provides a brief summary of the results of both experiments. (N refers to neighbourhood size).

<table>
<thead>
<tr>
<th>Experiment 1 Cue Depreciation</th>
<th>Experiment 2 Cue Appreciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject analysis: Marginal effect of cue in studied words. More errors in incremental condition</td>
<td>Subject analysis: A marginal appreciation effect at 3s and a reliable one at 4s</td>
</tr>
<tr>
<td>Item analysis</td>
<td>Item analysis</td>
</tr>
<tr>
<td>Cue depreciation effect in studied high N set</td>
<td>Revision effect: marginal in slow condition</td>
</tr>
<tr>
<td>Unstudied only hereafter</td>
<td>Abolished in the fast condition by a fall in incremental completions in high N set</td>
</tr>
<tr>
<td>Revision effect: higher incremental completions in high neighbourhoods</td>
<td>Appreciation effect: Found in both fast and slow conditions in the high N set</td>
</tr>
<tr>
<td>Appreciation effect: incremental completions higher than standard in high neighbourhoods</td>
<td>Found only in fast condition of low N set</td>
</tr>
<tr>
<td>No effect of neighbourhood size on standard cues</td>
<td>No effect of neighbourhood size on standard cues</td>
</tr>
<tr>
<td>Revisions only in incremental conditions, equal for high and low N</td>
<td>Fall in standard / fast completions due to failure to complete</td>
</tr>
<tr>
<td>Overt revisions do not explain Revision effect so must be covert revisions</td>
<td>Errors 50% non target length suggesting length information discarded</td>
</tr>
<tr>
<td>Appreciation effect related to overt and covert completion.</td>
<td>Early position restoration effect, failure to use end information: sublexical completion suggested</td>
</tr>
</tbody>
</table>

Table 3.14. Summary of Experimental degradation experimental results

The PSP model

Some of the secondary processes proposed in the introduction have been the focus of reviews and experiments in the last two chapters. They are collected together into a flow model in Figure 3.12. The model will be referred to as the Primary-Secondary Process model of word recognition, or PSP for convenience. Secondary processes are in shaded boxes. The stimulus enters the flow of processing at top left and is either an intact word or a fragment. The discussion is focused on unstudied fragment completion because the main interest of the thesis is in word identification and not memory.

The review of the fragmentation task reported results relevant to the proposed scanned completion process, and the experiments with the component-letter task
reported results relevant to the retrieved completion and revision process. The model proposes 5 secondary process routes to visual word identification (Table 3.15).

<table>
<thead>
<tr>
<th>Primary processes</th>
<th>Word level Representation</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact word</td>
<td>Parallel lexical access</td>
<td></td>
</tr>
<tr>
<td>Stimulus</td>
<td>Noisy Parallel Access</td>
<td></td>
</tr>
<tr>
<td>FRAGMENT</td>
<td>Lexical Facilitation</td>
<td></td>
</tr>
<tr>
<td>Secondary processes</td>
<td>Retrieved Completion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assembled Completion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Imagery Working Memory</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.12: The Primary-Secondary Process model of word recognition.

Routes 1 and 2 are specified by canonical primary process. Correct identification of degraded stimuli within limits is possible in interactive activation and matrix memory models. This is route 2, lexical facilitation.

Route 3 is cohort completion. This is a hypothetical process but I will argue that it is logically necessary.

Route 4 is the scanned completion or rapid refixation process suggested by Behrmann et al. (1998). It may be simulated by the fast continuous run procedure in the fragmentation task and explained in terms of CAM.

Route 5 is retrieved completion. The experiments in this chapter supported the retrieved completion process. Retrieval from the spelling system suggested as a possible mechanism of standard completions and initial completions to incremental cues.

Route 6 is retrieved completion and revision. Support for the revision process was found in both the revision and appreciation effects.

Route 7 is the assembly process suggested by several researchers as an explanation for letter-by-letter reading, and is likely to participate in revision.

Table: 3.15 Routes in PSP.

The model is a functional model and takes a systems level view of secondary processes (Reichle et al. 2000). The routes are viewed as optional components of identification strategies adopted to experimental and neuropsychological degradation. Lexical completions are closely tied to the orthographic input lexicon. The secondary processes are however dependent to various extents on the components of the linguistic processing system. They are overlearned orchestrations of sub-processes involving multiple components. They are however relatively constant and universal aspects of human meta-linguistic performance and hence require documentation.
Cohort completion

This process is hypothetical. The neuropsychological section of the thesis will present some evidence related to its inclusion as a secondary process. Warrington (1991) describes a patient RYT who was diagnosed as a right neglect patient with attentional dyslexia. This means that he fails to attend to letters at the ends of words. His attentional dyslexia means that he has difficulty identify single letters in strings of letters. Presented with a four-letter word at fixation, his condition means that primary processing is likely to be based on the first two letters of the word. It also means that serial scanning or rapid refixation may not process letters in his neglected field. If he is neglecting these letters, then presumably he is unaware of them, and would have no reason to look for them. He can read words presented for 150msec. Warrington’s conclusion was that RYT does not use serial letter processing in reading. His condition is one in which an abnormal distribution of attention results in the activation of an inappropriate word form. In other words, he does not retrieve words, he reads words by parallel access. It may not be possible, with 8-letter words for instance, for primary process to support identification on 50% of the stimulus. The cohort completion process may be necessary to explain identification in situations in which the other secondary processes cannot participate in identification. Given that serial processing is unlikely, if RYT were to show inhibitory effects of neighbourhood size on low frequency words, we might conclude that he is using lexical completion but that this was supported by parallel processing. This would provide support for the cohort completion process.

Scanned completion

Like cohort completion, no real evidence for the scanned completion process has been presented. Behrmann et al. (1998) suggested it as a possible mechanism for boosting word level activation, and noted some evidence for a normal refixation process used in difficult text. An analogy between the fast continuous run procedure in the fragmentation task, progressive demasking, and scanned completion, was made earlier. This was based on the idea that both scanned completion and fast incrementing (1s per fragment), supply the lexicon with progressively larger amounts of piecemeal information constraining target identity. Frameworks such as the IAM
suggest that this may be inhibitory for low frequency words with many neighbours, and indeed, Snodgrass and Hirshman (1991) and Luo and Snodgrass (1994) provide evidence for 'perceptual interference' supporting this idea. In the neuropsychological literature, Arguin et al. (1998) also suggest that such a process should be fundamentally inhibitory. This process implies intact attentional and eye movement processes, and the ability to re-scale attention to the letter level. The process feeds directly into the lexicon because it does not identify letters, but enhances letter level activation through focussing attention sequentially over letters, presumably from left to right when reading English words. The Neuropsychological section of the thesis will look for evidence of this process. Scanned completion may be distinguished from primary process and cohort completion by the detection of serial effects in word identification.

**Retrieved completion**

Retrieved completion is the identification of words from explicitly identified letters. Completion may be based on only a few letters of the word. The spelling system may be implicated in this process, but the debate on reading / spelling theories of oral spelling recognition suggested several alternative mechanisms. Several results combined to suggest that processes other than primary process were involved in completion of unstudied component-letter fragments.

- Completion rates for unstudied standard cues were generally at about 50%. Standard cues provide the best opportunity for lexical completion. If standard cues were completed by lexical completion, they would be expected to show inhibitory effects of neighbourhood size.

- Standard fragments were subject to a 15% drop in completion rate with a 1-second drop in time in the fast condition. Primary process would not be expected to be sensitive to time reduction from 4 to 3 seconds. The process of activating and selecting a candidate response would be expected to take less than a second in normal primary process.

- Initial completions in revisions were made between the first and second fragment of incremental cues. Both the revision and appreciation effects were explained by revision which assumes a relatively large number of 'early' completions based on
2-3 letters of an 8-letter words. Fragments of this size may not support primary process identification.

- The majority of errors made in the second experiment were longer or shorter than the target length. This suggested that the process involved in producing the errors discards word length information.

- The error gradient for standard cues provided evidence that information at initial positions of fragments was disproportionately influential in determining errors. This supported the notion that completions were retrieved on less than the entire fragment.

The secondary process of retrieved completion is likely to be engaged when lexical completion fails. The PSP model diagram is meant to convey the idea of a hierarchy of options starting with primary process and ending with assembly. It is acknowledged that fragments may be solved successfully by higher levels in this hierarchy, even with early incremental fragments. The suggestion is that standard fragments are predominantly, and not, inevitably completed by retrieved completion. The systems view of secondary processes (Reichle et al. 2000) would envisage flexible coalitions of component processes adjusting to the difficulty of the fragment at hand. Slowed primary processing may take up to a second, but with no evident candidate at this point, subjects are thought to use letter identities to retrieve a completion from the spelling system.

The retrieved completion process makes several predictions in neuropsychology. For instance, the loss of the spelling system would predict abolished revision and appreciation effects. Note that because it relies on letter identities, compromised letter identification would also predict abolished revision and appreciation effects. The process is thus associated with serial processing insofar as it relies on explicit letter identification.

**Revision**

Both experiments in this chapter were interpreted as providing evidence of a spontaneous revision process that mediates both the revision and appreciation effects. Standard cues evoke retrieved completions based on a few letters in the fragment. Early incremental fragments evoke similar completions based on the available letters.
Overt revisions were seen in both experiments, but it was argued that the results support the involvement of covert revision in both the revision and appreciation effects.

- Standard completion rates were equivalent in low and high neighbourhoods hence the availability of alternatives per se did not improve performance.
- Incremental completion rates in low neighbourhoods were equivalent to standard completion rates in high neighbourhoods, hence the opportunity to revise per se did not improve performance.
- Incremental performance was equivalent to standard performance in the low neighbourhood set hence the availability of alternatives is required for an appreciation effect.
- Incremental performance was equivalent in the low neighbourhood set for slow and fast presentation, hence when no alternatives were available (low neighbourhood), the opportunity to revise has no impact on performance.
- Fast presentation abolished the revision effect, hence when alternatives are available removing the opportunity to revise abolished the effect.
- Standard cue completion is reduced by a 1-second reduction in time, in both the high and low neighbourhood set. The reduction was due entirely to a failure to respond, suggesting that the fast condition affected a completion phase. This phase is not affected by neighbourhood size.

The suggestion is that retrieved completions are often wrong for both incremental and standard fragments. Subjects may be aware of this and revise completions spontaneously. With standard fragments, there is only enough time to make the initial completion. With incremental fragments, the revision process is possible but its ability to produce a better completion depends on the availability of alternatives. These alternatives may serve two functions. They may be instrumental in initiating checks because they imply the possibility that the initial completion may be wrong, and they provide the alternative. Low neighbourhood words may not be checked because they ‘feel’ right in the absence of alternatives, but also because even if they feel wrong, it may be more difficult to decide why in the absence of alternatives. Both retrieved completion and revision are sensitive to time. The combined results were taken to suggest that both the revision and appreciation effects were almost entirely
mediated by revision. The importance of this is not in the assertion of a process that all crossword puzzle enthusiasts are well aware of, but in the suggestion that the component-letter task may provide a means of studying the process in detail. The evidence is taken to support Revision as one of the most important secondary processes in normal word identification from degraded stimuli. The complexity of the process also suggests that it may be one of the first processes to be lost with neurological injury. Perhaps because it is likely to involve multiple processes, the loss of any one of which could compromise its function.

The processes mediating revision are likely to include working memory and the spelling system. The central executive function in working memory (Baddeley 1992) may orchestrate the complex set of processes involved in revision. The implication would be that abolished revision and appreciation effects might be diagnostic of impairments to this system. It also suggests that the effects may be particularly sensitive to interference from simultaneous central executive mediated activity. The processes involved in revision are likely to be the same as those involved in the final process, assembly. The distinction is that in revision these processes are employed to correct an existing completion. Assembly is used to describe situations in which the subject is thought to construct a completion by a deliberate process of identifying all the available information.

**Assembly**

The difficulty in specifying the assembly process was aired in the discussion of the reading-spelling debate on recognising orally spelled words. It was hoped that the neuropsychological section of the thesis would provide more data on assembly, but as will become evident events took a different turn.

The main contribution of the experiments in this chapter to the PSP model has been to look at tasks that might be useful in specifying the largely hypothetical processes proposed in the introduction. By obscuring letter identities, the fragmentation task may be particularly useful in researching the serial scanning and sequential refixation processes. The component-letter task on the other hand seems to engage the slower and more complex processes of retrieved completion and revision. Other tasks such as rapid serial visual presentation of single letters might be targeted
at uncovering the implications of specific processes. The review of fragment completion and the fragmentation task suggested a general principle, which is that lexical completion may be subject to inhibitory effects of neighbourhood size on low frequency words. The Snodgrass and Mintzer (1993) results and the results of the experiments reported in this chapter suggests that sublexical completion is not affected by neighbourhood size, and if the revision process is allowed to operate, neighbourhood size may be facilitatory. The experimental degradation section of the thesis has gone some way to clarifying and defining some of the secondary processes in PSP. Two areas of research in which secondary processes play an important role are discussed briefly before moving on to neuropsychological degradation. A final section makes some observations about the component letter task.

**PSP and Secondary process deficit**

The secondary processes proposed above have been discussed in relation to normal subjects and degraded stimuli. Secondary processes may compensate for normal variations in the quality of visual input. The rest of the thesis explores their role in peripheral dyslexia. Much of the thesis is thus focussed on the compensatory role of secondary processes when primary lexical access fails. This may be due to natural, experimental, or neuropsychological degradation. However, it is also important to note that secondary processes may be compromised by the same brain injury that compromises primary access, or may be independently compromised. Most letter-by-letter readers are right homonymous hemianopics (RHH). RHH’s are effectively blind to varying degrees in the right visual field, sometimes extending into the fovea. Reported cases of letter-by-letter reading without RHH (Greenblatt, 1976; Vincent, Sadowsky, Saunders & Reeves 1977) and numerous cases of RHH without letter-by-letter reading (Zihl, 1995; Leff, Scott, Crewes, Hodgson, Cowey, Howard, & Wise, 2000), means that the two conditions are not necessarily related. It is possible however that, in some cases, RHH might prevent effective letter-by-letter reading as a compensatory strategy to primary process impairment.

RHH is characterised by prolonged fixation times,
- Reduced amplitudes of saccades to the right
- Increased frequency of regressive saccades
- Reduced spatial reading span (the area from which information is acquired during fixations)
- Increased temporal duration of fixations
- Haphazard scanning of the impaired visual field. (Zihl, 1995).

These effects are likely to impact secondary processes. Zihl points out that very little attention has been devoted to reading impairments caused by visual deficits, and yet the most common cause of impaired reading is parafoveal visual field loss (Zihl 1989). Hemianopic dyslexia (Wilbrand, 1907) is not included in the current category of peripheral dyslexias, and is taken here to mean reading difficulties caused primarily by parafoveal visual field loss. Zihl also suggests a broader conception of word recognition as a process involving the serial interplay of sensory-perceptual and cognitive processes. This broader view of word recognition is similar to the one Jacobs and Grainger (1994) invite us to adopt, and argues for more research into secondary processes. Hemianopic dyslexics may lose or use many of the same secondary processes as patients with higher level perceptual deficits, and as such, may be just as informative about these processes.

Leff, et al. (2000) refer to this condition as hemianopic alexia. Their PET study delimited areas in left V1 and V2 concerned with right parafoveal vision which showed elevated activity related to reading text but not to the rate of word reading. This was located in the calcarine sulcus, spreading into the calcarine cortex. In conjunction with posterior parietal cortex (PPC) and right frontal eye fields (FEF), this area seemed to be involved in planning and executing accurate fixations to the right, which are essential for reading text. The V1 areas representing foveal vision were sensitive to the rate of word reading. They conclude that two areas in close proximity in V1 and V2 subserve two functions. The first is visual word recognition involving foveal V1 and left ventral prestriate cortex. The second is focused visual attention and the preparation and generation of eye movements in text reading, involving the left V1/V2 cortex representation of right parafoveal vision. Pure alexia is a perceptual deficit related to disconnection between the first area and the word form system, and hemianopic alexia is related to disconnection between the second area and the motor systems that plan and execute reading saccades.
Complete RHH resulting from destruction of left primary visual cortex and its afferents, disrupts rightward saccades during text reading. This is because it destroys the attention window, much of which is devoted to right parafoveal vision. Both ‘Pure’ and ‘Hemianopic’ alexia thus have an intimate connection to left prestriate visual cortex. This is recognised by the authors

“A right homonymous hemianopia that involves the central few degrees of vision abolishes the spatial attention window. The result is ‘hemianopic’ alexia, with slow text reading. However, lesion studies have demonstrated that single, whole word recognition is a function of left ventral prestriate cortex, and destruction or disconnection of this region results in slowed, error-prone, or absent single-word reading (“pure” alexia). It is our clinical experience that most patients with left occipital infarction and a right homonymous hemianopia are slow at both single-word and text reading, as vascular lesions do not respect functional boundaries” (ibid. pp. 177).

This raises the possibility that a left prestriate lesion could simultaneously affect both functions. By depriving both the word form system and the saccade generation system of visual information, a left prestriate lesion could result in both a difficulty in reading single words, and an inability to execute accurate saccades into the right visual field. Paradoxically, this might be described as a (loosely defined) pure alexic patient who could not read letter-by-letter because this reading strategy involves accurate, sequential, fixation on a series of letters extending into the right visual field.

Foveal V1 and left ventral prestriate cortex are part of the primary lexical access process. Parafoveal vision may also subserve lexical access when reading longer single words. The reading saccade generating and executing system might be considered a secondary process with respect to lexical access as it is now defined by Paap and Johansen (1994). Failure of this process might thus be considered a secondary process deficit. Both processes rely to some extent on the same right parafoveal information. Lexical access with short words may be subserved by foveal vision, but this assumes accurate fixation in the middle of the word. In a broader view of word recognition, one in which secondary processes are seen as inextricably integrated with primary process to deliver ‘reading’, secondary process deficits are as important as primary process impairment. They both prevent fluent reading, and they both provide data on the ‘normal’ word recognition system.
It was suggested earlier that Laxon, Coltheart and Keating’s (1988) report of larger facilitatory effects of neighbourhood size with a self-paced reading task in poor readers, might be understood in terms of secondary processes. Poor development of primary process may increase the probability of secondary process involvement in reading. The fact of a facilitatory effect in good readers is consistent with Andrews (1997) but the larger effect in poor readers may be explained by the revision effect. Explanations based on strategies tend to be vague however, unless those strategies can be decomposed into tangible processes.

Ziegler et al.’s (1998) investigated word identification with the fragmentation task and the self-paced procedure. The method of screen fragmentation used was identical to the method used by Snodgrass and Mintzer (1993). Subjects pressed a key to move through levels 1 to 8 of an incremental cue at their own pace. They could respond at any point but once a response was made they could see no further fragments in that cue and moved on to the trial. Note that this procedure allows flexibility in completion strategy and allows spontaneous revision before a committed response. They found that subjects adopted quite different strategies to the task. These are listed below with an interpretation in terms of PSP. Speed in this context refers to how early in the incremental cue a committed response is made.

- **Conservative strategy** (trading speed for accuracy) responded late and made few errors.

Subjects may have been both completing and quite carefully revising their completions, using all the processes at their disposal. This would have the effect of removing possible distractors on the way up to larger fragments. The effect of a forced completion procedure may be to impose this sort of strategy but motivation may have the same effect. These subjects should show a revision effect.

- **Guessing strategy** (trades accuracy for speed) responded early and made many errors.

These subjects might be thought of as using retrieved completion based on a few identified letters and forgoing the revision process. If so they should not show the
revision effect. If their responses are based on lexical completions then they should show an effect of neighbourhood size.

- **Balanced strategy**, subjects who were midway between the conservative and guessing extremes.

A moderate level of both completion and revision may have produced this profile. Manipulations of motivation may alter the balance of processes employed and shift this strategy in either a guessing or a conservative direction.

- **Impatient strategy**, Some subjects responded late and made many errors. This strategy of moving on rapidly to larger fragments without attempting to solve them, and responding to mid range fragments by guessing, was supported by the fact that these subjects seldom responded before the fifth cue in the series. Moving quickly to larger fragments suggests a strategy of cohort completion and no revision. The rapid transition through earlier fragments would not be expected to entertain or remove any distractors, and hence the high error rate. These subjects might be expected to show inhibitory effects of neighbourhood partly because of the self-imposed fast continuous run procedure, but also perhaps because of cohort completion.

It may be helpful to think about individual differences in reading in terms of strategies, if those strategies are quite clearly specified in terms of secondary processes. A further point raised by the component-letter task review was situations in which the use of secondary processes result in inhibited performance on incremental cues. The Bruner-Potter (1964) effect suggested that persistent guesses with pictures might prevent the efficient use of further information in cues. Peynircioglu (1990b) told subjects in one condition they were in an IQ test and in another condition that they were ‘practising’. High IQ associated with early completion would induce subjects to complete early. These results are interpreted with caution because neighbourhood size was not considered. Incremental performance was inhibited in the IQ condition but not the practice condition. Anxiety and motivation associated with the instructions may have altered the balance of processes used in the task. IQ instructions may have encouraged early completions, and perhaps a less balanced distribution of attention between the incoming evidence and retrieval based revision.
Thus, the effects of instruction may also be understood in terms of the secondary processes it encourages or discourages.

**Assessment of the component letter paradigm.**

There are several improvements, which might be made to this paradigm for further research. The experiments in this chapter were aimed both at exploring the component letter task and neighbourhoods, but also at addressing the existing literature on the cue depreciation effect with the component letter task. This is based on the set of words used and written responses. The word set and procedure are not however ideal and may be improved.

**The words**

Neighbourhood size, neighbourhood frequency and frequency should be varied orthogonally. Factors such as imageability regularity and consistency might also be explored. Several classes of words such as suffixed words should be avoided.

**The Fragments**

The specification of two letters, which uniquely identify eight letter words, defines the first fragment in the series. The process of adding letters at randomly selected positions thereafter to create larger fragments can result in some easy fragments. A different sequence of additions however can result in a much more difficult fragment. Snodgrass and Mintzer (1993) encountered this effect when they found that even with the screen fragmentation technique, the vagaries of random pixel deletion meant that fragments varied in their ease completion. They adopted an online fragmentation procedure that produced a different fragment for the same word on each appearance. This should be incorporated into the component-letter task. The possible fragments might be normed for difficulty, or all possible configurations could be used either randomly or counter balanced across subjects.

**The Procedure**

The time constraint on standard completions is exacerbated by written responses. Latency data might also furnish more insight into the processes involved in
completion. The use of voice triggered response timing and recorded responses would allow subjects to produce completions on the fly. Computer controlled recording would allow all responses and revisions to be timed accurately. The next experiments in this series will incorporate these improvements.

Conclusion Chapter 3 The Component letter task

The component letter task results mainly addressed the retrieved completion and revision processes. The Appreciation and Revision effects were related to the process of revision. These effects replicated and extended the Snodgrass and Mintzer (1993) results both into a new task domain and by distinguishing facilitation related to neighbourhood size (the revision effect) and facilitation related to cueing method (the appreciation effect). Note that revision may be applied to any completion and so the results of the second experiment were particularly directed at establishing the involvement of a sublexical process, retrieved completion, in the provenance of early completions. The empirical basis for these processes and effects will need to be expanded, but the current results support their role in fragment completion.

The review of experimental degradation produced some results implicating the scanned completion process, and the inhibitory effects of incrementing within primary process, and by analogy, the implications of this for some of the proposed mechanisms of letter-by-letter reading. Cohort and assembled completions have yet to be fleshed out at this stage of the thesis, but they were both plausible candidates for inclusion in the PSP model outlined in the discussion. The retrieved completion and revision processes thus received the most attention at this stage, but brief further discussions of the other processes helped consolidate the model as a coherent structure. The main function of the model is to serve as a thinking framework on which to hang results as they become available through experimentation and testing, but also through existing data which may be highly relevant but has yet to be gathered.

The functional nature of the model is thought to be appropriate to the systems level view of secondary processes. Recognition of a word from letter names, or ‘Revision’, are system functions which may be achieved by various combinations of component processes and routes.
Chapter 4: Neuropsychological Degradation

"Why sit on a one-legged stool when one can use a three-legged one?" (Kosslyn & Intriligator, 1992, pp. 104)

4.1 Introduction

Acquired Dyslexia

Understanding the reading difficulties of acquired dyslexia requires a broader view of word recognition. Acquired dyslexics (previously literate people who developed reading difficulties as a result of brain damage, often caused by stroke) are usually distinguished as peripheral dyslexics if they show signs of impairment at early pre-lexical stages of the word recognition process. Central dyslexics show signs of impaired semantic or phonological processing. This review focuses on peripheral dyslexia and letter-by-letter reading.

Peripheral Dyslexia

There are four widely recognised peripheral dyslexic conditions.

- Visual dyslexia is perhaps the least researched category of peripheral dyslexia. Marshall and Newcombe classed visual dyslexics as patients who tend to misidentify words as visually similar words (e.g. lend-land, easel-aerial, arrangement-argument) (Marshall and Newcombe, 1973; Newcombe & Marshall, 1981). These errors are common with degraded stimuli and normal subjects (see Experiment 2. Page 121). In visual dyslexia, they may be related to impaired visual analysis or word level processing deficits. A recent case of visual dyslexia, AB, highlights the difficulty in categorising these deficits (Lambon-Ralph & Ellis, 1997). The authors rule out attentional dyslexia, but are undecided on neglect or letter-by-letter reading as AB’s diagnosis.

- Attentional dyslexia is associated with difficulty in identifying letters embedded in letter strings or single words in text, though single word reading and single letter
identification are generally intact (Shallice & Warrington 1977). Asked to name the central letter in WRBEX, an attentional dyslexic is likely to name ‘R’ or ‘E’. A further feature of the condition is letter migration. Asked to read the words HIT and PAT an attentional dyslexic might respond ‘hat and pit’. Interestingly this is a characteristic of normal performance under brief presentation (Allport, 1977; Shallice & McGill 1978; Mozer 1983).

- **Neglect** patients tend to neglect one side of space. This is common after posterior injury to the right hemisphere leading to neglect of the left visual field, but right neglect has also been documented (Warrington & Zangwill, 1957; Warrington 1991). A common illustration of the condition is drawings of clocks that omit the numerals 7 to 11 (Ellis, Flude & Young, 1987). This attentional problem extends to reading, and in some cases may only be evident in reading (Warrington 1991). Mozer and Behrmann (1990) provide an account of neglect based on impaired attentional processing and Caramazza and Hillis, (1990) propose an explanation based on impaired representations. The hallmark of neglect dyslexia is errors that preserve the ends of words, for instance reading milk as chalk.

- **Letter-by-letter** readers labour over relatively short words, and often name the letters of words. They seem unable to access the pronunciation or meaning of words without identifying individual letters. This means that in some cases they take many seconds to read a single short word, and they generally take longer to read longer words (Warrington & Shallice, 1980; Patterson & Kay, 1982). Pure alexia is associated with letter-by-letter reading in the absence of other reading, writing or spelling deficits. Cases of surface dyslexia (Patterson & Kay 1992), surface dysgraphia (Behrmann & McLeod 1995), deep dyslexia (Buxbaum & Coslett 1996), and phonological dyslexia (Friedman et al 1998) have been reported associated with letter-by-letter reading. Early views on the condition proposed quite different functional deficits. Recent work has tended to place the impairment at early perceptual levels and suggests that, in most cases, the fundamental deficit is one of failing to activate essentially intact lexical orthography (Behrmann et al. 1998).
Zihl’s (1995) and Leff et al’s (1999) observations support hemianopic alexia / dyslexia as an additional category of peripheral dyslexia. Although perhaps blurring the distinction between perceptual and visual processing, it has the merit of focussing interest on the involvement of secondary processes in reading impairment.

**Theories of letter-by-letter reading**

Letter-by-letter reading was first brought to light by Dejerine (1891). His explanation was that the visual word form system had become ‘disconnected’ from the verbal and semantic systems by injury to structures connecting them. This explanation was accepted by the neurological community, and letter-by-letter reading settled into the category of disconnection syndromes until cognitive neuropsychologists began to take an interest in the condition in the 1980s. The initial neuropsychological investigations produced two different positions. One largely agreed with Dejerine’s assessment and went on to elaborate several proposed loci of disconnection, and the role of the right hemisphere in circumventing the problem of disconnection between orthographic, phonological, and semantic systems (Coltheart, 1983). The second major view was that the visual word form system itself was impaired (Warrington & Shallice 1980). Recent work has continued to elaborate these positions.

However, developing awareness of early perceptual processing deficits among letter-by-letter readers has added a third major position. This holds that input to the letter and word level representations from early perceptual processes is degraded, preventing normal activation of lexical orthographic representations (Sekuler & Behrmann 1996; Farah & Wallace 1991). Behrmann et al. 1998 locate the associated lesion in the posterior portion of the dominant hemisphere, sometimes accompanied by a lesion of white matter tracts such as the splenium of the corpus callosum or forceps major. A further development, with the increasing number of published studies, has been an awareness of the variability in performance of letter-by-letter readers. This variability extends to large differences in reading speed and the ability to read single words at fast presentation rates. Furthermore, some but not all patients show a word superiority effect when naming letters in strings, and the presence of deficits with non-alphanumeric material (Price & Humphreys 1992).
Behrmann et al. (1998) suggest that letter-by-letter reading researchers currently fall into two main groups, Peripheral theorists and Central theorists. The terms peripheral and central are used here not as categories of acquired dyslexia, but as theoretical positions in a debate over the functional deficit in letter-by-letter reading.

Peripheral theorists emphasise results indicating that letter-by-letter readers fail to activate orthographic representations adequately, such as better reading of print than script and the frequency of visual errors. Several different peripheral explanations have been offered, including

- A perceptual impairment affecting all forms of visual processing. Letter and word processing may be particularly vulnerable (Sekuler & Behrmann 1996; Farah & Wallace 1991).
- An impairment specific to orthography, letter identification, or rapid processing of multiple forms in parallel (Kinsbourne & Warrington 1962; Patterson & Kay 1982).
- An attentional deficit, which forces a serial, left right strategy, or problems switching attention (Rapp & Caramazza 1991; Price & Humphreys 1992).
- An impairment of letter processing resulting in very slow activation of the representation of even single letters, and impaired representation of serial order (Behrmann & Shallice 1995).

All these views suggest a problem activating an adequate orthographic representation of the stimulus. They are however not all mutually exclusive. Some of these theories extend the deficit into object recognition, and suggest impaired attentional mechanisms as a cause, but they all place the impairment at the early stages of processing before orthographic lexical access.

Central theorists point out that even though under certain circumstances letter-by-letter readers cannot explicitly identify a stimulus, some choose the correct semantic category of the stimulus at rates substantially above chance indicating semantic processing of the stimulus. Some have reasonable hit rates at lexical decision, indicating intact lexical level processing, or, are able to match spoken words to written words they can’t read. (Albert, Yamadori, Gardner & Howes 1973; Caplan & Hedley-Whyte 1974; Kreindler & Ionescu 1961; Shallice and Saffran 1986; Bub &
Arguin 1995; Howard 1991; Coslett, Saffran, Greenbaum & Schwartz 1993). Central theorists are impressed with evidence indicating processing systems beyond lexical access, and the implication, that lexical access must be intact. Central views agree that the deficit occurs after an orthographic description has been attained, and explain central effects by disconnection and/or the involvement of the right hemisphere. These explanations include disconnection of the reading system from consciousness (Schacter, McAndrews & Moscovitch, 1988; Young & De Haan, 1990), disconnection of visual systems from verbal and semantic systems, and disconnection of orthographic processing from phonological processing (Arguin et al. 1998). A final central explanation, which attempts to account for both peripheral and central effects, suggests that early orthographic processing is compromised, which results in a left hemisphere mediated strategy of letter-by-letter reading. The central effects are ascribed to a separate reading system in the right hemisphere (Buxbaum & Coslett, 1996).

It is also possible to divide current views into those that focus on residual primary process and possible loci of lesions within primary process, and those which highlight the involvement of secondary processes in the compensatory strategies of peripheral dyslexics. The Behrmann et al. (1998) view is one which focuses on primary process. This may have the advantage of contributing to the specification of the ‘normal’ system, but may be at the expense of understanding the predicament of peripheral dyslexics and the possibilities for remediation. Both views are correct and tackle different but related issues, however the current emphasis in research is on primary process. These two views are described below.

4.2 Primary Process in letter-by-letter reading

Behrmann et al. (1998) review evidence supporting an impairment involving the feature and letter levels in primary process, and suggest that a connectionist view of word processing can reconcile the central and peripheral views of letter-by-letter reading. Regarding right hemisphere mediated lexical and semantic effects, they conclude that there is no compelling evidence to change the view that the bilaterally distributed premorbid system continues to deliver output as usual by the combined contribution of both hemispheres. Behrmann et al. (1998) unify the peripheral and
central views by pointing to some properties of the IAM. This is perhaps the most widely known model of visual word recognition, but parallel distributed models offer similar explanations of effects in word recognition and patterns of deficit associated with injury (Mozer 1991; Seidenberg & McClelland 1989).

The IAM proposes that visual word recognition is mediated by an orthographic system structured as three levels of representations, features, letters, and words. Feature level representations are sensitive to the constituent features of letters, and respond to visual input by taking on activation levels commensurate with the visual evidence. These feature detectors constitute hypotheses about the visual input, and their activation levels determine the strength of hypotheses developed at the letter level. Letter hypotheses are sensitive to both supporting and conflicting evidence at the feature level and to competition from other letter level hypotheses. Outcome is a matter of multiple constraint satisfaction, not just from features and competing letters, but also from other word level representations. This interplay of influences results in competition at the word level settling over a series of exchanges of information between levels, to a candidate hypothesis defined by a higher level of activation relative to its competitors. In a current elaboration of the basic model (Grainger & Jacobs 1996), responses can be based on local or global activation at the word level, or on letter level activation. Behrmann et al. (1998) point out that the IAM is (1) interactive and (2) cascaded, and that these qualities almost guarantee detectable effects of central processing in the face of peripheral degradation.

Interactivity refers to the relationship between levels of processing implemented in the models. For example the model ascribes the word superiority effect, the tendency for letters to be better perceived in words than in nonwords, to feedback from word level representations acting as a constraint to letter level processing. Hypotheses about the identity of visual input are thus sensitive to information at several levels of processing simultaneously.

Cascaded processing refers to the transfer of information between levels in systems, and between systems. Information extracted at each level is available immediately to other levels. So for instance, word level representations are not inactive while letter level processing works on the input, but are constantly updated by the information at the letter level, as it becomes available. Intermediate stages of
processing feed information to other levels, allowing simultaneous development of appropriate hypotheses at multiple levels, constrained by currently available information. Cascaded processing is also thought to characterise relations between processing domains. Recent demonstrations of effects of feedforward and feedback spelling-to-sound-consistency on visual word recognition (Ziegler, Van Orden & Jacobs 1997) emphasise the intimate coupling of the phonological system to the orthographic one. Jacobs et al. (1998) have recently augmented the orthographic IAM with phonological representations, and are beginning to explore the dynamics of the modules working together. Behrmann, et al (1998) suggest that, just as lexical decision may be possible in the absence of overt identification, the cascaded relations of orthography and semantics predict correct categorisation of stimuli. This may be supported by activation which remains below a criterion required for identification. An essential contribution of these models is to outline how interactive and cascaded systems react to degraded input.

The unifying force of Behrmann et al.’s proposal is that these models can reconcile the apparently contradictory findings of both peripheral deficits and evidence of intact central processes. Furthermore, it allows us to predict and understand the implications of intact higher levels processing for impaired peripheral systems. Given this architecture, and its intimate interactive and cascaded relations with the semantic system, effects of semantic processing are to be expected. Semantic entities are normally graded in terms of imageability or concreteness ratings. One consequence of the processing assumptions of the IAM is that the effects of frequency (baseline activation at the word level), and imageability (number of semantic features), on activation levels, intensify over processing cycles. Since letter-by-letter readers take longer to process longer words, the implications are that effects related to differences in frequency or imageability should scale with word length. The frequency and imageability advantage should be larger for longer words.

In short, the Behrmann et al position on letter-by-letter readers is that letter and word levels of primary process are intact. Degraded input prevents letter level representations from accumulating activation through normal parallel processes. The deficit is at the feature level or in the connections between the feature and letter levels. Semantic and lexical effects are to be expected given the architecture, and
letter-by-letter reading behaviour is a reflection of a serial scanning mechanism employed to boost activation levels at the letter level. The result of this is longer processing time with longer words, and a predicted interaction of word length with lexical and semantic variables. In support of this view, Behrmann et al review 57 published cases, and find evidence for impaired letter processing in most, even if in some cases this amounts to an extreme slowing of processing. Evidence for the simultaneous presence of lexical and semantic effects comes from a retrospective analysis of data on seven patients studied over the last decade.

The notion of primary process used so far in the thesis has been limited to primary orthographic process. Including phonology and semantics in the discussion expands the notion of primary process. The interactive and cascaded relations between the orthographic lexical access module, and the semantic and phonological systems however, are primary processes. They qualify in all the senses in which Paap and Johansen (1994) distinguish primary from secondary processes with respect to orthographic lexical access. The cascaded processes between the domains are taken to happen much as lexical access does, that is, automatically and involuntarily. In this sense, we can understand the Behrmann, et al (1998) view as an explanation of the manner in which cascaded primary processes result in simultaneous evidence for peripheral impairment and intact central processing. The involvement of secondary processes in this framework is limited to the suggestion that scanning or refixation mechanisms may underlie the letter-by-letter reading behaviour.

Behrmann et al. consider variability in letter-by-letter reading (for instance some but not all patients show effects of semantic processing, some read tachistoscopic stimuli, and some show the word superiority effect) to result from three main factors

- **Degree of impairment.** Degree of impairment refers to the idea that, with extremely impaired low level processing, letter level activations are unlikely to result in much activity within the lexical access module. Word level representations will not support lexical decision, and little evidence of semantic processing will be evident in the patient’s performance. With minor impairments, lexical access and subsequent semantic processing will operate with near normal efficiency and effects such as interactions between word length and imageability
or frequency are unlikely to be seen. A medium level of impairment however, may be more likely to produce evidence of semantic processing in the absence of overt identification, or interactions between imageability and word length. One reason for variability in performance is thus the degree of impairment.

- **Locus of impairment.** In some cases, researchers have suggested multiple lesions as an explanation for variability. Hanley and Kay (1996) for instance, found that although two of their patients had equivalent letter identification abilities, they differed in their ability to read words. This suggested that in some instances, there might be word level lesions as well as ones affecting letter identification.

- **Strategy.** They refer to JWC (Coslett et al. 1993), who used a letter-by-letter strategy when reading words, but a whole word strategy in lexical decision. The implication of high scores in lexical decision, which depended on his strategy to the task, was intact lexical level processing. Hence detecting cascade effects depends on strategy.

These causes of variability are still rooted in a primary process view of letter-by-letter reading. The first two refer to loci within primary process, and the third refers to the idea that effects of cascaded primary process are not apparent with some strategies. Behrmann et al. did suggest a serial scanning process, which was adopted as an example of scanned completion in PSP. They also underlined the importance of an explanation for serial letter naming. "A significant limitation of Mayall and Humphreys' (1996) simulation, however, is that it does not address the hallmark characteristic of LBL readers, namely, their letter-by-letter reading." (Behrmann, et al. 1998, pp. 39). However, the Behrmann et al. account could also be described as a model of residual primary process.

A complementary perspective is to focus on the compensatory strategies adopted by peripheral dyslexics in their attempts to exploit residual primary process, and the secondary processes involved in these strategies. Each strategy is compatible with the idea that connectionist systems can explain cascade effects. In other words, the fact of residual primary process, and a theory of how it mediates cascade effects, does not explain the variability in compensatory strategies adopted to that residual capacity. Nor does it explain how those compensatory strategies come to identify words. In a sense, they are different issues.
4.3 Secondary processes in letter-by-letter reading


Cognitive psychologists have tended to be less interested in secondary processes than in primary process. On the subject of letter-by-letter reading, Patterson and Kay (1982) remark that (underlining added)

"One reason contributing to the relative neglect of this syndrome within cognitive psychology may be this: letter-by-letter reading is not, in the terminology of Warrington and Shallice (1980), a form of central dyslexia, but is rather one of the peripheral dyslexias. The functional locus of the deficit in letter-by-letter reading is probably relatively "early" in an information-processing sense. Questions about reading likely to be of interest to many cognitive psychologists, such as the organisation of the internal lexicon or the semantic system, may be addressed more clearly by syndromes of central dyslexia (deep dyslexia, phonological dyslexia and surface dyslexia) than by the peripheral dyslexias (attentional dyslexia, dyslexia involving neglect, and letter-by-letter reading). Furthermore, regarding peripheral dyslexias, there might even be some doubt concerning a critical assumption in the rapprochement between neuropsychological research and cognitive psychology. Patients with an acquired dyslexia clearly read in a way that is different from normal reading. It is generally assumed that this difference stems from the loss or impairment of one or more functional components of the normal reading system, rather than from reliance on wholly different procedures (Shallice, 1979, 1981; Coltheart, 1981; Patterson, 1981). Suppose, however, that there is disruption of a relatively early stage of processing; might this mean that the patient no longer has access to the rest of the normal system? Peripheral dyslexias, in other words, might not only be of less compelling interest to cognitive psychologists; in principle, they might even fail to warrant status as legitimately relevant to many issues of normal reading. Were this the case, of course, it would not eliminate interest in the nature of such Syndromes; but the interest might be found primarily amongst neurologists, speech therapists, even neuropsychologists-but not amongst cognitive psychologists. This, then, might explain in part why most studies of letter-by-letter reading derive from a neurological tradition rather than a psychological one. Whether this analysis is valid, or whether psychologists know little of letter-by-letter reading simply because it has not been brought to their attention, we believe that the syndrome deserves attention and that it does legitimately address questions of interest to those who study normal reading." (Patterson & Kay 1982 pp 413).

A current consensus is indeed that there is "disruption of a relatively early stage of processing" (Behrmann, et al. 1998).
Cognitive neuropsychology, like cognitive psychology, has generally considered the most interesting deficits to be those that tell us something about the ‘normal’ system. If one adopts the ‘pure perceptualist’ view of the ‘normal visual word recognition system’, then secondary processes are likely to be of little interest. However, one may adopt the view that the ‘normal system’ is best characterised as a primary lexical access process, working in conjunction with a set of secondary processes. These secondary processes are used routinely to enhance processing by redirecting and focusing attention, guessing, verifying, inhibiting incorrect hypotheses and so on. With this view, the concern that peripheral dyslexics may be using “wholly different procedures” becomes less persuasive. What may be more likely, is that with normal vision and an intact primary lexical access process, secondary processes are used less frequently. With injury, the same pre-existing secondary processes may be employed more frequently. The idea that letter-by-letter readers are using wholly different procedures may mean a concern that new processes have arisen in response to injury, or that processes never used in word recognition have been co-opted into word recognition. Both are possible. However, it is also possible that, if secondary processes used in normal word recognition are available to the patient, they will be used.

Howard (1991) considers evidence suggesting that stimuli presented to the right hemisphere of normal subjects are processed in a serial rather than parallel fashion.

“Letter-by-letter reading may therefore be simply a compensatory strategy adopted to cope with inaccurate letter identification of stimuli which are presented first to the visual areas of the right hemisphere. This raises the possibility that letter-by-letter reading may not be a particularly exotic variety of dyslexic reading, but instead reflect a basic property of normal visual word recognition.” (Howard, 1991 pp. 73)

A normal word recognition system which includes a basic (secondary) property of serial letter identification in response to noisy parallel access, is likely to rely much more on that strategy when faced with permanently noisy input. A serial processing strategy may be used for different purposes. Hendriks (1996) asked normal subjects to read in two ways while she recorded eye movements. In the first they were to pronounce the words sub-vocally and in the second to read for meaning. These two
reading styles were thought to emphasise phonological and lexical processing respectively. The results were that, compared to reading for meaning, the subvocal instructions induced larger numbers of fixations and shorter saccades, longer fixation durations, and lower vengeance velocities. She concluded “readers can adapt to different tasks by adjusting the size of the part of text analysed in parallel” (ibid, pp. 359).

This serial behaviour, aimed at smaller regions of text, had the effect of switching the word processing system into 'phonological mode'. The interesting idea here is that readers have a large measure of control over processing, not by parameter adjustment, but by behaviour. Cognitive impenetrability may be undermined by behavioural penetrability. This raises the interesting possibility that secondary processes, such as rapid serial refixations, far from being 'secondary', are the means by which we gain control of otherwise relatively automatic systems.

**Secondary processes as labels of deficits**

If the focus of interest in word recognition is broadened to encompass secondary processes, then the fact that any particular patient uses one of these processes, for instance serial letter processing, is at best a clue to the nature of their functional impairment. Howard (1991) observes that letter-by-letter reading may arise in response to various functional deficits.

"In any case, one would not necessarily expect to find the same underlying problem in all patients who read letter-by-letter; any patient for whom letter naming remains possible when word recognition is impaired (at any level) may resort to letter-by-letter reading to try to generate a reading response." (ibid. pp. 72).

A similar observation in Price and Humphreys (1992) prompted the suggestion that

"the categorisation of these and other similar patients as letter-by-letter readers is irrelevant and misleading, not only because it does not indicate the functional impairment involved, but also because it fails to describe the strategies the patients are adopting to read and may lead to the inappropriate application of therapy" (ibid. pp. 427).

These views have recently been affirmed by Kremin, Chomel-Guillaume, Ferrand, and Bakchine (2000). They report a French patient JO, who reads letter by letter in French, but not in English. JO, a right-handed 48-year old woman who had
suffered a left-sided fractured skull, acquired English at school and on “linguistic
vacations”. They conclude

“Thus letter-by-letter reading should be considered as a description of a symptom
rather than the consequence of a unique type of functional impairment. . Lexical
access in letter-by-letter readers may thus be subject to more variation than is
usually touched upon” (ibid. pp286).

In some cases, what we need to know is the functional deficit responsible for
the adoption of a normal secondary process as the default route to lexical access.
Furthermore, we need to know the manner in which this secondary process
accomplishes lexical access or identifies a word. The variety of suggestions on how
serial letter identification and naming may achieve lexical access or target identity
underlines the need for research into secondary processes.

Secondary processes in letter-by-letter reading: Varieties of
Completion

The hallmark effect of letter-by-letter reading is the word length effect. Letter-
by-letter readers take longer to read longer words. Henderson (1982) reported
increases in latency of the order of 6-63ms per letter for normal subjects. A failure to
find such effects in lexical decision (Frederiksen & Kroll, 1976) suggests that the
increases in naming latencies may be related to preparation of articulatory codes.
Word length effects have been reported with left visual field presentation (Young &
Ellis, 1985; Ellis, Young & Anderson, 1988). Humphreys (1985) provides evidence
that with normal fixation, short single words are read by parallel processing of letter
information without refixations. Reading single short words requires neither
attentional scans nor refixation. Letter-by-letter readers can show latency increases of
a few seconds for each additional letter in words they are asked to read, even in some
cases where letter naming behaviour does not accompany reading. Serial letter
processing is the most frequently suggested explanation of the word length effect.
Several processes involving serial letter processing have been suggested.
Varieties of lexical completion

• Serial enhancement of lexical representations by attentional scans

"In an attempt to enhance orthographic activations, subjects employ the normal reading strategy of making additional fixations (or covert attention shifts) when encountering difficulties in text. This sequential letter processing adds further to the activation of lexical/semantic representations" (Behrmann et al. 1998; pp.36).

Low word level activation in letter-by-letter readers invokes a process that focuses attention serially on the letters in words. The effect of this is to boost letter-level activations, which then feed up to the word level and enhance identification performance. Note that this process does not include letter naming and has an effect independent of naming. Latency increases with the number of letters in the word. This secondary process may not be intact in some patients.

• Serial enhancement of lexical representations by refixation

"Plaut (1998) has demonstrated properties of LBL reading following peripheral damage to the "refixation" model first described by Plaut et al. (1996). The model generates a sequence of phonemes as output in response to orthographic input presented over position-specific letter units. A critical aspect of the model is that, if it encounters difficulty in generating a particular phoneme in the course of pronouncing a word, it can refixate the input (using an internally generated attentional signal) to bring the corresponding peripheral orthographic segment to "fixation", where performance is better “ (Behrmann et al. 1998; pp.39).

Although the mechanism proposed by Behrmann et al. is a “normal reading strategy of making additional fixations”, it is a secondary process with respect to models of lexical access. Additional fixations have not, in the words of Paap and Johansen been considered a “ubiquitous part of primary lexical identification.”(Paap & Johansen, 1994, pp.1142), mainly because they are not required for short single word recognition. Serial fixation over all the letters of a word, accompanied by naming would certainly qualify as a secondary process.

• Serial enhancement of visual representations by attentional scans

Price and Humphreys (1992) call this ‘implicit serial processing’.

“By this we mean that the letters of words are not identified and named explicitly, but rather that the subjects scan their attention over individual letters or larger subword segments, building up a visual representation that can be used to access stored word knowledge.” (ibid. pp. 430).
Varieties of sublexical completion

• Identities and the lexicon
Patterson and Kay (1982) suggest that letter identities are explicitly identified and then “although the word-form system is primarily suited to operating on abstract letter identities in parallel, it can also accept a sequence of letter identities.” (pp. 433). This is explicit letter identification re-submitted to the lexical access module.

• Identities and the spelling system
One of the original ideas was that letter identities were somehow fed through the spelling system in reverse (Warrington & Shallice, 1980). Price and Humphreys (1992) call this explicit serial processing.

“By this we mean that individual letters of words are named explicitly, allowing the patient to use letter names to reconstruct a word either by mental imagery or, as Warrington and Shallice (1980) suggest, by operating spelling routes in reverse.” (Price & Humphreys 1992, pp. 430)

Patterson and Kay suggest that this may be an alternative secondary process to re-submitting letter identities to the visual word form system and called it Type I letter-by-letter reading.

• Identities and Imagery
Price and Humphreys (1992) suggested that letters may be identified and used to reconstruct words by imagery.

Any one of these processes might be adopted as a solution to a failure of primary lexical access. This is not an exhaustive list. Any of these processes may result in a word length effect. The point is that we have very little data on any of them. In other words, they may all be true in particular instances or under particular circumstances. To complicate matters further, the word length effect may not be due to serial processing at all in some instances (Howard 1991).

Price and Humphreys (1992) point out that a serial component of processing may not be required for a word length effect.

“The third strategy will be referred to as "faulty parallel letter processing," when patients with a deficit affecting parallel letter identification nevertheless attempt to read using a visual description of the whole word. The likelihood of identifying a word correctly from faulty parallel letter processing will decrease as word length increases because the more letters there are to be processed in parallel, the greater
the demand on an inefficient processing system (see Howard, 1991). Similarly, major effects of word length on R.T.s occur because faulty parallel letter processing will take longer to reach a level that activates word recognition, with the R.T.s being proportional to word length.” (ibid. pp 430)

‘Faulty parallel processing’ suggests, as in neglect, ‘something wrong with the ability to process in parallel’, which results in low activation at the word level. ‘Noisy parallel processing’ means that a variable, weak, noisy pattern of letter level activation will result in low activation at the word level. This may be due to low level perceptual, neuropsychological, or experimental degradation. It is likely that faulty parallel processing (abnormal distribution of attention over part of the stimulus) and noisy parallel processing (degraded stimulus or representation) will have similar impacts on processing at higher levels. Note however that faulty and noisy parallel processing are features of primary process, and not of secondary processes.

The letter-by-letter condition as characterised by Behrmann et al. (1998), is noisy parallel access resulting in low activation at the word level. A serial scanning mechanism is invoked to boost letter level activations, and it is this process that is responsible for the word length effect. On Price and Humphreys’ reckoning however, the serial boosting process is not necessary for the emergence of a word length effect. That is, there may be primary process causes of the word length effect as well as secondary ones. Noisy and faulty parallel access may produce a different word-length function from serial processes. Noisy and faulty parallel access may invoke cohort completion, and may be more likely with patients who have compromised serial secondary processes. Word length functions based on faulty or noisy parallel access because of compromised serial processes may be stepped, because short words may not need refixation while long ones might.

The preceding discussion makes several points. Letter-by-letter reading may reflect a variety of secondary processes adopted by patients to overcome a failure of primary lexical access when confronted with intact words. Serial letter processing may not be overt but implicit, and may or may not be the direct cause of a word length effect. As argued earlier, the fact of letter-by-letter reading does not tell us much about the patient’s impairment. It suggests that there is some impairment to primary lexical access, which has resulted in the adoption of a normal secondary process of serial processing to achieve identification. The problem is not so much that
we do not understand impaired primary process, but that we do not understand the secondary processes which patients invoke to circumvent impaired primary process.

**PSP and serial letter processing**

It will be apparent that the processes proposed in PSP are largely derived from the above suggestions. The explicit proposal of an initial limited set of normal secondary processes was followed by experimental reviews and results, which began to describe some of the characteristics of these secondary processes. The idea is that a consistent framework and terminology developed simultaneously in experimental and neuropsychological degradation may further research towards a broader view of word recognition, in both normal and peripheral dyslexic readers. The application of PSP to proposed inhibitory effects of letter-by-letter reading is an example of how this might work.

Arguin et al. (1998) suggest that letter-by-letter reading should be fundamentally inhibitory, and base this on the same principles as the CAM discussed in Chapter 2.

"In contrast, (to parallel processing) if overt word recognition was conducted by a strictly letter-by-letter procedure, as often assumed for LBL (letter-by-letter) readers, one should expect the effect of increased orthographic neighbourhood size to be inhibitory. Assume, for instance, a simple word recognition model in which a letter processing module sequentially feeds information about letter identities to another module representing the orthographic forms of words. Assume also, as suggested by observations by Arguin and Bub (1995; see Luce, 1959, 1977, for a detailed discussion), that overt recognition of the target is achieved once the ratio of activation of its lexical representation (i.e. signal) over the activation of other lexical representations (i.e. noise) exceeds some fixed threshold. With every letter identity that is sequentially passed to the word-form system, the activation of the target and of any other word compatible with the letter input received up to that point will increase to the same degree (assuming everything else is equal). Only once an incompatible letter identity is encountered will the activation of a nontarget representation begin to be lower than that of the target, and presumably this activation should decay over a period of time rather than vanish immediately. Statistically, what this means is that, with serial letter input, nontarget representations should be activated in greater numbers, to a greater degree, and for a longer duration if the target has many orthographic neighbours than if it has few or none. This increased background noise against which the activation of a target word with many orthographic neighbours must be assessed should be costly in terms of overt recognition performance. By contrast, if the letter input to the word form system is parallel, letter information incompatible with orthographic neighbours of
the prime is received at the same time as compatible letter identities. This should keep the activation of orthographic neighbours of the prime sufficiently low from the outset that any noise they produce within the lexical system remains manageable and does not prevent whatever facilitatory effect these neighbours may otherwise have on target processing to be manifest in performance. Congruent with the notion that orthographic neighbours may negatively affect reading performance when incomplete letter identity information is passed to the word-form system-as it is for some duration if reading is strictly letter-by-letter-are observations from a patient with neglect dyslexia (Arguin & Bub, 1997). This patient very often tended to ignore the first letter of words in her reading attempts and her results suggest that orthographic neighbours of the target that differed from it on their first letter were strongly activated. Thus, when the target had many such neighbours that were of a higher frequency than itself, the patient's neglect error rate was doubled relative to when the target had no such neighbours.” (Arguin et al. 1998 pp.73 underlining added)

Substituting pictemes with letter features, and distractors with neighbours, the argument is the same as the CAM argument (Chapter 2 section 2.4). By encoding features serially, letter-by-letter readers activate neighbours, which by virtue of the Luce choice rule, result in lower probability of identifying the target. Since the inhibition is related to neighbours, it is sensitive to their numbers and frequency.

Note that the example given above is a neglect patient. There is usually no evidence of serial letter processing with neglect (Warrington 1991). It is possible that neglect patients incur inhibition through attentional scans over the stimulus, but since this is an attentional disorder, this seems unlikely. Neglect patients process visual information in both visual fields, but attentional processes neglect this information in one or other field. The information from the non-neglected field may be processed in parallel. This means that the response produced is likely to be based on primary process, retrieved completion, or cohort completion. Primary process identification may be unlikely because of the level of degradation, and retrieved completion is not associated with inhibitory effects of neighbourhood size. An inhibitory effect of neighbourhood size in neglect dyslexia might indicate cohort completion. In letter-by-letter readers, it may be due to scanned completion. Hence, inhibitory effects of neighbourhood size in neglect patients and letter-by-letter readers may originate from different secondary processes.

It is difficult to decide if Arguin et al.’s serial process refers to scanned completion or to assembled completion. Behrmann et al.’s (1998) description of
letter-by-letter reading involved sequential scanning or sequential fixations on letters, which had the effect of enhancing letter level activation and hence word level activation. This process feeds activation into primary process by the normal route. If this procedure results in a sequence of letter level activations from left to right, both CAM and Arguin et al. would predict an inhibitory effect of neighbourhood size on low frequency words. Arguin et al. (1998) suggest that "a letter processing module sequentially feeds information about letter identities to another module representing the orthographic forms of words". Because the inhibitory effects of noise are mediated by the lexicon, it is necessary that the sequentially fed identities be delivered to the lexicon. On the other hand, it is not clear that the orthographic input lexicon accepts serial 'identities' as input. That is, a process of serial letter identification presumably results in a set of 'identities' and not a set of activated graphemes.

Letter identities might be used to retrieve a word from our knowledge of spelling, or be accumulated in working memory and assembled in mental imagery. It is not clear that they are re-submitted to the orthographic lexicon, which certainly does not accept letter names. Serial letter scanning or rapid refixation over letters might be expected to 'feed' activation into the lexicon in such a way as to 'create noise'. The behaviour of letter-by-letter readers is slow and involves naming letters, presumably to rehearse them, which seems more like an assembly process than a scanning one. Thus an inhibitory effect mediated by something like rapid scanning, or rapid refixation, is being proposed as an explanation for what seems to be a very different kind of secondary process. The evidence from experimental degradation is that rapid serial perceptual processing may be inhibitory, but the component-letter task results suggested that retrieving words based on letter identities does not show inhibitory effects of neighbourhood size.

Because 'feeding' the lexicon with letter identities was thought to be inhibitory, and hence by implication letter-by-letter reading must be inhibitory, Arguin et al. (1998) argue that their patient IH, who shows facilitatory effects of neighbourhood size, must be reading whole words. Andrews (1997) does suggest that normal reading would produce facilitatory effects, and IH does have accuracy rates of 85%. However, he also shows a word length function of 500msec per letter, which suggests a much slower letter-identity based process that might result in a facilitatory
The strategy adopted in this thesis is to attempt to identify normal secondary processes by first gathering up a set of likely suspects from the experimental and neuropsychological literature. This was done in the introduction. These normal secondary processes are integral parts of a broader view of normal word recognition and are worthy targets of research in their own right. It should be possible to specify this set of secondary processes with normal subjects and degraded stimuli by hypotheses and testing, guided by the specific proposals embodied in PSP. The experimental chapter suggested that this is feasible with appropriate tasks and models. The next chapter looks to neuropsychological testing for further specification of secondary processes, by looking closely at the processes involved in performance and their relationship to residual primary process.

**Conclusion Chapter 4 Neuropsychological Degradation**

This chapter reviewed the peripheral dyslexias, and letter-by-letter reading in particular. Theories of letter-by-letter reading were distinguished as ‘peripheral’ or ‘central’ by whether they focused on evidence of impairment to orthographic lexical access, or on evidence of post-lexical processing which implies intact access. It was suggested that these theories have in common the motivation to explain peripheral dyslexic conditions in terms of impairment to primary process. A complementary perspective was emphasised, which was to understand the performance of peripheral dyslexics as both the consequence of impaired primary process, and the employment of secondary processes as compensatory strategies. The variety of explanations for the manner in which letter naming may achieve word identification was used to illustrate the need for research into secondary processes. The meta-linguistic functions are generally less well specified in word recognition models and this may reflect their secondary status in normal word recognition. In a broader view of word recognition however, they become integral parts of the normal system. They may be
troubleshooting processes in normal reading, but may be the staple routes to access in neuropsychological degradation.

The idea that a broader view of word identification could serve as a focal point for normal and impaired reading was illustrated by the role of serial letter encoding within primary process, which has been discussed in both domains. The process as described by Arguin et al. (1998) and Snodgrass and Hirshman (1991) both predict inhibition related to neighbours. However, other results from normal subjects suggest that piecemeal encoding can be facilitatory in high neighbourhoods. Facilitatory effects of neighbourhood may be associated not only with primary process, but also with particular secondary processes. Inhibitory effects of neighbours may be incurred through scanned completion, but they may also be incurred through impaired parallel access. This hypothetical process, cohort completion, is very like intact access or lexical facilitation in that it relies on parallel access but, unlike primary process, it may be associated with inhibitory effects of neighbourhood size. This is explored in the experiments in Chapter 5 on neuropsychological degradation.
“I liked Sternberg’s piece, first because I’d never been compared to a cheesecake before, nutcake having been the preferred culinary epithet, and second because, if I had to argue against modularity, I imagine I’d do it Sternberg’s way: that is, by claiming that the apparent effects of modularity are actually the familiar effects of the novice expert shift – of overlearning in short. But I don’t believe a word of it.”

(Fodor 1985, pp. 39)

5.1 Introduction

Several experiments with a stroke patient AC are reported. The following history and clinical report is based on the work of Dr. Carolyn Bruce, at the Department of Human Communication Science, UCL.

History and clinical report

AC is a retired seventy-year-old right handed man, who was admitted to hospital in August 1996 with visual disturbances and poor coping at home. MRI revealed an old parietal infarct and ischaemic attacks involving the occipital lobe. On admission to a rehabilitation unit in September 1996, AC was noted to have a mild right-sided weakness and neglect, a right homonymous hemianopia, ideational dyspraxia, dysphasia, and a degree of hearing loss. Language evaluation showed significant auditory comprehension difficulties, word retrieval problems, severe dyslexia and dysgraphia. Speech and language therapy was directed at improving word retrieval and establishing a letter-by-letter reading strategy. After admission to a stroke group in November 1996, he showed steady improvement. Clinical testing was kept to a minimum until the end of 1997.

Perceptual Processing

AC had normal digit span and there was no indication of neglect on line bisection, or the Humphreys’ and Riddoch Heads and Tails test (Humphreys & Riddoch 1987). With the VOSP (Warrington & James 1991) there were some indications of deficits in
object perception (silhouettes and object decision) and space perception (dot counting and cube analysis). In general, AC found complex stimuli difficult. He was good at copying drawings of objects, but poor at delayed copying and drawing to name. There was some indication of picture recognition problems with the Pyramid and palm trees test (see Howard & Orchard-Lisle 1984).

**Word retrieval and comprehension**

Problems with word retrieval were evident in poor performance on the Boston naming test (Kaplan, Goodglass & Weintraub, 1976). His errors were mainly semantic. On word-picture matching, AC was within the normal range for both written and spoken words. Single word comprehension was normal with spoken words, both word and non-word repetition were good, and spoken synonym judgement was normal. Single word and sentence comprehension, and synonym judgements, were impaired for written words.

**Letters**

He copied 11/23 three-letter words and only 2/9 five-letter words correctly. AC showed signs of a deficit in matching letters to their names, naming and sounding letters, and naming letters in letter strings.

**Spelling**

AC spelled 138/144 words correctly and recognised 142 of them spelled out by the examiner.

**Reading**

Most indications of deficit came with tests involving written words. Visual lexical decision was poor. Delayed copying of words was extremely slow. He named all the letters in the words as he studied them before turning the card over to write. AC’s single word reading ranged between 50% and 60% correct on a number of tests, with a tendency to higher accuracy with high frequency words. His errors substituted letters at both the beginning and ends of words. Most of the words were read letter-by-letter.
Reading errors

He was generally anxious about reading words, and laboured over short words for tens of seconds, naming the letters, getting so far through a word and starting again, misnaming the letters as he pointed at them and so on. In some instances, the letter naming appeared to be driven by an incorrectly identified word. The words that influenced letter names were sometimes a neighbour of the target (guide →guild; grass → grave), but not always (enemy → earth; force → father). There was an effect of neighbourhood size on single word reading; more low neighbour items than high were read correctly (77% and 56% respectively N=53). Frequency appeared not to influence errors; many responses were considerably less frequent than the target.

Reading errors were words, usually sharing the same initial letter as the target, but sometimes sharing the final letter. In a test with 60 words, 73% of the errors shared the same initial letter, and 23% shared the same final letter. 68% of AC’s errors could be classified as visual errors (at least half of the letters in the error were present in the target). Errors were sometimes extensions of the target (mad → made; grave → gravel; tooth → toothache; mat → match; air → airs; feast → festive; nip → nibble); substitutions within words (shell → shelf; chart → quart; guide → guild) and unrelated words (student → photos; equipment → fibrous; net → emu). In at least 3 instances, there was a semantic relationship to the target (blossom → tulip; destroyer → deadly; sanctuary → port).

Conclusions from clinical testing.

The most striking aspects of AC’s clinical behaviour with words were his letter-by-letter behaviour and his near perfect spelling. His knowledge of the orthographic structure of words was apparently intact. He recognised all words spelled to him and spelled 138/142 words correctly. In contrast, his reading of short words produced accuracy rates of about 50%. He seemed to fit the letter-by-letter category of peripheral dyslexia. However, his accuracy rate suggested that this was not a particularly successful strategy for AC. He appeared to be a ‘behavioural’ letter-by-letter reader. Although not tested for a word length effect in clinic, it seemed probable that he would show this effect.
However, we decided not to focus on the letter by letter behaviour because this was unlikely to tell us why AC was reading letter-by-letter which could be for any number of reasons (Howard 1991; Price & Humphreys 1992; Kremin et al. 2000). Dr Bruce has noticed (personal communication) that if AC can be persuaded to be diligent and meticulous on letter identification, he will take very long amounts of time to do so, but does eventually get most of the words right. This is however, a highly artificial situation involving constant monitoring, encouragement, and feedback on letter accuracy which neither participant can sustain for long. Although one of the important objectives with any letter-by-letter reader might be to understand the manner in which letter naming subserves word identification, in AC’s case, on the whole, the strategy seemed to be unsuccessful. Testing was aimed at establishing the deficit underlying the employment of a letter-by-letter strategy, but also to establish why this strategy seemed so unproductive. This was likely to be related to letter identification in view of AC’s excellent spelling.

AC was taught to read letter-by-letter and this may explain his persistence in employing the strategy. Testing was designed to remove the overt letter naming behaviour. If serial letter identification was essential to AC’s reading it was likely to persist covertly and could be detected. However, it was possible that AC’s difficulty in identifying words could be a combination of two deficits, one primary and the other secondary. That is, AC’s problem could be compromised primary access, compounded by compromised serial letter identification and assembly.

Confirming AC’s RHH

To ensure that AC’s RHH status had not changed since diagnosis a computer program was written to test detection of targets systematically over the area occupied by the computer screen used for testing. This area covered 35 degrees horizontally and 12.6 degrees vertically. Targets were filled black circles covering a visual angle of 0.2 degrees on a white background. The screen area was divided into a 25*25 grid, giving 625 grid points at which the target could appear. Successive grid points were separated by 1.4 degrees horizontally, and 0.5 degrees vertically. The target appeared at each randomly determined point once. The target was preceded by a central fixation cross which remained on screen for 1 or 2 seconds determined at random. This was to
prevent AC from settling into a response rhythm and to bring attention back to fixation point. The target was visible for 200ms. AC’s task was simply to press the space bar on a keyboard whenever he detected a target. If no response was made within 1 second of target onset the next trial was initiated. The data was plotted onto the screen at the end of testing and captured for this document. Figure 5.1 shows the results. The numbers refer to his reaction time (ms) to detect target at that location, and the X’s to missed targets. The circle covers the fixation point.

Figure 5.1: Target detection over visual field.

Latency was recorded in case a gradient of response was found in the right field, but as is evident from the re-plotted data, AC has a complete RFIH. Parafoveal vision on the right appears to be restricted to 1 or 2 degrees which would prevent fluent text reading (Leff et al. 2000). The restricted right parafoveal field would also indicate single word reading problems unless AC compensates by adjusting fixation.
Testing objectives and experiments

Testing was designed to explore the extent to which AC’s reading could be characterised in terms of the secondary processes embodied in the PSP model. To this point, the model was largely specified by results from normal performance with degraded stimuli, and theories of letter-by-letter reading. Tests and results will be related to processes specified by the model. It seemed clear from AC’s clinical history that normal lexical access was impaired. Under clinical conditions with no time limits on reading, his behaviour suggested that his strategy was to fixate each letter in turn, often accompanied by pointing at the letter, and to name the letters. On some occasions, this produced the correct response but on many occasions, he produced an error. He sometimes reads words relatively quickly without naming the letters.

Neurological injury may have damaged feature or letter level representations or the connections between them, resulting in noisy parallel access. It is also possible however, that impaired visual processing related to RHH, or impaired attentional processing, may constrain input to an undamaged primary process.

Good line bisection made neglect unlikely. His poor word copying and difficulty in naming letters within letter strings suggested problems with either attention scaling, or accurate fixation. This could also result in noisy parallel access. Finally, the integrity of word level representations may have been compromised. On the surface, his letter-by-letter reading suggested intact secondary serial processing using, either attentional scans, or refixation assisted assembly. The preponderance of errors sharing initial letters with targets and the high level of errors (40-50%), suggested that AC based responses on less than all the letters in the word. An inhibitory effect of neighbourhood size on accuracy in clinical testing, where he had unlimited time, suggested that if he was using retrieved completion (which was likely because his spelling is excellent) he was not revising completions.

Seven experiments and an error analysis were conducted to explore AC’s reading in terms of component processes. The strategy of breaking procedures down into component processes in the experimental degradation chapters seemed to shed light on the effects reported in the literature review and the results of the experiments. It was hoped that a similar strategy would enable the characterisation of AC’s deficit, by
specifying the integrity of primary and secondary processes, and the way in which the relationship between residual primary and secondary processes contribute to his performance.

- Experiment 1 used several exposure durations with a visual search task to establish the integrity of parallel processing of simple visual features over the visual field. His RHH suggested that processing was likely to be compromised in the right visual field. Distractor effects would indicate serial processes, and accuracy at various exposures would indicate adaptations to RHH.

- Experiment 2 used a letter-naming task to assess accuracy and latency of naming letters in letter strings. Differences in naming first and third letters in five-letter strings would assess his accuracy at processing single letters within letter strings. Assembly, for instance, assumes the ability to identify individual letters within words accurately. Interactions between performance, frequency, and lexicality, were likely to reflect the integrity of word level representations.

- Experiment 3 used lexical decision at tachistoscopic rates to explore the integrity of word level representations. Words were presented at fixation, and left or right of fixation, at several exposure durations. Effects of frequency would indicate word level processing. Accuracy was likely to be high in his good visual field (left) at brief exposures. Adaptation to right field presentations through refixation was expected to increase latency. Non words were expected to invoke serial processing.

- Experiment 4. Single word reading under time restrictions with short, high and low frequency words, was used to establish his reading performance under speeded presentation. His assessment in clinic was not time-limited. The ability to read briefly presented words, and differences in accuracy with duration, were expected to assess the extent to which AC relies on a serial processes.

- Experiment 5. Neighbourhood size and frequency of 4-letter words were manipulated in a single word reading task. Inhibitory effects of neighbourhood size may implicate lexical completion, and facilitatory effects may indicate sub-lexical completion.

- Experiment 6. A single word reading task with 3, 5 and 8-letter words was used to establish whether AC showed a word length effect. Voice trigger timing was used to record latency. Frequency and imageability were varied orthogonally. A word length effect and an interaction of length with frequency and imageability would support a letter-by-letter diagnosis. The data could then be related to the processes already discussed in relation to theories of letter-by-letter reading.
• Experiment 7. Reading vertically aligned words is thought to require serial letter processing. Vertical words were used to test AC’s ability to processes serial letter identities.

• Finally, a computational error analysis was undertaken using error corpora from AC, a right neglect dyslexic RYT (Warrington 1991), and a visual dyslexic AB (Lambon-Ralph & Ellis 1997). The analysis was expected to reveal differences in error types, which could then be related to the PSP model.

5.2 Experiment 1. Simple Features.

Introduction

This experiment tested AC’s ability to process simple features in parallel. Displays of filled and unfilled circles measured his ability to detect targets left and right of fixation, and the impact of distractors on accuracy and latency. It is generally accepted that simple visual features are encoded in parallel over the visual field (Treisman & Gelade 1980). Simple disjunctive feature search time, (decisions based on the presence or absence of a single feature) should be independent of the number of distracting items in a display. Detecting an O among X’s is unaffected by the number of X’s in the display. The presence of a curved segment anywhere in the visual field signals the presence of an ‘O’. If curved segments and diagonal segments are processed in parallel, then the number of diagonal segments present should not affect accuracy or latency to decide that a curved segment is present. Treisman and Gelade (1980) did however report slightly longer times for larger displays. Effects of display size may indicate a deficit in low level parallel visual processing.

Behrmann and Shallice (1995) found an effect of display size for both their patient DS and their control subject, but because the effect sizes were within the normal range concluded that parallel processing was intact. The visual search displays used by Behrmann and Shallice remained onscreen until a response was made or until a 3 second deadline was reached. With this duration of display, shifts in gaze may mask a hemifield deficit. Rapp and Caramazza (1991) reported an effect of display size with patient HR using 250ms displays. A range of display durations was used (3s, 300ms, 150ms, 50ms) in this experiment. Processing deficits over the visual field
were expected to emerge at faster display rates. Deficits at faster durations but not at 3 seconds would indicate compensatory adjustments of fixation. This would be unlikely with neglect but not with hemianopia. The effect would be to bring intact parallel processing in his good visual field to bear on his bad field. Effects related to the number of distractors in the display would indicate a serial component to feature processing. The serial scanning process in the PSP model is thought to be a response to compromised parallel access. Evidence of serial processing in this task would establish this process as a secondary process open to AC. Strong effects of the number of distractors would suggest the use of serial scanning or refixation.

Objectives

To assess the integrity of parallel processing over the visual field. This is an important aspect of primary processing. In the event of compromised parallel processing, to detect evidence of serial processing.

Method

Four sessions using different presentation durations were run with AC over the course of August 1998. All aspects of the sessions were identical except for the duration of the stimulus display. The durations used were 3s, 300ms, 150ms and 50ms.

Design

Targets (filled circles) were presented with 0, 2, 5, or 11 distractors (unfilled circles). There were thus 4 levels of this factor Display (1,3,6,12 items). On some trials, a target was present. On other trials, the same size displays appeared with no target. This was the second factor Target with two levels (present/absent). The third factor was Quadrant of display (top-left, top-right, bottom-left and bottom-right). The experiments were run as single blocks of 160 randomised trials (80 target present and 80 target absent). There were 40 trials at each display size. The target was present in half the trials at each display size. Targets appeared equally often in all four quadrants. Reaction times to target present decisions (Yes /No) were recorded for each condition of the 4 * 4 * 2 design outlined above.
Apparatus and Materials

A computer program was written to control the display and record responses. Targets were filled circles (black on a grey background) among unfilled circle distractors. The circles were half an inch in diameter. Targets appeared equally often in the four quadrants of the display area (ten square inches), and distractors were randomly distributed over the display area, which covered 14° of visual angle. The experiments were run as single blocks of 160 randomised trials (80 target present and 80 target absent). There were 40 trials at each display size. The target was present in half the trials at each display size. Each trial was preceded by a 1 second “Ready” stimulus, and a 1 second “+” fixation point. The stimulus remained on screen until AC responded, or the time deadline was met, after which the trial was abandoned and the next trial commenced. The program recorded latency and accuracy.

Procedure

AC’s task was to press the ‘Z’ key on a standard keyboard with his left index finger for target absent and the ‘M’ key with his right index finger for target present. This served to record response and latency. The four testing sessions were run a week apart. There was a practice session before each test to allow AC to adjust to the new speed. He was allowed to do as many trials as he felt necessary to settle down to the task. He usually indicated his readiness to commence testing after about 50 trials. The program was then halted and reinitialised for the test proper. The display and procedure were identical in all the experiments reported below. The procedure was the same in all four sessions, except for the change in duration of the display. High Accuracy at 3 seconds and near chance performance at 50ms suggested that a single run would be adequate at these speeds. For the 300ms and 150ms tests, sessions were repeated on the same afternoon to increase the number of data points.

Results

All trials with reaction times 3 standard deviations above the mean in all the sessions were discarded. This meant discarding about 1-2% of trials in each experiment. This was necessary to remove trials on which AC was distracted. The analysis for each session first considers overall accuracy and reaction times, for both
present and absent trials. The next analysis looks at correct response reaction times as a function of target presence and display size. Finally, the effect of location on target detection is considered by focusing on correct target present responses. This indicates whether target detection is affected by absolute position in the visual field. Results and analyses are presented separately for each display duration. A combined analysis of the results at all four speeds is presented in the discussion. Summary data appears in Table 5.2 and Figure 5.3 on page 175.

3s presentation

A single run of 160 trials was used. Displays remained on the screen until a response was made or three seconds had elapsed. Accuracy and reaction times were 95% / 1027ms on present trials, and 90% / 2381ms on absent trials. There was no difference in accuracy by Quadrant $X^2=1.34$, df=3, $p=.7$, and no difference in accuracy by Display $X^2=6.67$, df=3, $p=.3$. AC’s reaction times were considerably longer than times reported by Behrmann and Shallice (1995) for DS (750ms and 1200ms). An analysis of variance using Target and Display with reaction times revealed a reliable effect of Target. Present trials were on average 1.3 seconds faster than absent trials $F(1,140)=266.19$, $p<.001$. The effect of Display was not reliable $F(3,140)=1.49$, $p=.2$. A marginal interaction of Display and Target $F(3,140)=2.49$, $p<.063$ prompted an examination of the simple effects. The simple effect of absent trials was significant $F(3,68)=3.27$, $p<.05$. Tukey at $p<.05$ indicated a reliable difference between single displays and 12 item displays. This effect of Display was restricted to the absent trials indicating exhaustive search on absent trials. The caution on absent trials accounts for the difference in latency compared to present decisions. An analysis of variance using Display and Quadrant with Target Present reaction times revealed no effect of Display and no interaction. There was however an effect of Quadrant $F(3,60)=9.81$, $p<.001$, related to higher reaction times in the right visual field. Post hoc comparisons using Tukey at $p<.05$ showed that Bottom Right reaction times were reliably different from the left quadrants, and marginally different from the Top Right quadrant. Mean times on the left and right were 829 and 1247 ms respectively, and were reliably different $t(74)=-4.56$, $p<.01$.  

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300ms presentation

Stimulus duration was set at 300ms. Two runs of the 160 randomised trials were used in the same afternoon with a rest period between runs. There was a 30% drop in accuracy on present trials compared to the 3-second duration test above. There was a reliable difference in accuracy across Quadrant, $X^2=11.4$, df=3, p=.01, related to lower accuracy in the right visual field. There were no differences in accuracy with Display. Mean response time to present trials was 641 ms, and to absent trials 819 ms. An analysis of variance using Target and Display with reaction times revealed reliably faster correct target present decisions than correct target absent decisions, by an average of 223 ms, F(1,227)=32.52, p<.001. There was no effect of Display on reaction times F(3,227)=.73, p=.5, and no interaction between Target and Display F(3,227)=1.26, p=.2. An analysis of variance using Display and Quadrant with Target Present reaction times showed that reaction times to targets were not affected by Display, F(3,87)=1.81, p=.1, but there was an effect of Quadrant F(3,87)=4.51, p<.01. Tukey at p<.05 indicated that bottom right reactions times were longer than left quadrant times but not longer than top right reaction times. Top right reaction times were not longer than left quadrant times. The interaction between Display and Quadrant was not reliable, F(9,87)=.52, p=.8.

150ms presentation

Stimulus duration was set at 150ms. Two runs of the 160 randomised trials were used in the same afternoon with a rest period between runs. Accuracy differed by Quadrant, $X^2=29.5$, df=3, p=.001, but not by Display $X^2=.45$, df=3, p=.9. Mean reaction time to present trials was 646 ms and to absent trials was 819 ms. An analysis of variance using Target and Display with reaction times revealed a reliable effect of Target F(1,218)=24.79, p<.001, with an average advantage for target present decisions of 204ms. The effect of Display, F(3,218)=1.94, p=.1, and the interaction between Target and Display, F(3,218)=.68, p=.5, were not reliable. An analysis of Variance using Display and Quadrant with Target Present reaction times revealed a main effect of Display F(3,76)=5.78, p<.01, due to very long reaction times to single target trials. The effect of Quadrant was marginal F(3,76)=2.66, p<.06. The pattern of
the previous experiments was maintained with higher reaction times to right field displays. Combining the quadrants into left and right fields produced mean reaction times of 605ms and 750ms respectively which were reliably different, t(90)=-2.622, p<.05. However accuracy on the left was 82.5% but only 32.5% on the right (N=80). This indicated that AC was missing most of the targets on the right. This is confirmed by the accuracy data in Table 5.1.

![Graph showing reaction time vs display size and visual field](image)

*Figure 5.2: Simple Features. Visual Field and Display size interact on reaction time.*

<table>
<thead>
<tr>
<th>Display</th>
<th>LVF</th>
<th>RVF</th>
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<tr>
<td>1</td>
<td>.8</td>
<td>.25</td>
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<td>12</td>
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<td>.35</td>
</tr>
<tr>
<td>Totals</td>
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</tr>
</tbody>
</table>

*Table 5.1: Simple features: Proportion accurate by visual field.*

Accuracy was consistently high in the left visual field and low in the right. A marginal interaction between Display and Quadrant F(9,76)=1.54, p=.15, and the consistent pattern of times and accuracy above, prompted a reconsideration of the data with Quadrant combined into Field (left and right). An analysis of variance using Display and Field with reaction times revealed an effect of Display F(3,84)=6.35, p<.001, again due to high reaction times to single targets, and an effect of Field with mean times of 605ms in the left visual field and 771ms in the right. The interaction between Field and Display was significant F(3,84)=3.07, p<.05, and explains the main effect of Display (Figure 5.2). The long reaction times to single target displays were restricted to the right visual field. The only effect of display size was very long
reaction times when a single target was presented in the right visual field. This may indicate an effect of the ‘mass’ of displays on the right. Larger numbers of distractors may serve to draw attention to the right earlier.

50ms presentation

A single run of 160 randomised trials was used with 50ms displays. There were no differences in accuracy by Quadrant or by Display. An analysis of variance using Target and Display with reaction times revealed reliably faster target present decisions (573ms) than target absent decisions (805ms), F(1,93)=15.51, p<.01. There was no effect of Display size F(3,93)=1.57, p=.2, and no interaction F(3,93)=.61, p=.6. An analysis of variance using Display and Quadrant with Target Present reaction times revealed no main effects or interactions. The level of accuracy (57%) suggested that at this presentation rate AC was guessing on many of the trials.

Discussion

A Accuracy

B Reaction Time

Figure 5.3: Simple features. Combined Accuracy and RT data

<table>
<thead>
<tr>
<th>Percent Accurate</th>
<th>Reaction time in milliseconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration 3secs 300ms 150ms 50ms</td>
<td>3secs 300ms 150ms 50ms</td>
</tr>
<tr>
<td>Left VF 100 80 82.5 77</td>
<td>829 562 604 552</td>
</tr>
<tr>
<td>Right VF 92 54 32 37</td>
<td>1247 705 755 626</td>
</tr>
</tbody>
</table>

Table 5.2: Simple features. Combined data by visual field

The consistent indications of a difference in processing efficiency between the left and right visual fields prompted a consideration of the data over the four
presentation durations by visual field. The two graphs in Figure 5.3 summarise the accuracy (A) and reaction time (B) data for the left and right visual fields.

Reaction time differences between left and right visual fields (Figure 5.3B) were reliable at 3s ($t(74)=-4.56$, $p<.01$), at 300ms ($t(101)=-3.3$, $p=.01$), and at 150ms ($t(90)=-2.6$, $p=.05$) but not at 50ms ($t(40)=-1.04$, $p=.3$). Longer response times on the right at 300ms and 150ms did not result in more accurate performance, and may reflect a shift of attention or refixation to the right after stimulus offset. The accuracy plot shows AC maintaining 77% accuracy on the left at 50ms exposure. This suggests that feature uptake is fairly well preserved in the left visual field. Response times for left field stimuli of between 550 and 600ms and absence of an effect of Display suggest relatively normal processing in the left visual field. Although accurate at 3 seconds, his performance in the right visual field falls to chance at 300ms. His accuracy on the left suggests that he is not guessing. The large latency difference at 3 seconds between left and right visual fields suggests that accuracy at 3 seconds on the right is sustained by refixation. The large time difference, and the absence of an effect of display size, suggested that AC was not scanning, but bringing the intact parallel processing resources of the left field to bear on the right. That is the entire field is processed in parallel but the right suffers a delay related to completion of processing in the left and refixation to the right. This suggests that neglect is unlikely, as he will shift attention if time allows.

Zihl's (1995) results indicate that shifts to the right may be haphazard and delayed. Having processed the left in parallel, he has time to shift attention to the right field. The drop in accuracy to 54% on the right at 300ms suggests that he can no longer refixate at this speed. Information is either not available in iconic memory to support covert shifts of attention, or he cannot scan iconic memory. The results are consistent with a low-level impairment in early visual processing in the left hemisphere. The accuracy levels at 50ms on the left suggest that AC has intact parallel processing and can detect targets on the right if he has enough time to shift his attention to the right visual field. Below 300ms, this is not possible, and so he misses the target and decides target absent. His accuracy on the left, however, suggests that he has not adopted a general guessing strategy and is simply not aware of targets on the right. The absence of an effect of display size in the series of experiments argues
against a general scanning strategy. Rather AC seems to gather information through parallel feature uptake, and shifts gaze or attention to acquire information in the right visual field.

Given enough time, AC picks up information in chunks. Hence, for example, if his fixation point in a word were somewhere central, it is probable that (with intact parallel processing on the left) he would acquire the initial letters in parallel. He may have to shift his gaze to encode the rightward letters. With briefly presented words and intact lexical processing, his situation might be compared to word stem completion. In the terms of the PSP model, primary identification would be possible based on this information. On successful trials, this partial information may be enough to identify high frequency words by primary process or cohort completion. He might however, retrieve a completion from his intact spelling system. With low levels of activation based on part of the stimulus, he may attempt to acquire more information, either by refixation or by serial scan. His ability to read accurately would then depend on the integrity of these secondary processes. An erratic fixation pattern associated with hemianopia might result in letter uptake at inappropriate points in the word if he uses refixation. There was no evidence of a serial scanning process in this experiment. If refixation were erratic and serial scanning impaired, AC’s options under time limited presentation would be restricted. They would be primary identification, cohort completion based on partially activated word level representations, or retrieved completion based on the identities of the initial letters of the stimulus. If serial secondary processes (scanning, refixation) were compromised, the option to revise or assemble completions would be precarious and uncertain. This deficit profile would place a large burden on intact word level processes and perhaps the spelling system. The next experiment looked for evidence relating to the integrity of lexical processing and the ability to acquire information about individual letters in letter strings.

**Conclusion E1 Simple features**

The results of the simple features detection task suggest that AC has substantially intact parallel processing in the left visual field. The employment of several durations revealed AC’s strategy for dealing with his RHH. The absence of effects of display size was not consistent with a serial search strategy but with parallel processing.
Accuracy in RVF seemed to be sustained by refixation to RVF, and the use of intact parallel process in his right hemisphere to process that field. The delay incurred in refixation meant that accuracy in RVF was at chance at 300ms. RVF delays when time did allow were about 400ms which suggests that this is the time AC needs to refixate without rescaling the attentional window.

5.3 Experiment 2. Naming letters in strings

Introduction

The word superiority effect (Reicher, 1969), refers to better identification of letters in words than of letters on their own, letters in pseudowords (orthographically legal letter strings), or letters in nonwords (orthographically illegal letter strings). A strong word superiority effect may be interpreted as an indication of intact word level processing. In the original IAM explanation of the effect (McClelland & Rumelhart 1981), top-down feedback from word level representations enhanced letter level representations. Some current explanations dispense with top-down feedback, and invoke dual read-out from word and letter levels to explain the effect (Grainger & Jacobs 1996). The idea is that, if the subject is able to base decisions on word or letter level representations, then words will have an advantage over letters because there are two sources of information to constrain responses. Although word superiority experiments usually use brief masked presentations, the effect has been found with paper-based tasks.

Lambon-Ralph and Ellis (1997) found a word superiority effect with their patient AB using such methods. AB was asked to name underlined letters in high and low frequency words, pseudowords, and nonwords. The target letters were in the first or third positions of the strings, which were four or five letters long, and were presented for unlimited duration. AB’s performance was not affected by letter position within strings (88% and 89%), but she was less accurate at naming letters in nonwords than in words and pseudowords. AB’s nonword performance was comparable to her performance on isolated letters (62%) both of which were lower than performance on words and pseudowords. AC’s performance in the previous experiment suggested that he might show an effect of position, with lower accuracy.
and longer response times to third position letters. One option open to AC on the previous experiment would have been to fixate at the extreme right of the display. This would have brought the entire display into his left field and acuity may have been enough to support simple feature detection over the display. He showed no sign of doing this, which suggests that AC may not compensate for his right field loss.

The implication of an effect of lexicality on a letter-naming task is intact word level processing. Activated word level representations would be required, either to provide feedback to letter level representations or to supply a second source of read-out. Thus if AC showed effects of lexicality with this task we might conclude that word level processing was intact. The visual field differences detected in AC’s performance in the previous experiment suggested that he might show an interaction of target position with lexicality. An initial assessment of AC’s single letter naming ability is reported before the main experiments. A general improvement in AC’s performance since clinical testing suggested that letter naming might have improved.

Methodological Notes

One method used to present stimuli to letter-by-letter readers with RHH is to restrict displays to the left of a fixation point. This only guarantees that the entire stimulus is in the left visual field for as long as it takes to make an eye movement, about 200msecs. This method may not be without problems. Howard (1991) suggests that demonstrations of word length effects with normal subjects and left visual field presentation may be related to a compensatory letter-by-letter reading strategy. A serial letter processing strategy is adopted because of inaccurate letter identification in stimuli presented to the right hemisphere. General uncertainty about lateralised presentation was also raised by Patterson and Kay (1982).

“In all of our tachistoscopic tests we used a fixation point just to the right of where the stimulus would appear, to try to ensure that the stimulus would be entirely within the patient's intact visual field. The wisdom of this procedure is debatable, as hemianopic patients may, to a variable extent, adapt their fixation to accommodate to the hemianopia. Our use of a fixation point seemed to be satisfactory, but we acknowledge that alternative procedures (such as providing two points or vertical bars and instructing the patient that the stimulus will appear between them) may be equally good or better.” (Patterson & Kay 1982 pp.421)
All stimuli in this experiment were presented in black, on a white background, within a grey screen area. This appeared as a white box on a grey background with a word just filling the box. The box always remained on-screen between trials and so AC always knew where the stimulus would appear.

**Initial Assessment of AC’s single letter naming ability**

An initial assessment of AC’s single letter naming ability was made using computer presentation to record latency. This is reported here briefly before the main experimental report. This was simply to update the results obtained in clinical testing a year previously. The test was very simple, and as such is not reported as a separate experiment but as part of the introduction to this experiment.

All letters were presented in black on a white background. The white background formed a box on the display screen (light grey) slightly larger than the size of a single letter. AC was allowed to position the box anywhere on the screen. This method of presentation was used to allow AC to determine the optimum viewing position for himself, and as the box remained onscreen between trials, he could adopt an optimum fixation point with respect to the stimulus. AC always chose a position towards the top left corner of the screen. Letters were 48-point size and covered a visual angle of about 1 degree. A computer program controlled presentation and recorded latency and accuracy. The program provided buttons on-screen, but unobtrusively positioned in the bottom right hand corner of the screen area, which were used by the experimenter to record response latencies and accuracy, and to initiate trials. Letters remained on display until a response was made. All 26 letters were presented once in a randomised sequence. Upper and lower cases were tested separately on different occasions.

With upper case letters AC ‘passed’ on ‘I’ and called ‘F’ ‘e’. He named 24/26 correctly in a mean time of 1.4 seconds. With lower case letters AC called ‘a’ ‘E’ and ‘i’ ‘L’. He named 24/26 correctly in a mean time of 1.9 seconds. The main indication of letter processing problems was latencies of the order of 1.5 seconds. One of the factors leading Behrmann et al. (1998) to conclude that letter-by-letter reading is fundamentally a peripheral impairment was that, even in cases where accuracy was at ceiling, letter-by-letter readers show abnormally long latencies to single letter naming.
Clinical tests in 1997 found AC able to name 18/26 upper and 17/26 lower case letters. His performance had improved since then but his latencies still indicate that it is a slow and difficult task for him. His accuracy levels however demonstrate that he can name letters accurately when they are presented as single entities and not part of letter strings. Accuracy in naming letters when they are embedded in words could now be assessed from the knowledge that though slow with occasional visual confusions, AC’s single letter naming accuracy is intact. The main experiment is reported next.

Objectives of main Experiment

To assess the effects of word level processing on letter naming by using words and non words. To assess AC’s ability to name single letters at the beginning and middle of arrays of letters (words and nonwords). Effects of position would be related to the ability to direct processing to letter scale and position.

Method

Design

There were two factors in the design, Type and Position. Type refers to the type of letter string, and had four levels high frequency words (HF), low frequency words (LF), pseudowords (PW; orthographically legal letter strings) and non words (NW; orthographically illegal letter strings). The second factor was Position. This refers to the position of the target letter to be named in the letter strings. There were two levels of position, first position and third position. Accuracy and latency to name were recorded.

Apparatus and Materials

The word set used in Lambon-Ralph and Ellis (1997) was used in this experiment. There were a total of 176 stimuli, 44 in each of the four conditions of Type (HF,LF,PW,NW). Mean frequency (Kucera & Francis, 1967) for HF words was 263.7 (SD 197.6), and for LF words was 8.2 (SD 10.8). The word set is included in the corpora section of the appendix in Table 2.
Equal numbers of four and five letter stimuli were used in each condition. Letters in the first and third positions were underlined in an equal number of strings in each condition. The letter strings were presented in a single randomised block of 176 trails. The program allowed the experimenter to control the initiation of trials to allow pauses in testing. Two pauses were requested by AC when he wished to cough. The letter strings appeared in black in a white box slightly larger than a five letter 48-point string. The box remained onscreen between trials, and as usual, was positioned at AC’s direction in the top left corner of the grey display screen. Discreet buttons in the bottom right corner allowed the experimenter to initiate trials, and record response latencies and accuracy.

Procedure

A practice session with unrelated stimuli was used before the experiment to ensure that AC understood the task. AC was seated in the normal position at a computer terminal in a quiet testing room. He was discouraged from pointing to the underlined letters on the screen. The aim was to remove all aids to fixation accuracy and serial letter scanning that he may use in clinical testing. With AC’s consent, the first trial was initiated. A string appeared in the pre-positioned white box, with one of its letters underlined by an underscore character. AC’s task was simply to name the letter. At response, the experimenter pressed the timing button, which removed the stimulus and recorded time. The experimenter pressed one of two buttons to record accuracy. Unless AC indicated otherwise, the next trial commenced by experimenter button press.

Results

Accuracy

Four trials (2 first position, and 2 third position) were discarded because response times were more than three standard deviations above the mean. Figure 5.4 shows higher levels of accuracy in the first position for all classes of stimuli. Overall, accuracy in low and high frequency words was similar at 74% and 75%. Legal and illegal nonwords also produced similar accuracy rates, 57% and 49%. Collapsing over
frequency and legality, letters were named correctly in 75% of words (HF and LF), and 53% of nonwords (PW and NW). This difference was reliable \( X^2 = 8.8, df = 1, p < .01 \). There was also an effect of position on accuracy. 79% of letters in the first position were identified correctly compared to 49% in the third position, \( X^2 = 17.04, df = 1, p < .001 \). With words, both first and third position (88% and 61%) identification rates were high and reliably different, \( X^2 = 8.3, df = 1, p < .01 \). With nonwords, accuracy was 69% in the first position but only 38% in the third position. This difference was reliable \( X^2 = 26.1, df = 1, p < .001 \).

<table>
<thead>
<tr>
<th>Position</th>
<th>HF</th>
<th>LF</th>
<th>PW</th>
<th>NW</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>91</td>
<td>86</td>
<td>76</td>
<td>64</td>
</tr>
<tr>
<td>Third</td>
<td>59</td>
<td>64</td>
<td>38</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 5.3: Letter naming. Percent accurate by position

*HF / LF = high & low frequency words PW = pseudoword; NW = nonword

Letters in words and nonwords were more likely to be identified in the first than the third position, but with nonwords, position had a much larger bearing on identification probability with more errors than correct responses in the third position. The difference in accuracy by position was marginal for low frequency words \( X^2 = 2.75, df = 1, p = .09 \), but was reliably different for high frequency words \( X^2 = 5.94, df = 1, p < .05 \), pseudowords \( X^2 = 6.2, df = 1, p < .05 \) and non words \( X^2 = 3.94, df = 1, p < .05 \).
Naming time

An analysis of variance using Type and Position with naming time revealed no effect of Type $F(3,102)=.47$, $p=.7$, but there was an effect of Position $F(1,102)=9.12$, $p<.01$. Letters were named in a mean time of 3034ms in the first position and 3669ms in the third position. Although the interaction between Type and Position was not reliable, $F(3,102)=1.44$, $p=.2$, the interaction plot shown in Figure 5.5, and the accuracy results above suggested that there might be an interaction restricted to words. Latency to name letters seemed to be sensitive to position in pseudowords, nonwords, and low frequency words, but not in high frequency words.

![Figure 5.5: Letter names. Reaction time by Type and Position.](image)

Separate analyses were conducted for words and nonwords. An analysis of variance restricted to words, using Frequency (high and low) and Position (first and third) with reaction times, revealed no effect of Frequency $F(1,61)=.30$, $p=.5$, a marginal effect of position $F(1,61)=3.58$, $p<.07$, and a marginal interaction between frequency and position $F(1,61)=3.70$, $p<.06$. There was a 1 second difference between first and third position response times for low frequency words, which was reliable $t(30)=-3.78$, $p<.001$. There was no difference in response times by position for high frequency words. A similar analysis for nonwords revealed an effect of position $F(1,41)=5.70$, $p<.05$, with responses to first position letters in 3057ms and to third position letters in 3825ms. There was no difference between pseudowords and nonwords, and no interaction. Collapsing over legality and comparing positions, revealed that, as a group, nonword strings were responded to faster when first position
letters were named than when third position letters were named \( t(43)=-2.411, p<.05 \). The accuracy results above showed reliably lower accuracy on third position letters for high frequency words but not for low frequency words. Thus although AC responds to third position letters in high frequency words as quickly as he responds to first position letters, he is likely to be wrong on third position letters.

Few of the letter errors formed another word when substituted into the target. A confusion matrix did not support a visual confusion explanation for the letter errors. For example [t was confused with o, l, u, and j], [i was confused with u, g, j, and k], and [d with n, h, k, and m]. Closer examination might reveal a relationship between target and response, but the position errors suggested a more complex relationship. Separating the errors for each position into position errors (the response was another letter from the stimulus string) and extraneous errors (the error was not a string letter) produced the following counts. In the first position, there were 13 extraneous errors, 3 second position errors and 2 third position errors. In the third position, there were 21 extraneous errors, 13 first position errors and 9 second position errors. 50% of third position errors were ‘position errors’ and were letters from the first or second position of the strings.

**Discussion**

Accuracy in naming letters in the third position of all letter strings was poor. The marginal difference between first and third positions for low frequency words still meant a 22% drop in accuracy between first and third positions. Accuracy was consistently higher in the first position than in the third. In this sense, there was no effect of lexicality because lexical status did not affect this pattern. The only effect of lexicality on accuracy was an overall tendency for letter identification to be better in words than in nonwords and pseudowords. In general, there was approximately a 30% drop in accuracy from first to third positions, reliable for all stimuli, and marginally reliable for low frequency words. If word level activations were implicated in improved accuracy in the third position, this could only be argued for low frequency words.

With high frequency words, his response times were equivalent for first and third positions, but as error prone in the third position as the other stimulus types. The
equivalent time for first and third positions is in marked contrast to the extra second he took with the other stimuli. If we assume that directing his attention to the underlined third letter is difficult for AC, then he might be tempted to report a letter from an identified word. That is, he may read letter information from an identified word rather than from the stimulus. Experiment 4 (this chapter) reports naming accuracy rates of 81% for high frequency and 43% for low frequency words. This suggests that AC was reading or completing the high frequency words in the letter-naming task. His letter errors were frequently letters from the second position not the third, and may be positional errors in a read off process. Stored letter position information is likely to be coded in relative rather than absolute terms (Humphreys, Evett & Quinlan, 1990) suggesting that a read off process would be inherently error prone.

That is, when the word is a high frequency word, AC identifies or completes a word and provides a letter response from the word rather than from the stimulus. He does not show a time difference between first and third positions because he is not refixating. This explains why the errors were frequently letters from other positions in the target word. With low frequency words and nonwords, AC takes almost a second longer to name letters in the third position. This may be because he refixates to the right only when primary process or cohort completion fail to produce a candidate response. Thus, he takes longer to identify letters in the third position for lower frequency words and nonwords. This suggests a general strategy of monitoring word level representations for primary identification or cohort completion, and only refixating when this process fails. At this point, we cannot rule out retrieved completion. However, if AC were retrieving completions based on the initial letters, it is not clear that there would be such a marked frequency effect. Data is presented later suggesting that the speed with which AC can produce responses to high frequency words supports lexical rather than sublexical completion.

Two different sources of error are thus proposed related to two different strategies. The additional second occupied by low frequency words and nonwords suggests a refixation to deal with third position letters. This does not raise accuracy levels appreciably but is reflected in time. The lack of an improvement in letter identification with refixation, supports the idea that this is generally unproductive for
AC because refixation is likely to be a haphazard affair, as it is generally for RHH patients (Zihl 1995). This probably also underlies AC’s general observation that when he looks at words they are ‘jumbled’. The main effect of lexicality is thus not reflected in its effects on letter report accuracy by position, but in the likelihood of AC identifying high frequency words. This is reflected in time but not accuracy, and may be related to inherent difficulties in accurate report of letters from particular positions in words ‘held in mind’.

The PSP model would explain these results thus. With high frequency words and intact left visual field processing, primary process is likely to identify the target or a cohort completion may be possible. Letter report in the face of compromised refixation or serial scanning is likely to be a haphazard affair. The speed with which AC produces third position responses on HF words suggests that he may be reporting letters from completions and not the stimulus. Relative letter coding may render this process inherently error prone. Slower report of third position letters in the other letter string types may reflect weak word level activation and the absence of a candidate. Under these circumstances, he attempts to gather more information. Failure to improve on accuracy with this extra time and the opportunity to refixate suggests that AC’s options in terms of secondary processes are limited. The differences observed between HF words on the one hand, and LF and non-word strings on the other, suggest a relatively preserved word level response to degraded input. One of the hallmarks of cohort completion may be an intensified frequency effect. The process of adjusting parameters in the IAM to force cohort completions may produce more high frequency errors than primary process. High frequency responses would be more likely, partly because they are the most active representations, but also because they are more resilient in large neighbourhoods. The process of amplifying compatible letter activations at the expense of incompatible letter activation may bias the system to produce more high frequency responses than usual.

**Conclusion E2 Naming letters in strings**

An initial assessment of AC’s single letter naming concluded that, although slow, single letter naming was intact. In the main experiment, accuracy was better in words than in nonwords and better at position 1 than position 3. Lexicality had no
effect on the pattern of good accuracy by position. Although similar in accuracy profile, high frequency words diverged from the other stimuli in latency. Response times to first and third positions were equivalent. The delay to name third position letters for low frequency words (600ms) relative to high frequency words suggested refixations to name the letters in position 3 for LF words. The absence of a delay with HF words suggested that AC was ‘completing’ high frequency words. The equivalent error rate in all stimuli suggested that AC was naming letters from the words he had identified. In some instances, this may have been the wrong word but inspection of the letter errors produced indicated that many were positional errors. The suggestion was that AC refixates to name third position letters only when he fails to find a plausible completion from information gathered in LVF. The poor level of accuracy when he does refixate indicates a problem with refixating and rescaling attention to letter scale.

5.4 Experiment 3. Lexical decision.

Introduction

The lexical decision experiment was used to explore three main aspects of AC’s word processing. Evidence of intact word level processing and representation, the frequency effect observed in the previous experiment, and evidence of serial processes involved in word identification. Earlier discussion noted some uncertainty about the task as an index of lexical access (Snodgrass & Mintzer 1993). This means that interpretation of results with the task depends on a theory of the task. As noted in the introduction (section 1.3 page 38), Grainger & Jacobs (1996) provide such a theory, and it is used here because the interactive activation framework seems to be a good bridge between normal word recognition research and peripheral dyslexia.

Low level perceptual degradation is thought not to preclude accurate decisions based on higher level representations by virtue of cascaded processing instantiated in the IAM (Behrmann et al. 1998). Hence accurate lexical decisions may be based on word level representations which may not be active enough to support overt identification. This effect has been found by some researchers (Coslett & Saffran 1989, Shallice & Saffran 1986), but not by others (Patterson & Kay 1982; Price &
Humphreys 1992). Coslett and Saffran (1989) suggest that the emergence of this effect depends critically on strategy. Patients are persuaded to stop attempting to read the words letter-by-letter, and base their decisions almost on guesses. The involvement of secondary processes in lexical decision is also highlighted by the Grainger and Jacobs’ analysis of the ways in which it may be accomplished (Grainger & Jacobs 1996). This was discussed briefly in the introduction and is most relevant to this experiment.

The visual search task in Experiment 1 concluded that parallel processing was intact in the left visual field and not in the right. High accuracy in LVF at 50ms suggested that AC should be able to process and make accurate decisions to short words and nonwords presented to the left visual field for brief durations. This would only be possible if mapping between the feature and word levels was reasonably intact. Accurate decisions at brief durations would support a conclusion of some degree of intact word level processing. No evidence of serial processes was found in Experiment 1.

A possible index of serial processing suggested by Howard (1991) was explored in this experiment. Howard points out that letter-by-letter readers often show a proportion of fast responses among otherwise slow responses. He argues that with impaired letter identification, on some trials enough letters are correctly identified to allow word identification by parallel access. On other trials, letter identification processes fail to resolve letter identities, and patients are forced to resort to a letter-by-letter strategy. This suggests that with non-words, the patient has no way of knowing whether resolved letter identities really indicate a non-word, or whether some of the letters have been misidentified. This means that if a patient uses a serial letter processing strategy when parallel processes fail, then nonwords should have longer latencies than words. This may give us a means of assessing the integrity of serial secondary processes or at least indicate whether they are being employed.

The first experiment interpreted longer latencies in RVF as the time taken by AC to refixate. Longer latencies to third position letters in the previous experiment were interpreted as the time AC takes to refixate to RVF and re-scale attention to letter scale. This took about 1 second. A sequence of such fixations might be expected to increase latencies considerably. On the theory of lexical decision described above
however, non-word decisions are based on a threshold of subjective time, $T$. This means that they would be expected to be longer than word decision times even with parallel access. Word decisions would be expected to be faster than nonword decisions simply because they are made on the basis the other two criteria. Non-word decisions are made only if these fail to produce a response. However, if nonword decisions are very much longer than word decisions, then it could be argued that $T$ is set in response to serial scanning times. Hence, large differences between word and nonword decision times may suggest serial processing.

The previous experiment also suggested that strategy might be determined by frequency. That is, refixation seemed not to be used with high frequency words. This was explained with the suggestion that AC is adept at identifying HF targets perhaps by primary process, but possibly by cohort completion. This suggests intact word level processing which should support accurate lexical decision to stimuli presented in the LVF, and this should be frequency sensitive. Lexical decision to low frequency targets may be less accurate if based on a muted word level response. Failure to identify or complete in the previous experiment was thought to trigger fixation adjustments, and these adjustments seemed to produce little gain in accuracy.

Objectives

To assess the integrity of word level processing with the lexical decision task. Lateral presentation was used to further assess the implications of hemianopia. To explore the theoretical interpretation of lexical decision in peripheral dyslexia. To look at the possibility of using the latency-lexicality interaction as an index of serial processing.

Method

Design

There were two factors. The first was the type of letter string, Type, with three levels, high frequency words (HF), low frequency words (LF) and nonwords (NW). The second was the visual field of presentation, Field, with two levels Left and Right. The levels of Field refer to presentation left or right of a central fixation point. A
single test was run with central presentation at 3 seconds. The next four tests used lateralised presentation, and were run at 3 seconds, 500ms, 300ms and 150ms respectively. Performance at these four durations was compared in an analysis which introduced a third factor, Time, with four levels.

Apparatus and Materials

Four separate sets of 120 stimuli from Besner and McCann (1987) were used in the experiments. Each set consisted of 60 words and 60 nonwords. All strings were four letters long. The words in each set were grouped as 30 high and 30 low frequency words. Frequencies were not provided in the source, and the words and nonwords are included in the corpora section of the appendix in tables 3 and 4. The tests were all run as randomised blocks of 120 stimuli. Computer programs controlled presentation and recorded responses. On this occasion, AC was not allowed to position the usual ‘white box’ in which the stimuli appeared on the screen. This was positioned in the middle of the screen and was wide enough to accommodate ten 48-point characters. Each stimulus presentation was preceded by a fixation point in the middle of the box. In the central presentation test, the strings appeared centred on the fixation point. With the lateralised presentation test they appeared one character width to the left or right of the fixation character “+”, which disappeared at onset. The program recorded responses from keypress and determined latency and accuracy.

Procedure

In all tests, AC was seated at the same computer terminal in a quiet room. Short practice sessions were used to remind him of the task. AC was instructed to press the M key for a word and the Z key for a nonword. He quickly adapted to responding without either letter-by-letter reading or naming the words before making decisions.

Results

Five separate tests are reported. These fall into two groups, Central and Lateralised presentation. There was one test with central presentation at 3 seconds. This is reported first. There were four tests with lateralised presentation run at
3 seconds, 500ms, 300ms, and 150ms respectively. The individual tests are reported and discussed first, followed by an analysis combining the four lateralisied tests in the discussion. This allowed a consideration of the interaction of stimulus type, visual field of presentation, and duration of presentation. Outliers in all the results tables refer to responses eliminated for reaction times 3 standard deviations above the mean.

**Central Presentation**

<table>
<thead>
<tr>
<th></th>
<th>HF</th>
<th>LF</th>
<th>NW</th>
<th>Words</th>
<th>Nonwords</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy %</strong></td>
<td></td>
<td></td>
<td></td>
<td>96</td>
<td>67</td>
</tr>
<tr>
<td><strong>Reaction Time (s)</strong></td>
<td>1.7</td>
<td>2</td>
<td>2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outliers</strong></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 5.4: Lexical Decision 3s Central. Percent accurate and RT in seconds.

There was no difference between word and nonword accuracy $X^2 = 1.5$, df=1, p=.2. Low performance on low frequency words, compared to high frequency words and nonwords, was reliable $X^2 = 11.4$, df=2, p<.01. A one way analysis of variance on correct decision response times showed a reliable effect of Type F(2,89)=7.93, p<.001. Tukey at p<.05 revealed no difference between high and low frequency word response times (p=.10). High frequency words were faster than nonwords (p<.001), and low frequency words and nonwords had comparable response times (p=.80).

At 3 seconds central exposure AC makes very accurate decisions to high frequency words and nonwords. His decisions to nonwords are slower than they are to HF words. This may indicate the adoption of a serial strategy to nonwords. Two points argue against this. The first is that in the previous experiment, his attempts at single letter identification drove response times up to 4 seconds. The second is that his response times to nonwords are only about 400ms longer than times to HF words. Refixations to the right field in the first experiment were thought to be responsible for similar delays in response in that field, which nevertheless supported high levels of accuracy at 3-second exposure. It may be more likely that AC makes additional fixations with nonwords and low frequency words. This does not improve accuracy with words however, because low frequency word responses were significantly less accurate than responses to the other stimulus types.

Low accuracy with low frequency words and high accuracy with nonwords may be related. If low frequency words fail to achieve criterion before the T deadline...
is met, perhaps due to generally low activation, they may invoke a ‘No’ response and hence an error. Nonwords presumably evoke little activity at the word level and also exceed T. The faster time with high frequency words may be related to primary identification or cohort completion, in which case the M criterion is exceeded, or may be related to global activity and the Σ criterion. The large accuracy difference between high and low frequency words suggests that the frequency effect found in the previous experiment is reliable. AC may identify high frequency words by ‘completing’ or ‘guessing’ words from fragmentary evidence. He could also do this with fragmentary evidence from low frequency words, but the low level of accuracy suggests that he doesn’t. He is more likely to decide that a low frequency word is a nonword. This suggests that the process he employs to identify words is largely unsuccessful with low frequency words. This may point to a lexical process. Shorter exposure durations in the ensuing experiments may allow more detailed conclusions on the processes AC is using.

**Lateralised presentation**

The lateralised presentation results are summarised in Table 5.9, on page 198. Analyses were conducted separately for each presentation duration and are presented before the combined analysis.

### 3 seconds

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Reaction times</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>3s</td>
<td>80</td>
<td>69</td>
</tr>
<tr>
<td>Outliers</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 5.5: Lexical Decision 3s Lateral. Percent accurate and RT in seconds

Nonword responses were more accurate than word responses $X^2=22.1$, df=1, p=.001. Overall, accuracy was not higher on the left than on the right $X^2=0.2$, df=1, p=.6. An analysis of variance using Type and Field with reaction time revealed no effect of Type $F(2,78)=.48$, p=.6. Word responses were made in 1.8 seconds and nonword responses in 1.9 seconds. There was a reliable effect of Field $F(1,78)=18.53$, p<.001, with responses on the left taking 1.5 seconds and those on the right taking 2.1 seconds. The interaction of Type and Field was not significant $F(2,78)=.31$, p=.7.
The fall in accuracy for low frequency words with lateralised presentation may indicate a disruption to AC's normal strategy. The maintenance of a combination of high nonword and poor low frequency word accuracy support the idea of a general bias to nonword decisions. The absence of a time difference between HF, LF and NW decisions in the left visual field may indicate that all decisions were based on parallel access with all stimuli. Consistent increases in latency with right field presentations of about 600ms suggest refixations to that field. So far in the experiments, there has been no evidence of a serial letter processing strategy. Relatively high levels of accuracy with high frequency words presented right of fixation may be related to shifts of fixation, which are possible at 3-second exposure rates.

500 milliseconds

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Reaction times</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>Left</td>
<td>87</td>
</tr>
<tr>
<td>Right</td>
<td>60</td>
</tr>
<tr>
<td>HF</td>
<td>1.14</td>
</tr>
<tr>
<td>LF</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.6: Lexical Decision 500ms lateral. Percent accurate and RT in seconds.

Overall, accuracy was higher with nonwords than with words $X^2=8.6$, df=1, $p<.01$. High frequency words were marginally more accurate than low frequency words $X^2=2.9$, df=1, $p=.09$. Left field responses were no more accurate than right field responses $X^2=1.6$, df=1, $p=.2$. Words were better identified on the left than on the right. High frequency words were identified more accurately on the left than on the right $X^2=9.7$, df=1, $p<.05$, but this did not apply to low frequency words or nonwords. High frequency words were more accurate than low frequency words $X^2=5.5$, df=1, $p<.05$ in the left visual field, but this was not the case in the right visual field $X^2=.07$, df=1, $p=.8$.

Decisions to high frequency words were more accurate in the left than right visual field and decisions in the left visual field were more accurate for high than for low frequency words (see Figure 5.6). Field did not affect low frequency word accuracy, and decisions in the right visual field were not sensitive to frequency. The accuracy results are consistent with intact lexical processing in the left visual field but not in the right. Responses in the left field are accurate with HF words, and show sensitivity to frequency. Low frequency word decisions are at chance in the right
visual field for both high and low frequency words. The high level of accuracy for nonwords may be related to the low level of accuracy in low frequency words. This is taken up in the combined analysis to follow.

Figure 5.6: Lexical Decision. Accuracy at 500 ms.

An analysis of variance using Type and Field with reaction times revealed no effect of Type F(2,165)=.46, p=.6, an effect of Field F(1,165)=4.67, p<.05, with reaction time of 1.16 seconds on the left and 1.3 on the right, but no interaction of Type and Field F(2,165)=.79, p=.5.

With high frequency words, accuracy in the left visual field is still high at 500ms, but right field accuracy falls (see Figure 5.7). This may be related to the equivalent latencies now found in both fields. Accuracy in the right field at 3s was thought to be sustained by refixation, and at 500 ms this may no longer be possible. With low frequency words, accuracy rises slightly in both fields even with falling latency. This may indicate a change of strategy as duration falls. With more time, AC may have been attempting to identify low frequency words at 3s and deciding nonword when this process failed. It is possible that as duration falls he changes the basis for his decisions from a failure to identify to an estimate of global activation. This change in strategy would be expected to affect nonword accuracy because some nonword targets would trigger word responses, and the general bias to nonword responses would no longer inflate nonword accuracy. The trend to lower nonword accuracy supports this.

300 milliseconds
There was no difference in accuracy by type $X^2=2.7$, df=2, $p=.2$, and words were no more accurate than non words $X^2=0.2$, df=1, $p=.6$. High frequency words and nonwords were equally accurate on the left and right of fixation. Low frequency words showed an effect of Field $X^2=5.03$, df=1, $p<.05$. An analysis of variance using Type and Field with reaction times revealed an effect of Type $F(2,75)=10.07$, $p<.001$. Tukey at $p<.05$ revealed that high frequency words were faster than nonwords ($p<.001$). The high and low frequency word difference approached significance ($p=.09$), but low frequency words were not faster than nonwords ($p=.23$). There was no effect of Field $F(1,75)=.07$, $p=.7$, and no interaction of Type and Field $F(2,75)=.89$, $p=.4$.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Reaction times</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
</tr>
<tr>
<td>Left</td>
<td>300</td>
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<tr>
<td>Right</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>1.03</td>
</tr>
<tr>
<td>Outliers</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.7: Lexical Decision 300ms lateral. Percent accurate and RT in seconds.

The most notable results at 300ms were the maintenance of high levels of accuracy in the left visual field for high frequency words, and a large increase in accuracy on the left for low frequency words. At 300ms, a shift of fixation is probably no longer possible for AC. Higher accuracy may be related to a change in strategy. At this presentation rate, AC may have stopped trying to ‘look’ at words in the left visual field, and may have began to base his decisions on word level activation. Assuming a lowered $\Sigma$ criterion or a ‘guessing’ strategy, performance would be expected to be higher, given a cascaded architecture and relatively intact letter level representations. This may be an illustration of the role of strategy in demonstrations of lexical effects suggested by Coslett and Saffran (1989). Left field processing may be able to support global activation at 300ms, but this may not be the case for the right field. Nonword accuracy continued to fall with duration in both fields.

150 milliseconds.

Overall, words were as accurate as nonwords. Neither of these differences was reliable. Low frequency words were equally accurate left and right of fixation. The left and right difference for high frequency words approached significance, $X^2=3.6$,.
df=1, p<.06. An analysis of variance using Type and Field with reaction times revealed an effect of Type F(2,68)=3.65, p<.05.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Reaction times</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>150</td>
<td>84</td>
</tr>
<tr>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>67</td>
<td>50</td>
</tr>
<tr>
<td>NW</td>
<td>HF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>67</td>
<td>66</td>
</tr>
<tr>
<td>NW</td>
<td>HF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>.903</td>
<td>.872</td>
</tr>
<tr>
<td>NW</td>
<td>LF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>.861</td>
<td>.929</td>
</tr>
<tr>
<td>NW</td>
<td>LF</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>1.14</td>
<td>.94</td>
</tr>
</tbody>
</table>

Table 5.8: Lexical Decision 150ms lateral. Percent accurate and RT in seconds.

Tukey at.05 revealed marginal differences between the word groups and the nonwords. Neither the effect of Field, nor the interaction was reliable. The maintenance of high accuracy with high frequency words in the left visual field at 150 ms underlines previous results indicating lexical influences on processing in this field.

**Discussion**

It was noted earlier that the interpretation of lexical decision results requires a theory of how the decision is made. The one adopted here is Grainger and Jacob's (1996) interactive framework. This revolves around the idea that three criteria are used in making the decision. M is the normal word identification criterion, also referred to as a local criterion because individual word unit activation levels exceed this criterion for identification to occur. In lexical decision, it is used to generate a 'yes' response. This criterion is a part of primary process. Making a lexical decision based on this criterion however will be considered a secondary process, because it may not be a ubiquitous part of normal primary lexical access. Σ is a global criterion, a summed value of all the individual word unit activation values, which may generate a 'yes' response when exceeded. This indexes high activity levels in the lexicon, but again, a lexical decision based on this criterion will be taken to involve a secondary process. T is a time criterion used to generate 'no' responses. T and Σ are adjustable but M is fixed. Criterion Monitor (CM) in PSP is there to provide secondary processes related to lexical decision. CM monitors activity in the lexicon, adjusts Σ and T criteria, and generates yes-no responses. It is assumed that CM has access to the initiation of an identification response by primary process, and generates a 'yes' response based on this. It has access to a global measure of lexical activity, and can generate a 'yes' response based on this and a pre-set but adjustable Σ criterion. If neither of these checks produce a response before a pre-set but adjustable delay after
stimulus onset $T$, then a ‘no’ response is generated. Note that CM needs to be able to make very sophisticated adjustments to $\Sigma$ and $T$ and this may require information from higher levels.

![Combined lexical decision data](image)

Figure 5.7: Combined lexical decision data

The objectives of the experiment were to assess the integrity of word level processing, and its interaction with field of presentation. To look for evidence of serial processing in the interaction of reaction time and lexicality, and to examine further the effect of frequency found in the previous experiment. Accuracy and Reaction time for all lateralis tests are given in Table 5.9 and plotted on the graphs in Figure 5.7.
The most obvious features of the series of results are,

- Consistent accuracy in the left visual field particularly for high frequency words.
- Latency differences between left and right visual fields.
- A steady decline in accuracy with non-words as the exposure duration falls.
- An improvement in accuracy with low frequency words as exposure duration falls.

These features will be considered throughout, but the discussion is organised by visual field.

Left visual field

The first experiment reported data indicating that parallel processing of simple features was essentially intact in AC's left visual field. High frequency words presented to this field should be very likely to be identified and hence to exceed the M criterion. Accuracy was high for HF words in this field even at 150msec duration. High frequency words have two advantages over low frequency words. Their resting levels are higher and so their activation levels may rise more quickly, but they also tend to be the robust members of neighbourhoods, and so are better able to resist competition from neighbours. Low frequency words start with low resting levels and are likely to be the weaker members of neighbourhoods. Several points combine to suggest that responses to HF words in the LVF were mediated by M, and hence implicate either primary process or cohort completion. This is another tortuous argument and so is made in list form.

- The very low accuracy for LF words in the LVF at 3 seconds presentation is remarkable, partly because it is so low compared to HF words, but also because accuracy rises as duration falls. This is accompanied by a simultaneous fall in...
nonword accuracy in LVF as duration decreases. Lexical decision latencies at 3 seconds are equivalent for all stimulus types in LVF.

- Nonword response times by definition determine T. That is, as duration of presentation falls, so does nonword decision time, and so AC must be adjusting T downwards as duration falls. However, if we look at accuracy for nonwords we see that this falls with duration as well until it is at chance at 150msec. This means that as duration falls more nonwords are classified as words.

- This is not a decision based on T. There are increasingly more ‘yes’ responses to nonwords. The M criterion is fixed and so cannot account for growing number of ‘yes’ decisions. If as T seems to be, we assume that Σ is adjusted downward with duration, we can account for both the rise in low frequency word accuracy and the fall in nonword accuracy thus.

- At 3 seconds AC makes ‘yes’ decisions on the basis of M. High frequency words exceed M and hence invoke correct yes responses. Experiment 2 reported latencies to name third position letters in low frequency words and non-words, which were 600ms longer than for high frequency words. This suggested that low frequency words were not as easily identified as high frequency words. If we assume that they are slow to rise, low frequency words may not exceed M before T. They are thus inaccurately classified as nonwords. Activation in response to nonwords presumably rises as slowly as low frequency words, and so exceeds T and generates ‘no’ responses. This accounts for accuracy in all types at 3 seconds.

- As duration falls CM (the criterion monitor component of PSP) adjusts both Σ and T downwards. This does not affect HF words because they exceed M. If we assume that Σ falls faster than T, then the lower Σ is, the more likely it is that AC will make a word response to low levels of activation associated with low frequency words and non-words. Hence, the rise in low frequency word accuracy, and the fall in non-word accuracy.

- Accuracy is consistently high for high frequency words in LVF. If AC were using Σ to make decisions about HF words, their accuracy rate would follow the pattern of low frequency words. Accuracy for HF words in LVF seems to be independent of Σ and hence must be based on M.
• M is the non-adjustable normal parameter and hence the results suggest that, with high frequency words presented to AC’s intact field, primary process may operate normally. However, it was suggested that parameter adjustments may also produce cohort completions and these are also based on M, although activation levels may be amplified. Σ is the global activation parameter which suggests that even when M is not exceeded by activation levels AC is able to monitor these levels and base simple lexical decisions on them.

An important aspect of the results was that high accuracy for HF words in the LVF indicated very accurate decisions, probably based on parallel access because they are still accurate at 150msec. They were probably based on M (a feature of normal primary process) because accuracy is independent of the Σ based changes in accuracy over durations. In conjunction, these results suggest that LVF decisions on high frequency words were mediated by M, through primary process, or cohort completion. There was a marked frequency effect however, which may indicate a deficit even with intact field presentation. If serial processing is indeed reflected in longer latencies to nonwords, then there was no evidence of serial processing in the LVF results, but this might be expected on the basis of intact parallel processing in the LVF. However, times in the RVF follow much the same pattern hence we may conclude that there is no evidence for serial processes in either field. Overall the LVF results suggest intact word level processing but with a large frequency effect.

**Right visual field.**

One of the most obvious features of RVF processing was the consistent increase in latency compared to LVF decisions to all string types at 3 seconds duration. Data was reported in Experiment1 indicating response time increases of about 600ms to detect features in the RVF. This was thought to index a refixation to the right to bring intact parallel processing resources to bear on that field. These time differences are also about 600ms and so it is likely that they also arise from refixation. For high frequency words, this produces erratic accuracy at about 65% over the first 3 durations after which it is at chance. Zihl’s (1995) account of RHH, which included erratic fixation in the RVF, may explain this. Accuracy will depend largely on where AC fixates when he moves fixation to the right. This may produce the erratic results
in RVF. The same relationship between duration and nonword accuracy is seen in the RVF, presumably for the same reasons outlined for LVF.

**Conclusion E3 lexical decision**

Central presentation at 3s produced accuracy for high frequency words of 96% and for low frequency words of 67%. There was no difference in latency at about 2 seconds. Slower responses to nonwords may have indicated the adoption of a serial strategy, but differences of about 400ms were considered more consistent with refixation in the light of the latencies recorded for letter naming in the previous experiment.

The lateralised presentation results were combined and analysed to explore the effects of time reductions on AC’s performance. The multiple criteria framework of Grainger and Jacobs (1996) was used to explain the results. Consistent accuracy with HF words in LVF with time reductions suggested that decisions to words in that field were based on the normal word identification criterion, and were independent of decisions for LF and nonwords in both fields. Accuracy in nonwords fell from excellent at 3s to chance at 150ms, while accuracy in LF words was poor at 3s and rose as duration fell. This pattern was not seen in HF words, which maintained consistent accuracy. The suggestion was that AC used the time in longer exposures to discriminate LF from nonwords. If, as the previous experiments suggested, the serial inspection of letters is a compromised function for AC, then he is unlikely to succeed. This means that the NW accuracy and LF inaccuracy at slower speeds may have been linked by AC’s propensity to decide nonword to LF words based on the time criterion. With less time, he may have changed strategy to basing decisions on global activation.

The results were interpreted as indicating intact lexical processing of stimuli presented to LVF. This means that if AC does not compensate for RHH, letters of words which do fall in his LVF may engage a substantial lexical response, perhaps enough for identification in many instances, but otherwise adequate for cohort completion.
5.5 Experiment 4. Reading Single words

Introduction

It was noted in the introduction that some letter-by-letter readers can read words at fast presentation rates. For example, Warrington and Shallice’s (1980) patient RAV, was able to recognise 87.5% of words presented for 100msec. AC’s testing in clinic had not used restricted displays and so we had no data on his ability to read under time pressure. Pilot tests established that AC could read about 50% of words presented for 3 seconds. This matched his accuracy rate in clinic. This rate also seemed to reduce and finally curtail his attempts to read words letter-by-letter. He did try to point at the screen and name letters at slower rates. The three second rate was chosen as the slow rate for this experiment because it seemed to produce equivalent rates of accuracy without the naming and pointing behaviour. The fast rate of presentation was 100msec. Several results from the previous experiments suggested that AC might be able to read words at this rate. Experiment 1 found little evidence of compromised simple feature processing in the left visual field. Feature detection was reasonably accurate in this field at 50 msec.

In terms of the interactive activation model, if his feature level representations are intact, the ones engaged by information in the left visual field should be activated. Given cascaded processing, we would expect this to have an impact on letter and word level representations. Experiment 2 reported accurate letter naming at the first position for all letter strings. This suggested that fast but inaccurate letter naming of third position letters in high frequency words might be explained by positional errors of letters reported from completions. Intact word level processing was also suggested by the results of Experiment 3, in which very accurate lexical decisions were made to high frequency words presented in the left visual field at 150 msec. It seemed on the evidence that a reasonable level of performance might be expected at 100msec. In terms of the PSP model, this would be supported by primary process and cohort completion. On the surface, the 3 second rate would be expected to produce higher levels of completion, but several results in the previous experiments indicated that AC may have few serial secondary processes which might improve performance with extra time.
The PSP model proposed scanned and retrieved completion, revision, and assembly, as serial secondary processes. Scanned completion assumes the ability to direct attention to particular points in the word, and the ability to narrow the focus of attention to letters. Retrieved completion assumes the ability to identify a few letters and retrieve completions from spelling. Assembly and revision assume the ability to scan or refixate accurately at letter scale within the stimulus. The low accuracy of third position letter report in Experiment 2 suggested that AC might not be able to direct either attention, or fixation, accurately within the stimulus. Both the visual search task and the lexical decision task failed to produce evidence that AC uses serial processes to gather more information. They both suggested however that he does refixate, bringing intact parallel processes to bear on the right visual field. The discussion of hemianopia in the introduction reported Zihl’s (1995) findings on right homonymous hemianopia (RHH), which included increased temporal duration of fixations, narrowing of perceptual span and haphazard scanning of the impaired visual field. Inability to direct individual letter processing accurately may explain AC’s apparent reluctance to use these strategies. Three seconds provides enough time for the serial processes to operate, but if they are dependent on accurate scanning, they may either not be used or may produce incorrect responses when they are. If the serial secondary processes were compromised, then the main secondary process left to AC would be cohort completion. This also predicts that more time may not produce higher accuracy rates.

Finally, an effect of frequency was evident with both the letter-naming task and lexical decision. The letter task results were consistent with the idea that AC identified high frequency words, and instead of naming the third position letters from the stimulus, was ‘reading off ’ the letter names. This was thought to explain equivalent time to report both positions with lower accuracy in the third position. Third position report was slower than first position report for low frequency words. A similar effect of frequency was found in lexical decision. Frequency effects are generally taken to be indicative of word level processing (Behrmann et al., 1998). Within the interactive activation model, this is implemented as ‘resting levels’. All word level representational units have a value assigned to them that is proportional to their frequency count value (usually Kucera & Francis 1967). The effect of this might
be thought of as a ‘head start’ for high frequency words. An equivalent amount of information pointing to high and low frequency words that have equivalent neighbourhood constraints will result in the high frequency word being identified. This is because it begins with an advantage that allows its activation to increase faster than the low frequency word, and through this greater activation, it is able to have a disproportionately larger inhibitory influence on the low frequency word. Persistent frequency effects are thus taken to reflect the integrity of this word level process. Because of frequency effects in Experiment 2 and 3, higher accuracy was expected for high frequency words.

Objectives

To explore AC’s ability to read at restricted presentation rates and without overt letter-by-letter reading. To assess his reading at tachistoscopic rates (100ms). Equivalent accuracy at 3s and 100ms would suggest that his accuracy rates were not sustained by serial secondary processes. To further document the relationship of stimulus frequency to his accuracy and latency.

Method

Design.

Two testing durations with different sets of words were used. In the first test, stimuli were displayed until a response was made, or a 3 second deadline was met. In the second test stimuli were displayed for 100ms and then removed. The two tests constituted the levels of one factor Time, with two levels, 3 seconds and 100ms. In both tests, high and low frequency words constituted the second factor, Frequency, with two levels, high and low. Accuracy and latency to name words were recorded.

Apparatus and Materials

The set of words used (240 at 3 seconds and 180 at 100ms) was taken from Besner and McCann (1987). They were all four letters long and were grouped by frequency (high and low). Frequencies were not provided in the source, and the words are included in the corpora section of the appendix in tables 3 and 4. Presentation of words, and response recording, were controlled by computer programs.
reading conditions were established for AC through several pilot sessions where display and font size preference was established. Font size was set at 48-point, which gives a visual angle of about 4 degrees for 4-letter words. The words appeared in black on a white background. The remaining screen area was dark grey. This gave the impression of words appearing in a white box. The box could be positioned anywhere on the screen and AC was allowed to specify the optimum location. This was always on the left of the screen. The box remained on screen between trials so that AC was never in any doubt about where the word would appear, and could fixate as he felt necessary. Buttons in the lower right corner of the screen allowed the experimenter to initiate trials and record both accuracy and latency.

Procedure

The procedure for both tests was identical except for the timing difference and the number of stimuli. The tests were run separately. The 3 second test was run first using 120 word randomised blocks, in two sessions with a fortnight separating testing sessions (N=240). The 100ms test was run with 180 stimuli in a single testing session a fortnight later. AC was allowed to specify the location of the white box and chose to place it at the top-left corner of the screen. The tests were run as single randomised blocks, but button controlled, so pauses were possible if AC wished to cough or simply to rest for a minute or two. Each test had two or three such pauses determined by AC. After a practice session, the experimenter initiated the first trial with AC’s consent. AC’s task was to read the words. At response, the experimenter pressed the timing button and one of two buttons to record the accuracy of the response.

Results

The 3 second results are presented first followed by the 100msec results and then a comparison of performance at the two durations.

3s Exposure

Words were displayed for 3 seconds. 240 words (120HF and 120LF) were used. AC named 53% of the words correctly. His mean time for correct responses was 1957ms and for errors was 3212ms. This was reliable t=8.9855, df=238, p<.001. He
named 70% of high frequency words and 37.5% of low frequency words correctly. This was reliable $X^2=25.5$, df=1, $p<.001$. Mean correct response time to high frequency words (1873ms) was marginally faster than time to low frequency words (2113ms), $t(127)=1.817$, $p=.07$.

100ms Exposure

The procedure was the same as above except that the words were on screen for 100ms. 180 words were used (90HF and 90LF). Four outliers (3LF and 1HF) were discarded from the analysis. Overall, accuracy was 60%. Mean time to correct response was 1181ms and to errors was 1610ms. This was reliable $t(174)=-9.299$, $p<.001$. AC named 81% of high frequency words and 43% of low frequency words correctly. This difference was reliable $X^2=27.4$, df=1, $p<.001$. There was no difference in mean correct response times to high (1198ms) and low (1148ms) frequency words.

Comparison of 3 seconds and 100msec results

Overall accuracy at 100ms exposure (60%) was higher but not reliably different from accuracy at 3s (53%) $X^2=1.6$, df=1, $p>.2$. The pattern of results is shown in Figure 5.8A. The high frequency word advantage in accuracy is seen at both display durations. Reaction times were equivalent for high and low frequency words at both durations. Accuracy was used as a factor in an analysis of variance on reaction times. This allowed a comparison of the time to make a correct response and the time to make an error, and the interaction of this with Time and Frequency.

<table>
<thead>
<tr>
<th>Time</th>
<th>Accuracy</th>
<th>HF</th>
<th>LF</th>
<th>HF</th>
<th>LF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 s</td>
<td>2500</td>
<td>53%</td>
<td>70%</td>
<td>37.5%</td>
<td>1873</td>
</tr>
<tr>
<td>100ms</td>
<td>1500</td>
<td>60%</td>
<td>81%</td>
<td>43%</td>
<td>1198</td>
</tr>
</tbody>
</table>

Table 5.10: Reading single words. Accuracy and RT in ms.

An analysis of variance was conducted on reaction times using Time (3s and 100ms), Accuracy (Correct and Error) and Frequency (High and Low) as independent factors. Response times for 3s and 100ms (2.5s and 1.5s) were reliably different $F(1,412)=153.24$, $p<.001$. AC also took about a second longer on errors than on correct responses at 3s duration (Figure 5.8B). The only reliable interaction was
between Accuracy and Time $F(1,412)=12.29, p<.001$. Post hoc tests revealed that AC took 800ms longer on correct responses with a 3 second display compared to a 100ms display, $t(236)=10.8, p<.001$. The equivalent time difference for errors was 1500ms which was also reliable $t(180)=8.7, p<0.01$. In other words, AC spent 1.5 seconds more on words he made errors on when display duration allowed. This time might have been occupied in serial letter processing or hypothesis checking. However, he also spent 800msec more on correct responses at 3 seconds compared to correct responses at 100msec.

![Figure 5.8: Reading single words. A: Accuracy B: Reaction times](image)

**Analysis of ‘Fast’ responses**

The PSP model suggests that patients may use a set of secondary processes in compensatory strategies. Patients may use different strategies within the same testing session. Howard (1991) suggests that mean reaction times may disguise these differences in processing. For instance, patients may identify words through primary lexical access on some trials, which should produce faster responses than trials on which they resort to a serial letter processing strategy. By setting the fast response criterion to twice the fastest correct response at each duration, the proportion of fast correct responses was computed for each duration and for high and low frequency words. These are given in Table 5.11 and plotted in Figure 5.9A. The same data were computed for errors and plotted in Figure 5.9B.
The frequency effect in correct completions was marginal at 3s ($X^2=3.68$, $df=1$, $p=.054$), and not reliable at 100ms ($X^2=.504673$, $df=1$, $p=.48$). Hence, with fast exposure, frequency did not affect the proportion of fast responses. All responses were ‘fast’. The marginal effect at 3s however suggests that, although the majority of correct responses fall into the fast response category, low frequency words are less likely to elicit fast correct responses. The level of accuracy achieved for low frequency words is sustained by a higher proportion of slow responses. Hence, if AC were using two strategies, he tends to use the slower one more often with low frequency words at 3 seconds. There was a reliable increase in the proportion of fast correct responses with 100ms duration for both high ($X^2=7.48$, $df=1$, $p<.01$), and low ($X^2=11.27$, $df=1$, $p<.001$) frequency words. If fast responses index one of two strategies, then the same strategy is employed for both frequency sets at 100ms. Accuracy is however no different at 100ms from accuracy at 3 s. That is, AC is able to achieve the same level of accuracy in low frequency words at 100ms without using this slower strategy.

The only reliable effect in errors was an increase in the proportion fast error responses to low frequency words from 3s to 100 ms duration. That is, AC spent less
time on low frequency errors at the faster rate. This is consistent with the idea that AC abandoned the slower procedure with low frequency words. The data suggest that although AC does adopt a slower strategy to low frequency words when time allows, this does not have an appreciable effect on accuracy. This would be consistent with a strategy that is invoked more often with low frequency words at slower speeds, occupies some time, but does not affect the accuracy of the response he makes.

**Discussion**

The first objective of this experiment was to assess evidence of word level processing, the integrity of primary process. AC was as accurate at reading words presented for 100msec as he was at words presented for 3 seconds. The initial surprise was finding that his accuracy at 3-second displays was comparable to his performance in clinic. This indicated that the letter naming behaviour, shown in clinic, but not with 3-second displays, had little impact on accuracy. The information on which identification was based could be acquired in 3 seconds without the behaviour. It was equally surprising to discover that much the same results were obtained with 100msec presentations. His response times were about 1 second with 100msec presentations, and his accuracy was equivalent to 3 second presentation, suggesting that all the useful work of word identification was accomplished within 1 second. Retrieved completion in the standard condition of the component-letter task with normal subjects was sensitive to time reductions to 3 seconds. These 1 second responses were thus unlikely to be mediated by retrieved completion. With 100msec presentations, refixation is not possible. Scanned completion involves directing attention to the letters in the stimulus thus boosting activation at the word level. The operation of this process at 100msec would only be possible if we assume that an iconic representation is scanned between stimulus offset and response, which would be possible because the words were not masked. More sophisticated testing would be needed to establish this.

It is unlikely however, that his performance at 100msec is supported by refixation assisted serial secondary processes or ‘assembly’. His reaction times to simple visual features in the left visual field in Experiment 1 were of the order of 1 second, and refixations to the right field produced times of about 1300msecs. Lexical
decision in Experiment 3 produced left field times of about 1.5 seconds and right field
times of about 2 seconds. These times are consistent with Zihl’s (1995) report of
increased temporal duration of fixation. With the extra requirement to narrow the
focus of attention to letter scale in the letter naming task in Experiment 2, his third
position times were about 3.2 seconds for high frequency words. Low frequency
words and non-words had latencies of about 3.8 seconds. These results suggest
that his responses at 100msec did not involve refixation. It seems likely that his
performance at 100msec was supported largely by primary process, cohort
completion, and perhaps serial scans of iconic memory.

Although no more accurate, AC spends about 800msec longer on correct
responses at 3 seconds compared to 100msec presentation rates. His reaction times go
up to about 2 seconds, but fail to produce higher accuracy. Refixations to the right
visual field in the simple feature tasks took about 400msec, but also sustained a high
level of accuracy. Refixations to name letters in the third position with the letter-
naming task in Experiment 2 occupied about 600 msec and produced no gain in
accuracy. His times thus suggest that he makes refixations with 3 second displays, but
also that this does not support higher levels of accuracy compared to 100msec
displays. As noted above in the letter naming task, refixating and narrowing attention
to letter scale seemed to increase reaction times to as high as 4 seconds. The absence
of an increase in accuracy when refixations are possible for AC, suggests that
although he may refixate, he does not acquire any useful further information in the
process. The absence of a candidate, through a failure of primary process or cohort
and scanned completion, may automatically trigger a refixation, which, in AC’s case,
produces no further gain in accuracy. Under these circumstances, completion based
on assembly might be out of the question.

The longer times spent on errors suggests that AC does invoke time
consuming secondary processes, and that they may be ineffective in producing correct
completions. It might be argued that with enough time to point at the letters and name
them as he does in clinic, retrieved completion or the assembly process should
produce better results. However, as mentioned earlier, his accuracy rate in clinic was
much the same as it was here. It was mentioned earlier that with extreme but
unsustainable diligence in letter identification AC does achieve high levels of
accuracy. This suggests that unlike YD (Dickerson 1999), AC is able to assemble in the sense of getting from a set of letter identities to the word, and that his problems centre on the acquisition of letter identities.

The results above are taken to indicate a highly functional primary lexical process. Accuracy rates of 80% on high frequency words, with little evidence of serial secondary processing, support this notion. The second objective of the experiment was to look for indications of serial secondary processing in completion. The discussion above suggests that this was minimal and may have been restricted to iconic scans or single refixations. The third objective was to look further at the effects of frequency seen in Experiments 2 and 3. High frequency words were read more accurately than low frequency words at both durations. Although responses were faster at 100msec than at 3 seconds, there was no difference between reaction times to low and high frequency words at either duration. High frequency words were 30% more accurate at 3 seconds and 40% more accurate at 100ms. It seems unlikely that an assembly process would produce differences of this order. The processes of identifying letters sequentially and consulting the spelling system (which we know is intact in AC) might be expected to produce the correct response with little effect from frequency. We have no evidence of serial scanning processes and so the effect is likely to be related to primary process and cohort completion.

It is likely that cohort completion would be subject to neighbourhood interference, and low frequency words are particularly sensitive to distractors under degraded conditions (Snodgrass & Mintzer 1993). The lower probability of low frequency targets being activated enough to be completed by primary completion (because of low resting levels), may mean that they are more likely to engage the cohort completion process. That is, even if they are not overtaken by a higher frequency neighbour response, they may produce the conditions that trigger ‘coerced’ lexical resolution more often than high frequency words. This process is likely to ignore conflicting evidence and simply produce the most active cohort member as a response. The effect of this may be to further reduce the probability of low frequency words being correctly identified. This might be tested with a computational model of the cohort completion process in conjunction with primary process.
In sum, the evidence suggests that word level processing is intact, although low frequency words seem to be disadvantaged. In terms of the PSP model, several results so far suggest that the constraints to primary access for AC are visual. That is information is not processed in the right visual field even at feature level. An analogy with experimental degradation might be a component-letter fragment consisting of the first few letters of the word. Primary process may be able to identify high frequency words through lexical facilitation, but in the absence of this, AC must rely on secondary processes. Under time pressure, a cohort completion may be generated by attentional modulation resulting in a rapid resolution of a low activation cohort. If the target is high frequency, this is likely to generate a correct response, and if it is low frequency, a neighbour error is probable. A notable aspect of AC’s performance is that he rarely ‘passes’. With more time, serial secondary processes would be expected to operate, beginning with serial scanning and even perhaps refixations and assembly. There was little evidence that AC uses these processes, and this may be because they are effectively precluded by an RHH related scanning and refixation deficit.

The next experiment looks at neighbourhood size, frequency, and the relationship between targets and errors.

**Conclusion E4 Reading single words**

The comparison of accuracy in clinic with letter-by-letter reading, at 3s without, and at 100ms all pointed to the equivalent accuracy rates found being supported by a fast lexical process. There was no latency difference between HF and LF words at 100ms, and yet accuracy on HF words was double the accuracy for LF words, a pattern repeated here at all presentation durations and in lexical decision. Response times to correct naming and errors rose by 800ms and 1 second respectively with 3s presentation compared to 100ms presentation, with no appreciable impact on accuracy. The results are consistent with AC making the attempt at greater accuracy with more time, by refixating to gather more information, and with the idea that, for AC, this is a singularly unproductive exercise. The results are consistent with responses produced at both durations by a lexical process, which operates with LVF field information, and is highly frequency sensitive. This may be primary lexical access but it may be unlikely that primary process incorporates such an extreme
frequency bias. The alternative parallel lexical process proposed is Cohort completion, which may, and this should produce inhibitory effects of neighbourhood size. This is tested in the next experiment.

5.6 Experiment 5. Neighbourhoods and Frequency.

Introduction

This experimental report is divided into two main sections. The first reports an experiment in which Frequency and Neighbourhood size are manipulated to look at their effects on accuracy and latency. The second section is a pooled error analysis. By the end of this experiment in testing, enough errors had been collected to perform an error analysis on the relationship between targets and errors in terms of letter positions. All errors from four letter words used in testing were pooled and entered into a computational analysis. The reason for including it at this point is that it sheds some light on the results of the final experiment of the series, on the word length effect.

Snodgrass and Mintzer’s (1993) results with the fragmentation task and normal subjects were reviewed in chapter 2. They reported two effects. The first was an inhibitory effect of neighbourhood size with both incremental and standard cues. The use of the incremental procedure implies effects related to serial encoding as described by the competitive activation model. However, holistic standard cues may be completed with serial scans, so with both sorts of cues, the involvement of serial processes in the inhibitory effect of neighbours is possible. Lexical completion in the absence of evidence of serial scanning was called cohort completion. This was described as adjustment of parameters in the interactive activation model or attentional modulation of word level activation. It is used to denote situations in which no further information is acquired by serial scanning or rapid refixation but a response is nevertheless made on the basis of very low word level activation. Scanned completion may be distinguished from cohort completion by evidence of serial processing. In the event of a demonstration of inhibitory effects of neighbourhood size for low frequency words with AC, the problem was going to be which lexical completion process to ascribe it to.
Several attempts to uncover evidence of serial processing in the previous experiments failed. This suggested that if the effect was to emerge it was unlikely to be related to serial scans and hence to the sorts of processes described by CAM or by Arguin et al. (1998). The absence of evidence of serial processing also suggested that inhibition related to assembly was unlikely. This is because the assembly process relies on serial processing to establish individual letter identities and although there was evidence of AC making single refixations to the RVF, considerations of time and accuracy implied that multiple refixations were not made. Retrieved completions were possible, but the absence of any gains in accuracy with time suggested that AC does not retrieve completions. Furthermore, if AC could retrieve completion, he was likely to be able to revise them. As we saw in the fragmentation task review and the component-letter task results reported in Chapter 3, this reverses the effect. A facilitatory effect of neighbourhood was reported. No time limit was put on the task, and so if AC could assemble or retrieve and revise responses he was free to do so in this experiment, in which case a facilitatory effect of neighbourhood would emerge.

However, the prediction was that it would not, and that there would be an inhibitory effect of neighbours. Furthermore, the effect was likely to be the consequence of cohort completion. It would also indicate that given the opportunity, AC does not spontaneously revise completions.

**Objectives**

To determine whether AC shows inhibitory effects of neighbourhood size and an interaction of this with frequency. The experiments in Chapter 2, and the Snodgrass and Mintzer (1993) results, suggested that perceptual identification unaided by revision process is sensitive to inhibitory effects of neighbours on low frequency words. To analyse a pooled corpus of errors to 4-letter words, looking for confirmation of a left right gradient of accuracy and the relationship of errors to targets in terms of frequency.
Method

Design

Two factors were used. Neighbourhood size as given by the Oxford psycholinguistic database (Quinlan 1992) was used to divide 64 four-letter words into high and low groups. Neighbourhood size is determined by counting the number of words that share 3 letters in the same positions with the target. This factor Nsize, thus had two levels high and low (HN and LN). The second factor was Frequency with two levels, high and low (HF and LF). The word set was orthogonally varied on these two factors. There were thus 16 words in each cell of the 2 by 2 design. Accuracy and latency to name the words was recorded.

Apparatus and Materials

Presentation and response recording were controlled by computer programs. The white box display was used as detailed in previous experiments. All words were four letters long and so the box was slightly larger than four characters of 48-point font. Trial initiation, timing of response latencies, and recording of accuracy were controlled by the experimenter using onscreen buttons as described in previous experiments. The 64 words were used as three randomised blocks, run a week apart to increase the number of data points. There were 32 high neighbourhood words with a mean of 21.3 neighbours (SD 5.2), and 32 low neighbourhood words with a mean of 8.3 neighbours (SD 4.3). In each set, 16 words were high frequency with a mean frequency of 172.8 (SD 217.9) (Kucera & Francis 1967), and 16 words were low frequency with a mean of 13.2 (SD 6.1). The word set is included in the corpora section of the appendix in Table 5.

Data from the three sessions were analysed to look for differences. There was an effect of neighbourhood overall, and this did not interact with the sessions. Effects of practice were unlikely because the times in the final session were longer than the times in the first session. There was no overall difference in accuracy between the three sessions. This meant that the analysis could be based on 192 data points.
Procedure

AC was seated in the usual manner before a computer terminal in a quiet testing room. A practice session using unrelated stimuli was used to remind him of the task. Each trial was initiated by the experimenter, and AC’s task was simply to name the word as quickly as he could. At response onset, the experimenter pressed the timing button, recorded accuracy, and, unless a pause was requested by AC, initiated the next trial.

Results

Accuracy

AC was more accurate with high frequency words (68%) than low frequency words (49%), $X^2 = 6.9$, df=1, p<.01 (Figure 5.10A). He was more accurate with low neighbourhood words (65%) than high (51%) $X^2 = 4.2$, df=1, p<.05). The high frequency advantage over low frequency words was reliable in the high neighbourhood set $X^2 = 5.0$, df=1, p<.05, but not in the low neighbourhood set $X^2 = 2.3$, df=1, p=.1. High neighbourhood words were less likely to be completed, and within the high neighbourhood set, high frequency words had an advantage over low frequency words. There was no such advantage of frequency in low neighbourhoods although the trend was in the same direction. The difference in accuracy for high and low neighbourhoods words was marginally reliable $X^2 = 3.3$, df=1, p<.07 for low frequency words but did not approach significance for high frequency words $X^2 = 1.19$, df=1, p=.2.

Naming Time

An analysis of variance using Nsize (HN, LN) and Frequency (HF, LF) with correct responses revealed a reliable effect of neighbourhood $F(1,108)=3.98$, p<.0486. Latencies to high neighbourhood words were longer than to low neighbourhood words (2076,1897ms). There was no effect of Frequency and no interaction between Frequency and Nsize. In order to look at the effects of frequency and neighbourhoods on accurate and error responses, Accuracy was included as a factor in a second analysis. This analysis used Frequency, Nsize and Accuracy (correct, error) with
reaction times. There was a reliable effect of Accuracy $F(1,184)=85.65$, $p<.001$, correct responses were reliably faster than error responses (1992ms and 2666ms). There was also an interaction between Accuracy and Nsize $F(1,184)=6.16$, $p<.0139$ (Figure 5.10B). Correct responses were marginally faster for low neighbourhoods words than for high neighbourhood words ($t(110)=1.901$, $p=.0598$). The opposite pattern, slower correct responses than error responses, was evident but not reliable ($t(78)=1.55$, $p=.1$). AC was marginally faster to make a correct response in the low neighbourhood set.

![Figure 5.10: Neighbourhoods. A: Accuracy. B Reaction time](image)

**Discussion**

**Main findings**

- The accuracy advantage of high over low frequency words was only reliable in the high neighbourhood set.
- The effect of neighbourhood on high frequency accuracy was not reliable.
- There was a marginal (.07) effect of neighbourhood on low frequency accuracy.
- High neighbourhood words were slower than low neighbourhood words.
- There was no effect of frequency on latency, and no interaction between frequency and neighbourhood size on latency.
- Correct responses were marginally faster (.06) than errors, but only in the low neighbourhood set.
AC’s overall accuracy was comparable to the previous experiment. There was no
time limit on this experiment, and his latencies of around 2 seconds were much the same as latencies to the 3 second condition in the previous experiment. Overall, high frequency words were more accurately read than low frequency words. In high neighbourhoods, high frequency words were more accurate than low frequency words. High frequency words are able to resist neighbour competition better than low frequency words. In the terms of the interactive activation model, their higher resting level allows them to accumulate activation quickly and inhibit the competition. Low frequency words have both the disadvantage of low frequency, and the disadvantage of the inhibitory influence of higher frequency neighbours. Hence, the reliable difference between high and low frequency words in the high but not the low neighbourhood sets. The effects of frequency and of neighbourhoods are mediated by lexical processing in the interactive activation framework. Low frequency words in high neighbourhoods have two disadvantages. They have low resting levels, and they are subject to inhibition from higher frequency competitors. Words with higher frequency neighbours are harder to identify than words without higher frequency neighbours in tasks such as progressive demasking (Grainger et al. 1989). These effects are thus based on a complex interaction between frequency and neighbourhood, both of which are thought to be mediated by lexical processing (Behrmann et al. 1998, Andrews 1989, Arguin et al. 1998).

Andrews (1997) reviews evidence for facilitatory and inhibitory effects of the frequency-neighbourhood interaction with normal subjects. She concludes that neighbourhood size is generally facilitatory for naming single short low frequency words, and inhibitory in perceptual identification tasks such as the fragmentation and progressive demasking task. Carreiras, Perea and Grainger (1997) report that the inhibitory effects of neighbourhood are particularly prominent in tasks which involve identification of specific target words, as opposed to lexical decision, for instance, which does not. The inhibitory effects of neighbourhood on low frequency words reviewed earlier have all arisen with tasks, procedures, and fragment types, which engage lexical completion.

The inhibitory effect of neighbourhood size on low frequency words reported by Snodgrass and Mintzer (1993) was marginal (.07) in the low frequency set, and absent
in the high frequency set. If AC’s single word reading was mediated by word level representations, then an inhibitory effect of neighbours on low frequency words would not be surprising in view of previous results. Several results in the previous experiments were thought to argue against sublexical completion. AC’s 1 second response time in the 100msec reading test, produced equivalent levels to accuracy to tests in which he had unlimited time, and suggested that he does not retrieve completions. The consistent indications of unproductive refixation, and the absence of any indication of serial processing, suggested that he does not assemble completions.

In any case, these are not thought to be lexically mediated processes, and the sublexical retrieved completion and revision processes were found to produce facilitatory effects of neighbourhood. The three possible lexically mediated routes in PSP (as it stands) are primary process, scanned completion and cohort completion. Scanned completion would be expected to produce inhibitory effects of neighbours. The general absence of evidence for serial letter processing argues against this option. However, the next experiment looks at the word length effect and so it is not ruled out. There is no evidence that lexical facilitation is inhibitory, and as an integral part of normal primary lexical access, it might be expected to benefit from neighbours (Andrews 1997). The most likely processes responsible for the effect are cohort and scanned completion, both of which may produce inhibitory effects of neighbourhood. The remaining experiments attempt to narrow the options further.

As mentioned in the introduction the rather unusual step of including a pooled error analysis at the end of this experiment is taken for two reasons. The first is that by this point in testing, enough errors had been accumulated to perform the analysis, and the second is that it informs the next experiment.

**Pooled Error analysis**

The following analyses are based on a corpus of 500 errors made to 279 four-letter words used in the tests reported in this thesis. A larger corpus, which includes longer word lengths, is included in the appendix. Of the 500 errors, 34% (170) were longer than the target, 4.5% (23) were shorter, and 61.5% (307) were the same length. Only same length errors were entered into the analyses.

**Positional match**
Table 5.12: Neighbourhoods. Target-Error letter match.

<table>
<thead>
<tr>
<th>Letter Positions</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% match</td>
<td>71</td>
<td>54</td>
<td>38</td>
<td>35</td>
</tr>
</tbody>
</table>

An analysis of the positional match between letters in targets and letters in errors confirms a general gradient of accuracy in identified letters over positions from left to right for AC. Figure 5.11 shows a gradual decline in the match between target and error from left to right. This provides general support for the idea that AC's ability to identify letters at the ends of even four letter words is severely restricted. His letter naming accuracy in the first position in Experiment 2 was about 90%. The drop to 70% match here may suggest erratic fixation. In view of the visual search (E5.1) and lexical decision (E5.3) results, which both indicated intact processing in the LVF, the gradient of accuracy in Figure 5.11 suggests that AC does not compensate for RHH. The use of the ‘white box’ method of presentation means that AC could compensate by fixating at the right of the box which was visible between trials. Serial inspection of letter positions might be expected to improve target–error match at rightward positions in the word. Several results suggest that given time, AC will refixate to the RVF, but this does not seem to improve performance on the rightmost letter positions.

**Neighbourhood Analysis**

Frequency ratings were obtained for the errors. Neighbourhood size was calculated for all the targets. All other words sharing 3 letters in the same position as the targets were considered neighbours and tallied (Coltheart et al. 1977). This information was used to explore the implications of this experiment, namely that

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inhibitory effect of neighbourhood should be reflected in the nature of the errors. With this definition 37% of the same length errors were neighbours of the target. Of these neighbour errors, 53% were higher in frequency than the target. This indicates a substantial influence of neighbours on performance, but underestimates the effect of orthographic similarity on errors. It was noted in the error analysis of Experiment 2 in Chapter 3 that distractors were often visually similar even if they did not qualify as neighbours under current definitions. If we loosen the definition of neighbours slightly to any word sharing 2 letters in the same positions with the target (visual neighbours), the proportion increases. Thus 67% of AC’s errors share 2 or three letters with the target, and 55% of these errors are higher frequency neighbours. It is probable that these figures still underestimate the effect of neighbourhood because all errors longer than the targets were not considered (37%). Most of these were extensions (love-lovely) and so were highly similar words. Overall, these results are consistent with the idea that a proportion of AC’s responses was completions, largely motivated by the initial letters of words.

**Conclusion E5 Neighbourhoods and Frequency**

With accuracy, there was an effect of frequency in high neighbourhood size words, and frequency made little difference in low neighbourhoods. The advantage of frequency in high neighbourhoods may be related to competition associated with neighbours. There was a marginal effect of neighbourhood in low frequency words, and no effect in high frequency words. Hence, the inhibitory effect of neighbourhood was more prominent in low frequency words. Both the advantage of high frequency and the advantage of low neighbourhood, with accuracy, were qualified by the other factor. This is consistent with a lexical competitive process in which frequency and neighbourhood size interact, such as the lateral inhibitory process embodied in word level representations of the interactive activation model of word recognition.

Only neighbourhood size had an effect on latency, and this was inhibitory. Primary process is associated with effects of frequency on latency, and facilitatory effects of neighbourhood size on latency. Thus although some responses may be primary identifications, the overall pattern of inhibitory effects of neighbourhood size on both accuracy and latency suggest a different process. The effect of neighbourhood
on latency might be related to a longer time to resolve cohorts in high
neighbourhoods. The process of cohort completion was compared to parameter
adjustments in the interactive activation model, which predicted an advantage for high
frequency and low neighbourhood words on accuracy. The latency advantage for low
neighbourhoods may be explained by faster resolution times associated with fewer
competing neighbours. Hence, the absence of an effect of frequency on latency and
the inhibitory effects of neighbourhood size may be explained by the intervention of
cohort completion. Overall, the results suggest a lexical completion process, which is
not primary process, and in view of previous results, is not serial. Cohort completion
may be the most suitable of the secondary processes proposed to explain these results.

5.7 Experiment 6. The Word length effect.

Introduction

The hallmark effect of letter-by-letter reading is the Word Length effect. Linear increases in identification latency with word length suggest that, whether or not patients name letters, a serial process is involved in establishing letter identities. The more letters in the word the longer this process takes, and hence the word length effect. One of the early studies of letter-by-letter reading (Warrington & Shallice 1980) concluded that the probable cause of letter-by-letter reading was a compromised word form system. The purpose of letter naming was to establish letter identities. In much the same way that the spelling system may be consulted on the spelling of ‘Dog’, to which it should provide the information d-o-g, letter identities may be fed ‘in reverse’ to the spelling system, thus identifying the word. We have little data for this secondary process. It seems clear however from Behrmann et al.’s (1998) review, and the results on AC so far, that letter-by-letter reading is consistent with considerable residual primary process function. An alternative suggestion by Patterson and Kay (1982) was that the established identities are submitted to the word form system. The variety of possible mechanisms was reviewed in Chapter 4.

This experiment will focus primarily on the suggestions of Behrmann et al. (1998) and their implications. They suggest that letter-by-letter behaviour is an extension of a normal process of scanning or refixation seen in all readers when
reading difficult text. Serial letter processing serves to enhance letter activation by attentional rescaling to letter scale or multiple refixations, hence enhancing word level activation. Frequency and Imageability are seen as ‘markers’ of lexical processing.

- Frequency is the resting level of lexical units, and imageability is the sparseness of semantic level representations (highly imageable words have more semantic features). Lexical and semantic representations are partially activated and would be expected to support processing in proportion to their activation. This will scale with frequency at the lexical level, and cascaded relations with semantics predict a scaling with Imageability. Processing would converge more quickly on high frequency and imageability targets.

- They suggest that word length should interact with these top-down effects. Weekes (1997) reports no effect of word length on naming latency for high frequency words, a small one for low frequency words and a large effect with nonwords using normal subjects. They suggest that this may be related to processing time. As processing time increases, higher level representations accumulate more activation and are thus able to exert a stronger top-down effect. That is, the longer it takes to process a word, the more likely it is that any advantages it might have in terms of frequency or imageability will impact processing through the cascaded relations between levels of representation. An initial frequency differential increases as processing proceeds in systems that use lateral inhibition, and are cascaded. Given these conditions, effects of both frequency and imageability would be expected to intensify the longer processing goes on.

- Because letter-by-letter readers take longer to process 8 letter words than to process 3 letter words, for instance, the implications are that the effect of frequency and imageability will be larger for 8 letter words than for 3 letter words.

- The top-down effects are seen as impacting latency to name. The predictions for both frequency and imageability are supported by Behrmann et al. (1998) with results from a number of their patients.

Behrmann et al. do not discuss the possibility that the lexical variables may interact with length on accuracy. This is explored in the analysis reported below. It is possible for instance, that longer processing time may increase the probability of an
error, or index a change in strategy that may be more error prone. Longer processing may also amplify the inhibitory effects associated with neighbourhood size and neighbourhood frequency Grainger and Segui’s (1990). A further question not discussed, was the issue of the interaction of the three factors. If imageability effects derive from semantics and frequency effects from the orthographic input lexicon, then presumably, on additive factors logic (Sternberg 1969), frequency and imageability should show an additive relationship. Their effects are both scaled by processing time, and derive from separate processing domains and hence might be expected to have independent effects related to the same manipulation. However, interpretations of data in terms of “processing stages” become difficult when cascaded relations blur the boundaries between ‘stages’.

Serial processing is associated with effects of frequency and imageability principally because of its effect on processing time. Thus, any other process, which also prolongs processing within an interactive-cascaded system, might be expected to show similar effects. A word length effect is compatible with parallel as well as serial processing (Howard 1991; Price and Humphreys 1992). Primary process, in coping with degraded input, might be expected to take longer to process words, and this slowing of processing might be expected to scale with length simply because of the additional processing requirements involved with longer words. In other words, even if a word length effect is demonstrated for a patient, further tests would be required to decide whether the cause of the effect could be attributed to serial letter processing. Furthermore, if serial processing is not available to a patient, they may still show a word length effect and this may still interact with frequency and imageability. There is a possibility however that the word length function produced in this case may not be the same as one produced by serial letter processing, that is a linear function. The previous experiments failed to find any evidence of a serial component in AC’s identification of words, which on the surface might suggest that a word length effect was unlikely. However, it may still be a feature of AC’s reading. The main objective of the current experiment was to establish if AC showed a word length effect, and to explore the predictions made by Behrmann et al (1998) with respect to length, frequency, and imageability, and their interactions.
Note that the experiment was conducted on a computer and as usual, AC did not name letters. If a word length effect were to emerge, it would be unrelated to naming behaviour.

Objectives

To establish whether AC shows the word length effect. To explore the relationship between word length, Frequency, and Imageability. To consider the possibility that the WLE is not necessarily tied to serial processes.

Method

Design

There were three factors. Imageability ratings from the Oxford Psycholinguistic Database (Quinlan 1992) were used to assign 360 words into high and low imageability groups. This was the first factor ‘Image’ with two levels, high and low (Hi, Li). The same words were sorted by frequency data from the same database into high and low groups, to serve as the second factor, Frequency, with two levels high and low (HF,LF). The 360 words were made up of equal numbers of 3, 5 and 8-letter words, which constituted the third factor, Length, with three levels 3, 5, and 8. There were 30 words in each cell of the 2 * 2 * 3 design. Accuracy and latency to name the words was recorded.

Apparatus and Materials

The word set described above was made up of 120 words of each length (3,5,8). Mean frequency (Kucera & Francis 1967) for high frequency words was 1018 (SD 2739) and for low frequency words was 2.92 (SD 3.8). Mean imageability ratings (MRC, Quinlan 1992) for high image words was 531.2 (SD 86.6) and for low image words was 295.7 (SD 65.8). In each length group, 60 of the words were high and 60 were low frequency. Half of each group of words was high and half low imageability. Presentation and response recording were controlled by computer programs. The display used the ‘white box’ method described in the previous experiment. The box size was slightly larger than an 8-letter string, and remained a constant size throughout. All words were presented centrally in the box in black 48-point font.
Response times were determined by a voice trigger unit connected to a microphone and to the computer. A second microphone recorded all responses as individual sound files on to the computer for later analysis. Accuracy was determined from these sound files. Each trial was initiated by the experimenter with a button as described in previous experiments. This allowed for pauses for coughs and so on.

Procedure

AC was seated at a computer terminal in a sound attenuated test booth. An initial practice session was used to remind AC of the procedure and to calibrate the voice trigger equipment. AC was allowed to position the white box on the screen and as usual positioned it to the left side of the screen. The experiment was run as a single randomised block of 360 trials. Button control allowed rest pauses at points requested by AC. The necessity to be as quiet as possible until response, meant that coughs, seating adjustments, and itches, had to be fitted in with ‘time out’ calls. AC understood the conditions of testing and requested pauses when required. Each trial was identical and started with the experimenter pressing a button. A ready signal appeared in the box for 500ms, and was then replaced with the trial word. A voice response removed the word from the box and timings were calculated from word onset to trigger. These were recorded by the program along with a recording of the actual response. The next trial commenced with another button press.

Results

Two 3 letter and two 5 letter words (all low Imageability low frequency) were discarded from the analysis due to times longer than 3 standard deviations above the mean. Twelve words (3.3%) failed to trigger the voice key and were eliminated from the analysis (5 high and 7 low imageability), (9 low and 3 high frequency), (3, 3, and 5 for 3, 5, and 8 letter words respectively).

Accuracy

Overall accuracy was 58%. Highly imageable words were more accurate than low (66% and 51%), $X^2 = 7.38$, df=1, $p=.01$. All 2 by 2 $X^2$ values are corrected for continuity (Yates). Separate analyses for high and low frequency words showed,
however, that the advantage of high Image words over low Image words was reliable in the low frequency set $X^2 = 15.74$, df=1, $p<.001$, but not in the high frequency set $X^2 = .01$, df=1, $p=.93$ set. High frequency words were no more accurate than low frequency words (59% and 58%) $X^2 = .01$, df=1, $p=.926$.

<table>
<thead>
<tr>
<th>Imageability</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Frequency</td>
</tr>
<tr>
<td>Low</td>
<td>69</td>
</tr>
<tr>
<td>High</td>
<td>69</td>
</tr>
</tbody>
</table>

Table 5.13 Percent Accurate for Imageability and Frequency by Length.

A: Imageability by Length

B: Frequency by Length

Figure 5.12. Percent Accurate for A: Imageability and B: Frequency by Length

Accuracy by length was 69%, 61% and 45% for 3, 5, and 8 letter words. These differences were reliable, $X^2 = 14.67$, df=2, $p<.001$. There was no difference between 3 and 5 letter word accuracy $X^2 = 1.44$, df=1, $p=.231$, but 8 letter word accuracy differed from 3 ($X^2 = 13.14$, df=1, $p<.001$) and 5 letter word accuracy ($X^2 = 5.36$, df=1, $p<.05$). A separate analysis of Low Image words revealed differences in accuracy with length $X^2 = 18.69$, df=2, $p<.001$. There was no difference between 3 and 5 letter words $X^2 = 2.80$, df=1, $p=.09$, but there were differences between 8 and 3 letter words $X^2 = 17.0$, df=1, $p<.001$, and between 8 and 5 letter words $X^2 = 5.47$, df=1, $p<.05$. These differences in accuracy with length were restricted to the Low Image set. The corresponding analysis for High Image words was not reliable $X^2 = 1.47$, df=2, $p=.478$.

Differences in accuracy for Low Frequency words with length were not reliable $X^2 = 3.22$, df=2, $p=.199$, but were for High frequency words $X^2 = 13.9$, df=2, $p<.01$. There was a difference in accuracy between 3 and 8 letter words $X^2 = 11.7$,
The difference in accuracy for low and high imageability 8 letter words was reliable $X^2 = 9.38$, df=1, p<.01. This effect of imageability was not reliable for 5 letter words $X^2 = 2.57$, df=1, p=.109, or for 3 letter words $X^2 = .02$, df=1, p=.89. These results are in line with Behrmann et al.'s (1998) prediction of larger effects of imageability for longer words. The effects of word length on accuracy were not linear, and were confined to differences between 8 letter words and the shorter words in the low imageability set, and differences between 8 and 3 letter words in the high frequency set.

**Reaction time.**

An analysis of variance using Image, Frequency, and Length on naming times for correct responses revealed no effect of Image $F(1,189)=.06$, p >.8, no effect of Frequency $F(1,189)=1.31$, p=.2., and an effect of length $F(2,189)=17.39$, p<.001. There was an interaction between imageability and frequency $F(1,189)=4.45$, p<.05. Neither the interaction of imageability ($F(2,189)=1.82$, p=.16) nor of frequency ($F(2,189)=.18$, p=.8) with length were reliable.

The effects were qualified by a 3 way interaction between Length, Image and Frequency $F(2,189)=3.36$, p<.05. The interaction is shown Figure 5.13. The 3-way interaction was caused by an interaction between imageability and length in the high frequency set ($F(2,97)=5.52$, p<.01), and not in the low frequency set ($F(2,92)=.37$, p=.7). The simple effects of low imageability were not significant in either the low ($F(2,32)=2.13$, p=.14) or the high frequency ($F(2,49)=1.62$, p=.20) sets. The high imageability simple effects were however significant in both frequency sets, LF($F(2,60)=5.56$, p<.01) and HF($F(2,48)=11.08$, p<.001). Hence there was no word length effect for low imageability words in either frequency set, but there was for high imageability words in both sets. In the high frequency / high imageability set, the simple effect was due to a large increase in latency between 5 and 8 letter words ($t(29)=3.36$, p<.01). There was no 3-5 letter difference and so the simple effect is a stepped function. The word length effect in the low frequency, high imageability set does appear linear, but the 3-5 letter difference was not reliable ($t(20)=1.6$, p=.11), the
5-8 difference was marginal ($t(49)=1.75$, $p<.09$) and only the 3-8 difference was reliable ($t(39)=3.35$, $P<.01$) and so this is also a stepped function.

![3-way interaction between length, Image and Frequency](image)

Figure 5.13: 3-way interaction between length, Image and Frequency

The restriction of length effects to high imageability words is difficult to accommodate with a serial processing explanation for latency increases with length. The serial processing explanation does however assume that the same processing strategy is applied to all words. The stepped functions are more consistent with a change in strategy to cope with longer words. Note that the word length effect in accuracy was restricted to the low imageability set. Hence, high imageability words are associated with good accuracy over length and increasing processing time. Low imageability words are associated with consistent time and decreasing accuracy.

The largest imageability difference, in 8-letter high frequency words, was marginal ($t(21)=1.9$, $p<.07$) and all the other imageability differences were not reliable. The high imageability / high frequency 8-letter word time may be a spurious result associated with low data points. However, it is possible that their special status engages semantic level processing to the point of interfering with the task. Besner Smith and MacLeod (1990) for instance, suggest that semantic processing can 'block' letter processing under certain circumstances. That is, if AC were to focus on the semantics of these correctly identified long words (an unusual event for AC) he may be delayed in making responses. Hence there were no effects of imageability or frequency scaling with length, and the word length effects, which were restricted to
the high imageability sets, were not linear, but stepped. That is, there were no differences between the shorter word lengths, only differences between them and 8-letter words.

Proportion Fast responses

An alternative method of exploring serial effects was undertaken. Times by Length (3,5,8) were 1207ms, 1341ms and 1963ms. Post hoc t tests revealed differences between 5 and 8-letter words $t(118)=4.18$, $p<.001$ and between 3 and 8-letter words $t(129)=5.45$, $p<.001$, but not between 3 and 5 letter words $t(149)=1.57$, $p=.12$. The graph in Figure 5.14 shows the resulting step function. The usual function for letter-by-letter readers is a linear one. The 140ms difference between 3 and 5 letter words, and the 600ms difference between the 3/5 and 8-letter words, suggested that AC might be using a different strategy to read 8-letter words.

![Figure 5.14: Word length effect](image)

One method of determining the degree to which a patient uses residual parallel processing in conjunction with a serial processing strategy, suggested by Howard (1991), is to plot the log of the proportion of correct fast responses against word length (Figure 5.15). The criterion for a fast response is arbitrary. Any response latency less than twice the shortest recorded latency in an experiment is considered ‘fast’. Howard reasons that on any trial there is a probability $p$ that a letter is recognised correctly. For a word, $n$ letters long, the probability of all letters being recognised correctly $C$ is $p^n$. Thus $\log(C) = n \log(p)$. On some trials $1-p^n$, one or more letters are misidentified, and the result may be another word, in which case the patient makes an error, or the result will not be a word, in which case the patient resorts to a
serial letter processing strategy. As word length increases the probability of relatively fast, parallel responses declines, because \((1-p)^n\) increases the probability of the serial processing strategy. A plot of log (proportion of correct fast responses) by word length would produce an increasingly steep slope with word length for patients who process predominantly letter-by-letter. This is because as word length increases, the probability of a fast response falls off rapidly. A mixture of parallel processing and serial processing when letter identification fails would produce a linear slope through the origin. The gradient of the slope is the probability of misidentifying a letter.

![Figure 5.15 Log proportion of correct responses](image)

Figure 5.15 Log proportion of correct responses

Note that the argument might also be applied to an alternative strategy of single refixations rather than serial processing. That is, with AC, fast responses may be made from letters processed in parallel, and slow responses involve a refixation to bring parallel resources to bear on his impaired field, not an adoption of a serial strategy. In this experiment, AC’s minimum time to make a correct response was 610ms, and so criterion was 1220ms. Overall, accuracy by length (3,5,8) was 69%, 61% and 45%. Of these correct responses 68%, 51%, and 22% were fast responses and their log values were -0.17, -0.29 and -0.65. AC produces large numbers of relatively fast responses at short word lengths and only 22% of his responses are relatively fast at 8 letters.

The log values are plotted in Figure 5.15. It might be argued that the plot shows an increasingly steep slope with length and hence is the profile of a predominantly serial reader. However, several factors argue against this interpretation.

The line drawn through the origin and through the points for 3 and 5 letter words is consistent with Howard’s (1991) prediction for a predominantly parallel and
intermittently serial reader. Accuracy and latency were equivalent for 3 and 5 letter words, and the mean latency difference between them was 140ms. This suggests that the 3 and 4 letter words were processed in the same way, predominantly parallel and occasionally serially. However, because of the absence of indications of serial processing, I would want to argue that this slow process might have been refixations.

![Distribution of responses to 8-letter words](image)

Figure 5.16: Distribution of responses to 8-letter words.

The times involved are important. Howard’s patients were much slower (e.g. PM takes 15 seconds to read a 9-letter word, and the fastest responses at this length were 2.5 seconds). AC’s times were much faster (mean latency for 8-letters words was 1963ms, and the fastest response was 767ms). There were 11 responses below criterion. Figure 5.16 shows that the majority of AC’s slow responses to 8 letter words were still below 2 seconds. In other words, the absolute magnitude of the times involved put some bounds on the possible mechanisms mediating the fast and slow responses. In this case, the evidence suggests that slow responses are more consistent with more frequent refixations or longer fixation times. The times involved in refixation and scaling attention to letter scale in Experiment 2 were about 4 seconds. This argues against AC being able to undertake serial letter identification over 8 letter words in 2 seconds. The serial processing deficit is tested directly in the next experiment by vertical word reading.

**Discussion**

**Main Findings**

**Accuracy**
• High Image words were more accurate than low, but only for 8 letter words in the low frequency set.
• There was no overall effect of frequency.
• There was an overall effect of length but later analyses showed that this was confined to differences between 3 and 5 and the 8 letter words in the low imageability set, and to differences between 3 and 8 letter words in the high frequency set.

Latency
• A 3 way interaction. Imageability and length interacted in the high but not the low frequency group.
• Word length effects were restricted to low imageability sets, with no differences between 3 and 5 letter words, but differences were found between 3 and 8 letter words.
• The only reliable difference between high and low imageability latency was for 8 letter words.

A word length effect is generally taken to mean a linear increase in naming time with word length. Letter-by-letter reading implies a serial sequential letter encoding process which would be expected to produce longer naming times with each additional letter processed and hence the linear time function. A linear function was not found for AC. His overall times to name 3 and 5 letter words were similar at about 1.3 seconds, and different from his times to name 8-letter words at about 2 seconds. The word length effect was only reliable in the high imageability sets, and was stepped in both. The stepped function was also apparent in the analysis of the proportion of responses that might be considered ‘fast’ at the different word lengths. The prediction with these proportions was that a gradual decrease in the proportion of fast responses would be expected with increasing word length. The results 68, 51 and 22% respectively also suggested a stepped function. This stepped function was also found in accuracy restricted to low imageability words. The 3 and 5 letter words produced accuracy rates of 69 and 53 percent while 8-letter words were reliably less accurate at 27 percent. This is a word length effect of sorts, just not a linear one. That is AC reads 3 and 5 letter words equally accurately and in the same time. A serial process would be expected to produce a reliable difference between 3 and 5 letter words. He is reliably less accurate at 8-letter words and takes reliably longer to read them.
This suggests that an additional component is involved in processing 8-letter words, that this takes time, and that it introduced an element of error. The additional time of about 600 msec suggests a refixation to deal with 8-letter words. The extra time may reflect the involvement of serial letter processing, however two results from previous experiments suggest that a single refixation may be a better explanation. In Experiment 1, accuracy in the right visual field at 3s presentation was explained by refixation and not serial processing because there was no effect of display size. This time increment was about 400msec. In Experiment 2, AC was reliably slower at naming letters in the third position compared to the first. This may have been related to refixation, but also to narrowing the scale of processing to letters. The times on this task were much longer generally (3s compared to 1 second on features) and the additional time to third position naming was 600msec. These results combine to support the idea that AC refixates for 8-letter words, and that the gain from bringing intact parallel processes to bear on words, unlike simple features, is small. Perhaps this is related to erratic fixation in the impaired field (Zihl 1995). This also supports the idea that his responses to short words are largely based on information acquired in the left visual field by parallel processes. In terms of the PSP model, his responses are based on cohort completion. Refixation may produce little more information than the original intake in the left visual field. The combination of high accuracy with length increases, coupled with increases in time for high imageability words argues for a lexical / semantic completion process rather than a sublexical process.

The relationship of word length to frequency and imageability was complicated by the absence of a linear rise in processing time with length. The equivalent processing times for 3 and 5 letter words meant that no differences would be expected in this length range. However longer processing times would suggest differences between this range and 8-letter words. The discussion above raised the possibility that this time was largely occupied with adjusted fixation and so may not produce an effect. The original prediction is based on the same processes operating at all lengths. Overall high imageability words were more accurately read than low imageability words. The difference was not reliable for 3 letter words, marginal for 5 letter words and significant for 8-letter words, where low completion rates for low imageability words were largely responsible for the effect. This trend to effects of
imageability on accuracy by length could be taken as support for Behrmann et al.‘s (1998) prediction. There was no effect length on accuracy with high frequency words was restricted to a difference between 3 and 8 letter words.

The main finding was a stepped word length effect. This is interpreted as adding another piece of evidence in support of the notion that AC does not use serial secondary processes to identify words. Refixation may be involved in processing 8-letter words, but short words appear to be processed largely by primary process or cohort completion.

**Conclusion E6 Word length**

High imageability words were more accurate than low imageability words but only in low frequency words and only for 8 letter words. High imageability words were equally accurate across length while accuracy fell between 3 and 8 letter words in the low imageability set. Hence, the main indication of a word length effect in accuracy was a stepped function in low imageability words. Larger effects of imageability at longer word lengths suggested a larger role of top-down processes with longer words. The absence of an effect of length on high imageability words also suggested higher level involvement in processing. In the absence of indications of a serial letter processing strategy, this would be consistent with a lexical completion process that is delayed by longer words.

The latency data produced a 3-way interaction. The only effect of imageability was for 8-letter words in the high frequency set, due to a large increase in latency for high imageability words. This may have been a spurious result based on few data points. The only effects of length were found in the high imageability sets, and these were differences between 3 and 8 letter words and so stepped functions. Overall, the conclusion was that AC does not show a linear word length function. The stepped functions were consistent with a change in strategy between the shorter and 8 letter words. The absence of linear imageability effects with length may thus be explained by the stepped word length effect.

The analysis of proportions of ‘fast’ responses was interpreted as consistent with the idea that AC used a predominantly parallel process with short words and a
different strategy, which may have involved more frequent use of refixations, with longer words.

5.8 Experiment 7. Vertical words.

Introduction

The letters in single short words are processed in parallel (Humphreys 1985). Mirror reversed words, vertical words, words rotated through more than 60 degrees, or words with letters displaced from the horizontal line may result in word length effects (Howard 1991). These manipulations are thought to prevent normal parallel access to orthographic lexical representations. A serial letter processing strategy is thus used to identify words, resulting in a word length effect. Ellis, Young and Anderson (1988) report slower lexical decision latencies and Young and Ellis (1985) report lower accuracy, with vertically aligned words compared to horizontal ones. Letter-by-letter readers are seldom tested on vertical words, because the change in orientation should have no effect on their reading if their primary method of word identification is serial letter identification.

A comparison of error corpora for RYT (Warrington, 1991) and AC is undertaken in the next section. RYT is a neglect patient with attentional dyslexia and had been tested on vertical word reading. He read 13% of vertically aligned words correctly compared to 55% accuracy for horizontally aligned words. There was no time limit on reading. RYT adopted a slow serial letter processing strategy. Warrington suggests that his very low accuracy might be due to poor spelling. It may also have been related to his attentional dyslexia.

The results of the previous experiments suggested that serial letter identification is compromised by AC's condition. This predicted problems in vertical word reading. This experiment tests AC's reading of vertical words.
Method

Design

Thirty high and thirty low frequency 4-letter words were used. These were presented in random order. The words were on view for a maximum of 3 seconds, but unlimited time was allowed for a response. The experimenter recorded accuracy and time to response by button press.

Apparatus and materials

The words were taken from Besner and McCann (1987). Frequencies were not provided in the source, and the words are included in the corpora section of the appendix in Tables 3 / Set 2. Words were presented on a computer screen in 48-point font using the white box method described in previous experiments. The box was wide enough to accommodate one letter and tall enough for a four letter word. AC was allowed to position the box on the screen, and directed it to the top left-hand corner.

Procedure

AC was seated at the normal viewing distance at a computer terminal in a quiet room. Each trial was initiated by button press. The task was simply to name the word on the screen. Responses were recorded by the experimenter before initiating the next trial with AC’s consent.

Results

AC identified 9/30 high frequency words, and 4/30 low frequency words. Accuracy with horizontal presentation of 4-letter words in Experiment 4 was 70% for high and 37.5% for low frequency words. The corresponding rates here were 30% and 13%, and were not reliably different ($\chi^2 = 2.45$, df=1, $p=.12$). The characteristic frequency effect on accuracy was thus abolished by vertical presentation. Latency to name the words was 4178ms for high and 4316ms for low frequency words. This difference was not reliable ($t(58)$=.30, $p=.76$). Response times with horizontal presentation were about 2 seconds, hence vertical alignment doubled latency.
Table 5.14: Vertical Words. Targets and errors. * Note: pass = no response

Discussion

The results suggest that AC does have a deficit in serial letter processing. If we assume that cohort completion plays a role in his identification of horizontally aligned words, then the fall in accuracy in this experiment, particularly for high frequency words, could be explained by the loss of this secondary process. Three seconds may not be enough time for AC to identify all the letters, but it should have been enough to identify the first two. If AC's identification of horizontally arrayed words were retrieved completions, he would have been expected to perform as well with vertically arrayed words. This may mean that AC identifies more letters in horizontal words than vertical words, or that parallel processing plays a role in his performance with horizontally arrayed words. The latency difference between the two experiments suggests that the involvement of cohort completion in horizontal words may be the better explanation.

The results also suggest however, that AC's serial processing deficit may not be entirely explained by his RHH. This condition would be expected to affect fixation accuracy within the right visual field. The requirements of this task were to fixate down through the letter positions. This may indicate a higher level deficit. However, it seems likely that serial letter processing is not an option open to AC, which may explain the absence of evidence for scanned retrieved or assembled completion in the
previous experiments. The results are interpreted as further evidence for a cohort completion process.

**Conclusion E7 Vertical words**

The very poor accuracy and the absence of effects of frequency on accuracy or latency suggest that AC was using ‘pure guessing’ as a strategy on this task. Most of his errors began with same letter as the target and so AC was encoding the first letter. Many of the second letters were also encoded and appeared in errors. The vertical alignment of the words meant that this may be a situation in which, without the aid of lexical processing, AC was forced to retrieve completions. The very poor accuracy is thus a reflection of the difficulty in pure guessing a target word correctly from its first or first and second letters. As such, the experiment supports both the serial processing deficit hypothesis, and the cohort completion hypothesis. That is, AC’s normal level of accuracy demands the intervention of a more precise completion process not based on serial processing.

The apparent difficulty in serial letter processing in a vertical plain may not be consistent with an entirely RHH based explanation for the serial processing deficit. This will require further testing establish.

**5.9 Computational error Analysis**

**Functional deficit and classification in peripheral dyslexia**

AC’s initial classification in clinic as a letter-by-letter reader was based largely on his behaviour. The label is a correct description of his behaviour in clinical confrontation with no time limits. However, this behaviour only raises his performance above the levels of accuracy we saw at 3 seconds and 100msec presentation rates, if he treats each word almost as a puzzle, and is meticulous about letter identification. This is not a mode of ‘reading’ he can sustain, and so he names letters in words while reading, but derives no increase in accuracy from the process. It was suggested that this might be related to scanning difficulties associated with RHH. He may read letter-by-letter for several reasons. The first is that he is probably unaware of the fact that he does just as well without it. The second is that because it is
a normal strategy, it seems the thing to do when a word fails to ‘pop’ into mind as it should do, and the third is that he was taught to do it. The proposal developed from the previous experiments is that AC is compromised on the very processes that might support higher accuracy with letter-by-letter reading namely serial secondary processes. By using limited presentation and removing the overt behaviour, it was hoped that the functional deficit leading to a failure of primary lexical access, to which the behaviour is a response, might be uncovered.

Much of the discussion in the experimental reports suggested that AC’s performance could be explained by supposing that his main strategy in reading words was to gather fragmentary information from the beginning of words, which then formed the basis of primary identification or cohort completion. There was little evidence to suggest that he used a letter processing strategy, and little evidence of revision processes. This predicts that his error patterns should be very similar to error patterns produced by right neglect patients. If right neglect patients fail to use information at the ends of words, and presumably have no motivation to verify their hypotheses against information they are neglecting, then there may be similarities between AC’s performance and right neglect performance. In other words, right neglect patients may not acquire more information by means of refixations or serial secondary processes because the information does not ‘exist’. AC does not acquire more information because, although he knows it’s there, he can’t acquire it. Both conditions thus produce responses based largely on partial information acquired in parallel. The ensuing error analysis compares AC’s performance with two other peripheral dyslexics, RYT (Warrington 1991) and AB (Lambon–Ralph & Ellis 1997)

Objectives

To compare RYT’s (a right neglect-attentional dyslexic) error profile to AC’s. RYT’s condition implies that he is restricted to using left visual field information and has no access to serial secondary processes. AC’s deficit might be described as equivalent to RYT’s in these terms, and so their error profile should be similar. AB (a possible neglect/visual dyslexic) is included in the analysis.
Participants

RYT

Warrington (1991) reported a right neglect patient, RYT who showed few signs of neglect other than with words. Warrington’s clinical assessment of RYT suggested two aspects to his reading difficulties

• “an "attentional dyslexia" which resulted in a decrement in his ability to read words and letters that were presented in the context of other words and letters. Thus his ability to read words and letters in an array was less good than when he attempted to read them in isolation (Shallice & Warrington, 1977).” (ibid. pp.196)

RYT’s reading accuracy was essentially the same with tachistoscopic presentations at 150ms as it was in free vision, and so “establishes that he is not attempting to read using a letter-by-letter strategy” (ibid. pp.202). Note that this condition would probably affect serial secondary processes and hence probably preclude letter-by-letter reading were he to attempt it.

• “a right neglect dyslexia affecting single word reading, which is the focus of this case report.” (ibid. pp.196). Her conclusion was “that right neglect dyslexia is a reading-specific deficit in which there is activation of an inappropriate visual word form.” (ibid. pp.193)

RYT is unable to uses serial secondary processes because of attentional dyslexia and hence does not use a letter-by-letter strategy. Furthermore, his right neglect means that he acquires partial information with which he activates inappropriate word forms. In the terms of PSP, he relies on primary completion or cohort hypotheses for responses and neither assembles nor revises hypotheses. AC showed few signs of neglect but acquires partial information probably because he fails to adjust fixation point to compensate for RHH. AC might be classified as an attentional dyslexic on the strength of his performance in the letter-naming task in experiment 2. However, Zihl’s (1995) analysis of RHH suggests that haphazard scanning and fixation related to this condition may be sufficient cause. The absence of secondary serial processes in both patients and their reliance on primary process or cohort completion suggests that they should produce very similar errors. Similar patterns of error would go some way to supporting the view of AC’s deficit developed over the course of testing.

Chapter 5, Page 242
AB

Lambon-Ralph and Ellis (1997) were unsure on AB's classification and “consider whether it constitutes a distinct form of peripheral dyslexia or whether it can be accommodated within one of the recognised categories (e.g. neglect dyslexia).” (pp. 954). He is included because the analysis may address the uncertainty over his classification.

AC

AC’s classification as a letter-by-letter-by-letter reader looks unlikely at this point. The possibility of new categories was raised by Lambon-Ralph and Ellis (1997). The proliferation of forms of peripheral dyslexia may not be productive, but a possible new category, which may be warranted, is Hemianopic Dyslexia (Zihl 1995) or Hemianopic Alexia (Leff et al., 2000). Zihl (1995) points out that parafoveal visual field loss is the single most common cause of reading difficulties. The condition is just as interesting as any of the other peripheral dyslexias in terms of providing data on which to build a broader model of word recognition. It might be included as a category of peripheral dyslexia. However, the main thrust of the thesis is to describe deficits in terms of residual primary and secondary processes. The number of possible conditions in these terms probably defies labelling. The focus would then be on the particular mix of component processes any particular patient brings to the task of identifying a word. Remediation in individual cases would then be based on devising a suitable strategy based on a detailed inventory of the surviving processes.

Analysis

Since Warrington and Zangwill (1957), the only documented examples of right neglect have been Hillis and Caramazza, (1989), Caramazza and Hillis (1990), and Warrington (1991). Both Warrington and Lambon-Ralph and Ellis published error corpora for their patients RYT (179 errors) and AB (204 errors). Over the course of testing, a 769 item-error pair corpus was accumulated for AC. Warrington (1991) performed an extensive error analysis, which is replicated here. Warrington’s analysis adopted a proposal for the definition of ‘neglect errors’ made by Ellis et al., (1987). They suggested that a neglect error is one where the response is identical to the target,
to one side of an identifiable ‘neglect point’, and where target and error have no other letters in common beyond that point. All three error corpora were analysed with a computer program written specifically for the purpose. The programs were checked against the data published by Warrington (1991), as a check on the accuracy of the algorithms used, and then applied to the AB and AC corpora. This ensured the same criteria for all three corpora in all error analyses presented below.

Comparison of RYT, AC and AB on neglect characteristics

The three corpora were compared with reference to the points characterising neglect dyslexia suggested by Warrington. These are numbered and listed below for reference. The comparisons will follow the same order as the points below. Where points are related (e.g. 2 & 3) they are treated together.

The main points characterising neglect dyslexia

“Error responses of left and right neglect dyslexia frequently have the following characteristics in common

• For the individual patient word length is not an important variable for competence in single word reading; except in those instances where a paradoxical inverse word length effect has been recorded (e.g. De Lacy Costello & Warrington, 1987; Patterson & Wilson, 1990).

• 2. There is maintenance of target word length in the neglect error response.

• 3. When exact maintenance of word length does not apply, additional letters are as common as omissions in the neglect error responses.

• 4. There is (with one notable exception, viz. Patterson and Wilson) a gradient of accuracy across words irrespective of word length.

• 5. A strictly defined neglect point is a function of word length.

• 6. Qualitatively similar responses have been reported with tachistoscopic presentation and in free vision.

• 7. Semantic similarity is infrequent and neologisms are uncommon responses.”

Warrington (1991 pp202)
Point 1 Word length.

RYT showed a stepped word length effect. His accuracy was around 50% for 3 to 6 letter words, and fell to 22% for 7 letter words. AC’s accuracy in Experiment 5 was 69%, 61% and 45% for 3, 5 and 8-letter words. Short word accuracy was equivalent but different from 8-letter accuracy. AC and RYT may both be sensitive to long words. AB showed no effect of word length on either accuracy or latency, may acquire information over the entire visual field, and hence may not be as sensitive to long words as RYT and AC.

Point 2 & 3 Error length

2. "There is a maintenance of target word length in the neglect error response.”

3. “When his exact maintenance of word length does not apply, additional letters are as common as omissions in the neglect error responses”

<table>
<thead>
<tr>
<th></th>
<th>-5</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RYT</td>
<td>0</td>
<td>1.1</td>
<td>4.5</td>
<td>9.5</td>
<td>25.7</td>
<td>31.8</td>
<td>20.1</td>
<td>5</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>AB</td>
<td>.49</td>
<td>0</td>
<td>2</td>
<td>4.4</td>
<td>19.1</td>
<td>35.8</td>
<td>24</td>
<td>7.4</td>
<td>6.4</td>
<td>.49</td>
</tr>
<tr>
<td>AC</td>
<td>.13</td>
<td>.65</td>
<td>1.3</td>
<td>3.5</td>
<td>8.5</td>
<td>50.7</td>
<td>23.2</td>
<td>9</td>
<td>2.2</td>
<td>.78</td>
</tr>
</tbody>
</table>

Table 5.15: Error Analysis. Percent errors for error-target length differences.

Figure 5.17: Error Analysis. Error lengths compared with Target length

Figure 5.17 shows the count of positional matches between errors and targets for the entire corpora of all three patients. Analyses of normal subjects’ error responses to component-letter fragments (Experiment 2, chapter 3) showed a preponderance of same length errors, and a degree of symmetry in the considerable numbers of errors longer and shorter than the target. There was a tendency to produce
more shorter than longer errors. AC makes considerably fewer errors 1 letter shorter than RYT and AB, and has a higher rate of same length errors than both RYT and AB, but overall the profiles are very similar for all three. Errors shorter than the targets are less common with AC, but the longer error profiles of all three fit almost exactly.

**Point 4 Length independent gradient of accuracy**

“4. There is (with one notable exception, viz. Patterson and Wilson 1990) a gradient of accuracy across words irrespective of word length.”

Following Warrington (1991) all positional matches between target and neglect errors were computed and divided by the total number of positional comparisons (matches and mismatches). This was done for each word length in all three error corpora, and plotted using two abscissa types, normal and variable. The variable abscissa allows beginning middle and end regions of the words to be superimposed (see Figure 5.18). RYT and AC show superficially similar gradients in normal plot. AB’s normal plot looks quite distinctive. The difference between RYT and the other two emerges when we look at the variable plot. Here we can see that it is not the gradient which is the important difference, but the fact that both AB and AC have a spread of accuracy at the ends of words. RYT is consistently unable to use information from the ends of words of any length. That is RYT is just as likely to neglect the end of a three-letter word as a seven-letter word.

AB’s profile on longer words is compromised by few data points on his performance on 7 and 8-letter words. For shorter words, AB’s gradient is very similar to RYT’s. Although accuracy gradients are present in all three, there is a constant gradient for RYT, which is not present for AB and AC. The fact of a gradient does not discriminate between peripheral dyslexics but the variability of gradient with length does. AC is more accurate at the ends of shorter words than he is at the ends of longer words. This may indicate a difference between the effects of degradation related to a visual defect and those related to an attentional deficit. That is, neglect dyslexics may have constant gradients while hemianopic dyslexics may have variable ones.
The same information is plotted on both the normal and variable abscissa graphs. In variable abscissa plots, word positions are categorised as beginning, middle and end.

Figure 5.18: Error Analysis. Normal and Variable abscissa plots.
AC may acquire more information about length with short words than he does with longer words. Overall, this point might be taken to confirm that AC is not a neglect dyslexic and that AB might be.

Point 5 Neglect points

5. “A strictly defined neglect point is a function of word length”

The mean neglect point for words of each length in the corpora were calculated from identified neglect errors. AC’s profile is almost identical to RYT (Figure 5.19). They both show a neglect point at about the fourth letter in seven letter words, the third in 5-6 letter words and the second below that. AB follows the initial part of the profile but seems to be able to deal with six letter chunks of information. A neglect point at the sixth letter of seven letter words suggests that AB uses information from the entire visual field. Much the same information about words may be lost through unadjusted hemianopia as through neglect.

<table>
<thead>
<tr>
<th>Word length</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>RYT</td>
<td>1.7</td>
<td>2.3</td>
<td>3.1</td>
<td>3.2</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>1.9</td>
<td>2.9</td>
<td>3.5</td>
<td>4.5</td>
<td>6.3</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>2.4</td>
<td>2.7</td>
<td>3.5</td>
<td>3.6</td>
<td>4</td>
<td>4.9</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Table 5.16: Error Analysis. Neglect points for neglect words

Figure 5.19: Error Analysis. Neglect points for neglect words

Point 6: Reading speed

“Qualitatively similar responses have been reported with tachistoscopic presentation and in free vision.”
As we saw in Experiment 4, this is a feature of AC’s reading. We have no data on this for AB.

Point 7: Semantics

“Semantic similarity is infrequent and neologisms are uncommon responses”. This applies to AB and AC.

Proportion of neglect errors: A new point?

Errors classed “right neglect” by the Ellis et al. (1987) definition were computed by identifying neglect points in all word error pairs and classifying those with no letters in common beyond that point as neglect errors. Errors that failed the neglect criteria but had at least 50% of letters in common with the target were classed as ‘visual’. The results for RYT, AB and AC are shown in Figure 5.20.

<table>
<thead>
<tr>
<th></th>
<th>Neglect</th>
<th>Visual</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>RYT</td>
<td>53</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>AB</td>
<td>34</td>
<td>62</td>
<td>4</td>
</tr>
<tr>
<td>AC</td>
<td>35</td>
<td>58</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 5.17: Error Analysis. Percent Neglect, Visual and other error types

Figure 5.20: Error Analysis. Proportion of Neglect, Visual, and other errors

Proportion of neglect errors is a good discriminator between RYT and the other two. Both AB and AC have higher proportions of visual errors than neglect errors while the reverse is true for RYT. The strictness of the definition used and the proportions of target words used, and hence the number of errors available for analysis will have an impact on the proportions but this nevertheless seems a reliable indicator.
Proportion neglect errors does not however support the idea that AB is a neglect dyslexic.

**Discussion**

The diagnosis of RYT as right neglect with attentional dyslexia meant that AC and RYT could be described in terms of the PSP model as both relying on primary process or cohort completion. The conditions leading to lexical access could be considered equivalent. Though one is probably visual and the other attentional, the effect from the point of view of word level representations may be the same. Intact word level processing meant that both AC and RYT could form lexical completions, but attentional dyslexia in one and erratic scanning in the other suggested that serial secondary processes were compromised in both. A favourable comparison between RYT and AC would go some way to supporting the description of AC’s deficit developed here. The points on which AB differed from AC and RYT may be related to her non-field based deficit. AB’s error gradients for shorter words were similar to RYT’s but she made fewer errors to long words. AB’s ability to read longer words was reflected in a neglect point of 6 for 7 letter words. Both AC and RYT had neglect points of 4 for 7 letter words. Finally, AB showed a similar preponderance of visual over neglect errors as AC. Several points suggest that AB is not a neglect dyslexic. She may have intact serial secondary processes and may gather information from both fields. She is not hemianopic and does not show neglect.

**AC and RYT**

**Similarities**

- They were both more accurate on shorter words than long words. A stepped function was found at 8 letters with AC, and RYT’s data suggested a similar stepped function at 7 letters.
- Both AC and RYT show a tendency to make errors shorter and longer than the target. AC may make more longer than shorter errors but on the whole their profiles were similar.
• The remarkable similarity of RYT and AC’s word length–neglect point function suggests that AC’s information pick-up is field based, consistent with unadjusted hemianopia.

• Both showed qualitatively similar responses with tachistoscopic presentation and in free vision

Semantic similarity and neologisms were uncommon in both.

Differences

• The variable abscissa plot of gradients of accuracy for neglect errors was particularly informative. RYT was just as likely to make errors at the ends of short words as he was at the ends of long words. AC was more likely to make errors at the end of longer words. RYT’s combination of attentional dyslexia and neglect probably mean that, not only is he unlikely to be able to use serial secondary process, but he is unlikely to want to because of his neglect. AC however is aware of his deficit, and is able to refixate if time allows. He is likely to use some residual secondary function to compensate, and this may be more effective with short words than with long words. Erratic fixation associated with RHH may also mean that on some occasions, when he fixates further to the right, short words may fall entirely in his left visual field. Neglect, however, implicates a higher level process of abnormally distributed attention, and so is unlikely to be affected by variability in visual encoding. RYT’s constant gradient implies insensitivity to the amount of visual information encoded, while AC’s variable gradient suggests that the probability of a correct response is related to the proportion of the stimulus encoded. This is likely to be higher for short words. AC’s higher accuracy with shorter words is likely to interact with frequency.

• The larger proportion of neglect errors produced by RYT, and larger proportion of visual errors produced by AC may be explained by the previous points.

In general, the comparison confirms the portrait of AC’s reading suggested by the previous experiments. It also suggests that they can both be characterised in terms of the PSP model. The differences between them can be explained by AC’s propensity to refixate. Both are compromised on serial secondary processes. The difference between them is in the nature of their field-based deficit. RYT’s is an attentional
deficit, and AC’s is a visual deficit. The overall similarity between AC and RYT, is
due mainly to the restricted use of secondary processing in both patients.

**Conclusion Computational analysis**

The prediction of considerable similarity between RYT and AC was based not
on their diagnosed conditions, but on the implications for residual secondary
processing of a specific aspect of their conditions. The implication of compromised
serial letter processing is a severe limitation in the secondary process options
available to the patient. In RYT and AC’s cases, the options seemed to be restricted to
primary process, cohort completions or retrieved completions. RYT’s choices would
be limited by neglect and attentional dyslexia. AC’s by an RHH related deficit in the
ability to encode individual letters accurately in RVF. The substantial similarity found
in their error profiles supported the idea that they both rely to a considerable degree
on cohort completions. This was seen as another piece of evidence for the cohort
completion process as one of the secondary process set proposed at the outset, and for
the characterisation of AC’s condition which had emerged over testing.
Summary and Main findings

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<thead>
<tr>
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<tbody>
<tr>
<td>Consistent accuracy in LVF 100% at 3s</td>
<td></td>
<td>24/26 and 1.5s on assessment No effect of F by position</td>
<td></td>
</tr>
<tr>
<td>Accuracy in LVF &amp; RVF equivalent at 3s</td>
<td></td>
<td>Accuracy better in words &amp; in position 1</td>
<td></td>
</tr>
<tr>
<td>Accuracy at chance in RVF at 300ms</td>
<td></td>
<td>HF latency equivalent in first &amp; position 3</td>
<td></td>
</tr>
<tr>
<td>RVF times delayed by 400ms at 3s</td>
<td></td>
<td>LF 1s delay in position 3 compared to 1 LF 600ms delay in position 3 compared to HF LF &amp; NW latency lower in position 1. Accuracy equivalent for all in position 3</td>
<td></td>
</tr>
<tr>
<td>1.3s delay on absent trials at 3s</td>
<td></td>
<td>Responses for HF may have been based on completions</td>
<td></td>
</tr>
<tr>
<td>No effect of display size at any duration</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Parallel processing intact in LVF and not RVF</td>
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<tbody>
<tr>
<td>Central Effect of frequency on accuracy (96%HF 67%LF) but not on latency. 2s latency</td>
<td></td>
<td>3s F effect on accuracy (70%, 37%) and marginal on latency (1.9s, 2.1s).</td>
<td></td>
</tr>
<tr>
<td>Lateral Consistent accuracy in LVF for HF</td>
<td></td>
<td>100ms F effect on accuracy (81%, 41%) no effect on latency.</td>
<td></td>
</tr>
<tr>
<td>600ms delay in RVF at 3s &amp; high RVF accuracy</td>
<td></td>
<td>Spends 1s less on errors and 800ms less on corrects</td>
<td></td>
</tr>
<tr>
<td>HF accuracy advantage in LVF only at 500ms</td>
<td></td>
<td>no change in accuracy</td>
<td></td>
</tr>
<tr>
<td>LF accuracy increases in LVF with less time</td>
<td></td>
<td>Marginal effect of F on fast correct at 3s</td>
<td></td>
</tr>
<tr>
<td>NW accuracy falls with less time</td>
<td></td>
<td>HF accuracy at 100ms suggests parallel access</td>
<td></td>
</tr>
<tr>
<td>No evidence of serial delay in NW latency Evidence for lexical processing in LVF related to M criterion but not in RVF.</td>
<td></td>
<td>Delays at 3s non productive refixations to RVF</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intact word level processing supported</td>
<td></td>
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</tbody>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Accuracy Effect of F (68%, 49%). Low N more accurate than high (65%, 51%) High F advantage only in low N set. Low N advantage marginal (.07) in low F set and not reliable in HF set</td>
<td></td>
<td>Accuracy No overall effect of F. Effect of Image restricted to low F and to 8 letter words. Effect of length in low Image (.69, .53, .27) but not high (.69, .69, .60). Effects of length restricted to differences between shorter and 8 letter words.</td>
<td></td>
</tr>
<tr>
<td>Latency High N slower than low N (2.1, 1.9). No effect of F, and no F*N interaction on latency. Correct responses faster than errors, and marginally faster in low N set. Effects of N on accuracy and latency, and marginal effect of N on low F accuracy suggest lexical completion. Supported by error corpus analysis</td>
<td></td>
<td>Latency 3 way interaction Image and length interact only in high F set. WLE only in high image sets. 3 – 5 and 5-8 letter differences not reliable only 3-8 reliable Only image difference was at 8 letters Results not consistent with serial processing strategy. change in strategy for 8 letter words</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computational error analysis.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 7. Vertical words.</th>
<th>Page 245</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy HF 30% LF 13% Very low compared to horizontal words also at 3 seconds (70%, 37.5%)</td>
<td></td>
<td>Similarity with RYT Stepped accuracy by length function, target-error length effects similar, similar neglect points suggest field based deficit, ms reading</td>
<td></td>
</tr>
<tr>
<td>Latencies doubled compared to horizontal and no difference between high and low frequency latencies.</td>
<td></td>
<td>Differences RYT as likely to neglect end of short as of long words, AC better at short words. RYT makes more neglect than visual errors and AC the reverse.</td>
<td></td>
</tr>
<tr>
<td>Serial letter processing may be compromised and may not be only related to RHH. Higher level deficit suspected.</td>
<td></td>
<td>Similarities suggest both AC and RYT rely on parallel processing, cohort completion.</td>
<td></td>
</tr>
</tbody>
</table>

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Table 5.18: Summary table of neuropsychological degradation results

The summary and main findings Table 5.19 is meant as a quick reference to the results. Page numbers are provided for more detailed reference to particular results. Abbreviations are, HF-LF- high and low frequency, NW-nonword, N-
neighbourhood size, RHH-right homonymous hemianopia, WLE-word length effect, RVF-LVF-right and left visual field, s-seconds, ms-milliseconds.

**AC’s impairment and compensatory strategy**

A series of seven experiments and an error analysis were used with AC to explore the extent to which his reading deficit could be characterised in terms of residual primary process. The extent to which his compensatory strategy to this deficit could be characterised in terms of component secondary processes was also explored. The main factors influencing AC’s reading are listed below.

- **He bases his responses largely on information encoded from the left visual field.**

  Accuracy in LVF was high in both simple feature detection and lexical decision at fast exposures. Parallel feature processing is only intact in LVF. Letter report was at 90% at the first position in the latter naming task. He shows a sharp gradient of accuracy from left to right on the positional match between targets and errors for 4 letter words.

- **Restricted encoding is related to unadjusted RHH.**

  In laterised experiments, AC’s latency to RVF presentations are longer than LVF presentation. Except for HF words, latency to third position letters was longer than to first. There is a marked position match gradient between targets and errors, even when the display provides enough information for adjustment. The similarity of his error profile to RYT suggests they base their responses on similar LVF information.

- **When he attempts to gather more information he refixates to RVF.**

  With no indication of an effect of display size on target present decisions, refixation to RVF in visual search took about 400msec. This suggests a baseline time for simple refixation without attention rescaling. Third position latencies in the letter task were about 1 second longer than first position time. This suggests that when he attempts to acquire letter information times rise significantly above baseline times. He took 800msec longer on words he read accurately at 3 seconds compared to words he read accurately at 100msec. This may be only enough time for a refixation with attention re-scale. No improvement in accuracy resulted however.
• Refixation to acquire letter information is largely an unsuccessful strategy for AC.

  In the letter-naming task and reading tasks, refixations produced no gain in accuracy. His accuracy at 100msec was not lower than his accuracy at 3 seconds. He refixates at 3 seconds. He refixates on 8-letter words in Experiment 6 but accuracy was higher for short words to which he did not refixate.

• He does not use serial secondary processes.

  No effect of display size was found in visual search. Increases in latency with RVF presentation and longer words, are no more than latency difference between first and third position letter naming times, which only require 1 letter scale refixation. On the assumption that RYT does not use serial processes, the similarity in their profiles suggests that AC does not. He is particularly poor at vertical word reading, and only shows stepped word length effects.

• This is related to difficulty in scaling attention to letter scale and refixating at this scale.

  The 1 second difference in first position and third position times, compared to 400msec in the visual search task, suggests that re-scaling attention to letter scale is difficult for AC.

• His responses are restricted to primary identification and cohort completion.

  His responses are based on part of the stimulus. He shows inhibitory effects of neighbourhood size for low frequency words. His errors are often higher frequency neighbours of the target. He shows marked effects of frequency on accuracy in reading single words

• He does not revise completions.

  No evidence of revision was seen in experimentation. It is unlikely that he can verify his responses against the stimulus if he cannot use serial processes.

• His error profile is very similar to RYT's

  AC's profile suggested that his errors might be very similar to those made by a right neglect patient who also has attentional dyslexia. (RYT, Warrington, 1991). Attentional dyslexia precludes the use of serial letter processing. They both have right-field based deficits and are both compromised on serial letter processing. They were compared on points characterising neglect (Warrington 1991). Their errors were similar on several points. They were both more accurate on shorter words than long
words. Both show a tendency to make errors shorter and longer than the target. They have almost identical word length–neglect point functions. Both showed qualitatively similar responses with tachistoscopic presentation and in free vision. Semantic similarity and neologisms were uncommon in both.

The differences between them were that RYT is as likely to make errors at the ends of short words as long words. AC makes fewer errors at the ends of short words than long words. RYT makes more neglect than visual errors and AC makes more visual errors than neglect errors. RYT’s attentional deficit may account for his constant gradient. Erratic fixation associated with RHH and a propensity to refixate may account for the variability in AC’s accuracy, with a higher probability of encoding the entire stimulus for shorter words. Higher accuracy with shorter words for AC may be restricted to high frequency words. These observations suggest that like AC, RYT should show an inhibitory effect of neighbourhood size. This was not tested with RYT. However, in the course of proposing that inhibitory effects of neighbours should arise in letter-by-letter reading, Arguin et al. (1998) gave an example of a neglect patient (EB, Arguin & Bub 1997), who does. Both the results from testing AC and the comparison between AC and RYT suggest that they both complete on the basis of part of the stimulus.

**Serial secondary process deficit**

The most important aspect of AC’s performance in reading single words, may be his apparent inability to use serial secondary processes. The most likely reason for this may be RHH although his poor performance with vertical words suggests there may be higher level impairments. Much of the evidence reported above suggested that AC bases his reading on an encoding of the initial letters of words, and that his attempts at gathering more information were largely unsuccessful. The absence of indications of serial processing suggested that AC does not use scanned completion. There was also no evidence that he used more time to retrieve completions. The poor results in the letter naming task in the third position suggested that letter identification in letter strings is difficult for AC. Retrieved completions are thought to be retrieved on the basis of letter identities. This may be related to attentional dyslexia, but may be more parsimoniously explained by the abnormal fixation patterns associated with RHH. If AC fails to identify letters on which to base retrieved completions, it is
unlikely that he can either assemble or revise completions, and there was no evidence to suggest that he uses these processes. The presence of an inhibitory effect of neighbourhood size suggested an element of lexical completion, probably cohort completion.

Cohort completion

Andrews (1997) suggested that inhibitory effects of neighbourhood size in perceptual identification paradigms are related to ‘sophisticated guessing’. The Massaro et al. (1980) model of reading suggested a secondary recognition process which “attempts to close off the letter string into a word”. It also suggested a more sophisticated ‘rehearsal and recoding’ process which uses working and long term memory to find solutions to identified letter string. These were considered ‘sophisticated-unconscious’ and ‘unsophisticated-conscious’ guessing respectively. The manner in which sophisticated guessing “closes off” letter sequences into words was thought to be either by serial amplification or by parallel amplification. The adoption of the interactive activation framework within which to explore and describe secondary processes, offered quite coherent mechanisms by which ‘closing off’ might be achieved. This suggested scanned completion and cohort completion, the lexical completion processes. These processes may be related to attentional modulation of word level or letter level processing respectively.

AC did not provide an opportunity to study scanned completion, or sub-lexical completion. At least, no evidence was found that he does use these processes. The status of cohort completion as one of the lexical completion processes is based largely on a process of elimination. With RYT, it may be possible to argue that his responses are based on primary process and lexical facilitation. However, Arguin and Bub (1997) report a neglect patient, EB, who shows inhibitory effects of neighbourhood size. This, and the comparison between RYT and AC, suggested that RYT might also show this effect. Thus, cohort completion may play a role in neglect dyslexia. With AC, the argument is largely one of eliminated possibilities. If he is deprived of all the other secondary processes by his deficit, then AC’s responses are lexical completions based on a parallel process, and not a serial one. In other words, they are cohort completions. The results of testing, and the similarity of his performance to RYT, are
taken to support this description of AC’s performance and the credibility of cohort completion as a secondary process.
"When the beginning reader has to decipher the alphabet code without appropriate instruction, he will come up with at least one of the strategies I have outlined here. Most children will use more than one. If a child sticks with any of the first four strategies: letter-name decoding; name-to-sound translating; sight-word memorising; or real word guessing, this will inevitably lead to reading failure (no exceptions). A child’s poor reading strategy will not self-correct without appropriate remedial help" (McGuinness, D. 1998, pp. 24)

6.1 Overview

The conclusion to the thesis is organised as listed below.

- Summary of review and experimental chapters
- A broader view of word recognition
- Experimental degradation
- Neuropsychological degradation
- PSP
- Further research and PSP

6.2 Summary of review and experimental chapters

A review of mainstream visual word recognition research revealed a trend towards a broader view of word recognition, which encompasses both primary and secondary processes. The distinction was initially based on the idea that primary process is the common element in tasks, all of which bring task specific processes to word identification. A preliminary set of secondary processes was proposed. Lexical completions were closely related to primary process, and sublexical completions involved explicit letter identification. Secondary processes were seen as prominent in two areas of research, experimental and neuropsychological degradation. These were the subjects of review and experimental chapters.

The review chapter on experimental degradation suggested that secondary processes played an underestimated role in some fragment completion paradigms.
Two tasks were identified which both involved the gradual incrementing of information specifying a target. The fragmentation task results indicated that scanned completion, suggested as one of the possible explanations for serial letter processing, may be inhibitory. An examination of the task concluded that the perceptual inhibitory effect described depended largely on the incrementing procedure and degradation technique used. The component letter task was thought to engage sublexical completion processes and revision. These processes, unlike lexical completion processes may produce facilitatory effects of neighbourhood size. These were found in the experiments reported in Chapter 3. The results replicated the Snodgrass and Mintzer (1993) results and extended them to another task. The results were interpreted as supporting the retrieved completion and revision processes proposed. Having gathered some support for the scanned and retrieved completion, and revision processes, the Primary Secondary Processing model of word recognition was proposed. This was described as a systems level functional model of primary and secondary processes.

The review of letter-by-letter reading in Chapter 4 suggested that the peripheral-central views of the condition concealed a primary process focus of research. It was suggested that the variety of possible mechanisms suggested as mediating the identification of words from letter names, highlighted a need for research on secondary processes, which could only be addressed with normal subjects. This had been the topic of the previous chapters. The compensatory strategies adopted by peripheral dyslexics were expected to vary, not only with the nature of their primary process deficit, but also with secondary process deficits. The importance of residual serial processing was likely to impact explicit letter identification and hence sublexical completion.

A series of tests with AC gradually led to the conclusion that his condition had deprived him of accurate serial letter processing, and that his main route to word identification was cohort completion. Parallel processing of simple features was compromised in RVF, and he seemed to refixate parallel resources when time allowed rather than adopting a serial search strategy. Naming letters in the third position of letter strings was inaccurate for all stimuli and relatively fast only for high frequency words. This suggested both privileged access for high frequency words, and a
difficulty in accurate letter scale fixation for low frequency and non-words. Lexical
decision confirmed intact lexical processing for LVF stimuli, and provided further
support for the serial letter-processing deficit hypothesis. Very low accuracy for low
frequency words and high accuracy for non-words at long exposures may have been
related to an inability to distinguish the two types of string even with refixation.
Improving accuracy with shorter durations for low frequency words was thought to
indicate a lexical strategy based on global activation levels. A single word reading test
provided support for cohort completion. Accuracy at 100ms was equivalent to both 3s
exposure, and accuracy in clinic, where AC had unlimited time to read words and
used a letter-by-letter strategy. These results also suggested that, although AC will
attempt to gather information from the RVF, this is largely unproductive. Inhibitory
effects of neighbourhood size were expected with lexical completion and were found
in both accuracy and latency in Experiment 5. The significance of this inhibitory
effect is that effects of neighbourhood, and of frequency, are thought to be mediated
by lexical processing. The association of sublexical completion with facilitatory
effects of neighbourhood, and the absence of indications of serial processing, meant
that AC’s word identification was probably mediated by cohort completion.

Because cohort completion is based on parallel access and noisy input, it was
still possible that a word length effect might be found with AC. Word length effects,
of a sort, were found on both accuracy and latency, but they were stepped functions.
He was more accurate and faster on 3 and 5 letter words but with no difference
between the two lengths. The only differences emerged in comparisons between 3 and
8 letter words. The results were consistent with a change in strategy from one based
predominantly on parallel processing aided occasionally by refixation for short words,
to one based predominantly on refixation for 8 letter words. The results were not
consistent with a serial letter processing strategy for reading single words. This was
largely confirmed by very poor accuracy in a test of vertical word reading employed
in the final experiment. The hypothesis that both AC and a neglect patient with
attentional dyslexia (RYT) were limited to cohort completions by their conditions,
was tested with a computational error analysis on their error corpora. The results
found considerable similarities in their errors.
6.3 A broader view of word recognition

The main theme of the thesis was the argument for a broader view of word recognition. One that is adequate to the task of elucidating everything from tachistoscopic lexical decision by undergraduates to the tortured selection of a meal from a menu by AC. Delving into the realm of ‘central’ processes may not be comfortable. It may seem that “chaos will ensue” and this may be what “compels researchers not to study the role of such important processes”. However, it is argued not only “that we must investigate strategic and individual difference effects in reading tasks, but that we can do so successfully”. The functional systems level view adopted by PSP may be the appropriate level of analysis. ‘Central’ processes may not be mysterious if they are viewed as processes at the other end of a continuum of automaticity from primary process (Cohen et al. 1990). The need to “pursue strategy as a phenomenon to be understood rather than avoided” may be more pressing in areas such as language therapy and cognitive neuropsychology than in mainstream experimental psychology. The general underspecification of meta-linguistic functions in models of word recognition means not being able to answer apparently simple questions like how we identify ‘dog’ from ‘d’, ‘o’, and ‘g’, one of our first accomplishments on the road to literacy. The specification of these processes must come from research with normal subjects, and so mainstream and impaired word recognition research may need a focus of delimited secondary processes to work with.

The secondary processes proposed to join primary process in this broader view were largely selected with peripheral dyslexia in mind. It was argued at several points however that secondary processes are relevant to research in various areas. Understanding multiple route behavioural plasticity, meta-linguistic functions, compensatory strategies in neuropsychological degradation, developmental dyslexia, and strategy effects with normal subjects have all been discussed. Integrating secondary processes with primary process in computational modelling was discussed, and indeed, the suggestion there was that it may not be possible to fully understand primary process without considering secondary ones. The involvement of secondary processing in neuropsychology has been the topic of much of the thesis. The focus on
primary process in experimental psychology means that its most studied tasks may not be suitable to secondary process research, and several alternative tasks were discussed. The combination of computational, neuropsychological, and experimental research on secondary processes may be enough to finally implement Coltheart’s vision.

6.4 Experimental Degradation

The main points to emerge from the experimental degradation chapters were the theoretical and empirical basis of inhibitory effects of neighbourhood in scanned completion, and the role of retrieved completion, and revision, in the appreciation and revision effects.

Scanned completion

The interest in scanned completion was largely motivated by the implications of perceptual interference for letter-by-letter reading. The idea that attentional scans or rapid refixations might boost lexical activation over criterion had been suggested by Behrmann et al. (1998) as an explanation for serial letter processing. Several strands of evidence suggested that this might be an inherently inhibitory strategy. The Competitive Activation Model (Snodgrass & Hirshman 1991; Luo & Snodgrass 1994), Arguin et al.’s (1998) analysis of the effects of supplying the lexicon with letter identities sequentially, and Grainger and Segui’s (1990) progressive demasking technique all pointed to inhibition. The implications of these results are that some of the processes suggested in the literature, as mechanisms which might support word identification from serial letter identification, may be unworkable. It is possible that ‘imagery’, or the spelling system, are interposed between letter identities and words precisely because the orthographic input lexicon is a parallel mechanism and not a serial one. Hendriks’ (1996) results suggested that normal subjects use multiple fixations when reading subvocally, but the identities established by these multiple fixations were presumably aimed at the grapheme-phoneme decoder and not the orthographic input lexicon. Normal subjects also refixate in long words while reading for meaning, but this may be to bring parafoveal information to the fore for an
essentially parallel process. Computational models may be able to rule out some suggestions, but experimental evidence with normal subjects would still be needed.

The scanned completion process was, however, only one possible conception of letter-by-letter reading behaviour. Retrieved and assembled completion was proposed as alternative descriptions of the process. These slower processes are based on explicit letter identification and may not be associated with inhibitory effects of neighbourhood size.

The Revision and Appreciation effects

The suggestion that under certain circumstances neighbours may facilitate the identification of words was explored with the component letter task. The implications of this were that if letter-by-letter readers used slower completion processes based on letter identities, they might show facilitatory effects of neighbourhood size. The facilitatory effect reported by Snodgrass and Mintzer (1993) depended on the formation of preliminary completions, the elimination of competitors, and the availability of alternative completions. The slower completion processes in PSP depend on letter identification, which implicates serial processes. There was some evidence of serial processing with standard cues in Experiment 2 of Chapter 3, which used the component-letter task and normal subjects. The sensitivity of completions to a 1-second cut in time suggested that processes beyond primary process were involved. The variability in error length suggested that word length information in the fragment was largely lost. The overlooked information at the ends of fragments suggested an attentional focus at the letter or sublexical level. The bias to restoring information at the beginning of words suggested that words were retrieved on the basis of a few identified letters.

These factors pointed to a serial process of establishing some but not all letter identities. This may also have allowed enough time for assembly, but then higher accuracy rates might have been expected. The results pointed in the main to two component processes in PSP, retrieved completion and revision. The results of both experiments suggested that component-letter fragments were completed in two phases. The first was to retrieve a completion based on a few letters in the fragment. Standard cues were thought to have little opportunity for revision and showed no
effect of neighbourhood size. Retrieved completions may not be sensitive to neighbourhood size because they tend to produce ‘visual’ neighbours based largely on similarity at the beginning of words. Incremental cues were thought to provide the opportunity for cycles of completion and revision, which were more likely to produce the target, and were sensitive to neighbourhood size because high neighbourhood words may be associated with immediately apparent alternative completions. The results of these experiments were taken to support the retrieved completion and revision processes.

The component letter task results introduced two facilitatory effects of neighbourhood size related to sublexical completion and revision. The Revision effect was the finding that incremental cueing produces higher performance in high neighbourhoods than in low ones. This was related to the availability of alternative completions to the revision process. The Appreciation effect was the finding that in high neighbourhoods, incremental performance is higher than standard performance. Standard cues afford little opportunity for revision. The implications of these effects were that if letter-by-letter readers use similar processes, then facilitatory effects of neighbourhood size may be found. These effects may be unrelated to the lexical facilitatory effects reported by Andrews (1989).

6.5 Neuropsychological Degradation

The neuropsychological part of the thesis noted the idea that cascaded relations embodied in connectionist systems explained the role of residual primary process in peripheral dyslexia. The impact of this residual processing may however depend on the patient’s strategy. Thus, semantic effects emerge most often when the patient is induced to guess and not when they letter-by-letter read (JWC, Coslett et al. 1993). Patients seemed to use a variety of compensatory strategies, perhaps to the same functional deficit. It was suggested that these strategies may be described in terms of normal secondary processes, and that the problem is not so much that we do not understand residual primary process, but that we do not understand secondary processes. A secondary process view of peripheral dyslexia was described as a complement to the prevailing primary process view of peripheral dyslexia. The main ideas were thus
• Residual primary process is adequately characterised by cascaded and interactive relations within the orthographic system and between it and the semantic and phonological systems.
• Almost as important as residual primary process is the compensatory strategy adopted by the patient to this residual processing.
• This strategy is likely to be made up of residual normal secondary processes.
• If so, then the processes and effects identified in the experimental degradation paradigms will be relevant in peripheral dyslexic reading.

The series of experiments with AC progressively added up to the conclusion that he has a serial letter-processing deficit. This effectively precludes him from accurate letter-by-letter reading. The results also pointed to a lexical completion process, which is parallel, highly frequency sensitive on accuracy but not latency, and subject to inhibitory effects of neighbourhood size. This was cohort completion.

Cohort completion

By a process of elimination, the experiments in the neuropsychological section indicated cohort completion as the main secondary process open to AC. This substantiated its inclusion in PSP as one of the lexical completion processes. There was little evidence of serial letter processing in AC’s performance. Serial processing might have been evident in performance on several tasks.
• In visual search by effects on display size
• In accurate report of letters in the third position in strings
• By longer response times to nonwords in lexical decision
• By differences between reading at 3 seconds and 100ms
• By a linear time function with word length

None of these experiments produced an indication of serial processing either by attentional scan or eye movements. It is clear that more precise methods are needed to establish this. However if AC used serial processing as a staple method to word identification, as his behaviour in clinic suggested, some indication of this was expected in these tests. If AC uses slower serial fixations in clinic then the level of accuracy attained there suggested that the process must be largely ineffective. These results meant that AC’s reading during these experiments offered little opportunity for
studying serial secondary processes. There were however consistent indications that AC will refixate, but the times involved suggested that this was mainly a single refixation designed to deploy intact parallel processing.

Cohort completion was introduced to describe situations in which serial processes can be ruled out. Cohort completion may be largely responsible for the inhibitory effects of neighbourhood on low frequency words seen with AC. If serial scanning can be isolated by behavioural measures, the distinction between primary process and cohort completion may rest on this effect. The implication of AC’s deficit in serial processing was that his responses were largely restricted to primary identification and cohort completion. Inhibitory effects are not associated with primary lexical processing. Inhibitory effects of neighbourhood are implicated in lexical completion, and given that serial processes were being ruled out of AC’s performance, it seemed reasonable that the demonstration of inhibitory effects of neighbourhood might be ascribed to cohort completion. The Cue depreciation experiments had shown, however, that with normal subjects, incremental cues need not be inhibitory, and may be facilitatory. Given enough time, AC might have used serial refixations, assembly, and perhaps revision, to read words. In this case, a facilitatory effect of neighbourhood might be expected. AC was given unlimited time in Experiment 5. Inhibitory effects were found in this experiment and there was a trend in that direction in clinic.

The second line of evidence supporting this characterisation of AC’s reading was in the comparison between AC and RYT. On the surface, an RHH patient who reads letter-by-letter, and a right neglect patient with attentional neglect, might not be expected to have much in common. However an implication of attentional dyslexia in PSP is that serial scanning, assembly, and revision, should be largely absent because they all require letter processing within strings. AC’s deficit on serial processing may be related to RHH (Zihl 1995) but the functional implications may be similar to the functional implications of neglect. Right neglect and RHH involve different loci of injury, but the consequences, in terms of the information delivered to higher levels of primary process, may be functionally much the same. The implications were that both AC and RYT rely on primary process and cohort completion, based largely on information gathered in parallel from the left visual field. The similarity in their error
profiles largely supported this. The evidence for cohort completion was thus largely established by eliminating serial alternatives, demonstrating inhibitory effects of neighbourhood, and by drawing parallels between AC and the implications of a conjunction of attentional dyslexia and neglect.

6.6 PSP

Since Massaro et al.'s (1980) model of text reading, the focus of research in both cognitive psychology and cognitive neuropsychology has been on primary processes. The need for research into secondary processes is underlined by several developments.

- The explanation of inhibitory effects of neighbourhood size for low frequency words in perceptual identification paradigms by unspecified sophisticated guessing processes (Andrews 1997).
- The variety of hypothesised secondary processes implicated in the compensatory strategies of peripheral dyslexics (Price & Humphreys 1992).
- The concern to address issues of strategy in mainstream word recognition research (Coltheart, 1978; Stone & Van Orden 1993), and in developmental dyslexia (Hendriks & Kolk 1997).

The most prominent secondary processes suggested by the experimental and neuropsychological literature were formed into a coherent structure, the PSP model of word recognition. The processes are all regarded as normal secondary processes, and hence may be a focus of discussion and dialogue between mainstream word recognition, acquired dyslexia and developmental dyslexia research. The main
contributions to the model made by experimentation in the thesis were the results with normal subjects implicating retrieved completion and revision, and the results with AC implicating cohort completion.

The PSP model view of word identification has been productive in this thesis. The overall aim of thinking about word recognition in terms of primary and secondary processes was not new. Massaro et al.'s (1980) model has much in common with PSP. Grainger and colleagues have been working with this idea for some time (e.g. Jacobs & Grainger 1994), and this means that much work which is directly relevant to modelling PSP has already been done and is in progress. The step of proposing a limited set of secondary processes which might form a reasonably comprehensive processing system, and using that as focal point between experimental, computational, and neuropsychological degradation is perhaps slightly novel.

The merit of PSP is that it moves discussion to specifying procedures, strategies, and effects, in terms of processes. The secondary processes proposed are in their infancy compared to work on primary processes, but the thesis has demonstrated several points at which PSP has clarified issues in both experimental and neuropsychological degradation. More important perhaps is the idea that it may represent a framework both domains have in common and can work with, and hence might facilitate the transfer of results between them. An illustration of this might be the manner in which discussion of inhibitory and facilitatory effects of neighbourhood size in mainstream word recognition research was brought over to peripheral dyslexia in a language of processes, not of experimental procedures. PSP has been instrumental in

- Identifying the role of neighbours in the Cue Depreciation (component-letter task) literature. Offering a principled framework for reinterpreting existing results related to motivation and strategy in terms of shifts in the balance of primary and secondary processes used, and clarifying the role of neighbourhood size in the slower secondary processes
- Extending the Snodgrass and Mintzer (1993) results into a new task domain and suggesting how the different degradation techniques used in the tasks might be combined with procedures to isolate secondary processes.
Proposing two effects, the appreciation and revision effects, which may have useful applications in indexing strategies associated with individual differences in reading, and the residual secondary processes open to peripheral dyslexics.

Providing a common framework for a dialogue between experimental and neuropsychological degradation.

The alliance of PSP with the functional overlap / nested modelling program (Jacobs & Grainger 1994) is seen as critical to its role as a link from neuropsychology to both mainstream word recognition research and connectionism.

Clarifying the limits of inhibition related to serial letter processing and suggesting conditions under which it may be inhibitory, and conditions under which it may be facilitatory.

Providing a language in which to specify peripheral dyslexic deficits in terms of varieties of residual primary process and residual secondary processes. PSP expects a loose correspondence between residual primary process and performance, because performance is determined by the combination of primary and secondary processes.

Making principled predictions within peripheral dyslexia based largely on the implications of availability of secondary processes.

Assessing the implications of particular remediation methods for particular patients based on a specification of both residual primary and secondary processing.

6.7 Further research and PSP

Several lines of research into specifying secondary processes can be pursued simultaneously. These are outlined below.

Literature review

Each of the secondary processes probably connects with a well-defined literature. For instance, results from eye scanning studies are particularly relevant to scanned completion. Studies of word recognition from orally spelled words, imagery, and rapid serial visual presentation, may produce data and results relevant to the
assembly process and to the reading-spelling route debate. Thus, each of the secondary processes proposed may need a detailed literature search for relevant data before further experimental work.

Experimental degradation

The idea that different fragment types in combination with different procedures may isolate particular secondary processes for study was raised and demonstrated in the contrast between results in the fragmentation and component letter tasks. The association of several manipulations, such as vertical alignment, mirror reversal, and LVF presentation, with serial letter processing was discussed. Several variables, such as frequency, neighbourhood size, and imageability are associated with lexical processing. By judicious combinations of these variables and manipulations, research with normal subjects should be able to specify the secondary processes.

Neuropsychological degradation

Detailed testing for residual secondary processes as well as primary process, changes the emphasis from one of categorisation to one of explaining performance in terms of component processes. The impairment of important secondary components of processing, such as serial letter identification, may produce very similar performance profiles to different anatomical injuries. The performance of any particular patient could then be described in terms of the response of a well-defined system to the injury. This response could be further broken down into the residual primary process available to the patient, and the residual secondary processes employed. In language therapy, this would allow an assessment of the compensatory strategy employed by a patient in terms of its suitability in the light of the residual process options open to the patient. Hence, in view of the results of testing it is unlikely that a good case could be made for encouraging AC to continue to attempt to read with a letter-by-letter strategy. Research would thus place more emphasis on testing for secondary process deficits.
Computational models

The functional overlap and nested modelling approach described in Jacobs and Grainger (1994) may be a good framework in which to model compensatory strategies. The simplest to implement is probably the cohort completion hypothesis. With the development of more secondary modules, the serial refixation one being perhaps the most pressing (Plaut, 1997), more complex secondary processes may become amenable to computational implementation.

Theoretical Integration

Results in a widely dispersed literature including cognitive psychology, neuropsychology, developmental psychology, language therapy, and computational modelling tend not to coalesce without a focal point. A model of secondary processes may serve that purpose and encourage the integration of results into a common theoretical framework.
References:


Patterson, K., & Wilson, B. (1990). A Rose is a Rose or a Nose: A deficit in initial letter identification. Cognitive Neuropsychology, 7, (5/6), 447-477.


**Appendix**

**Corpora.**

**Cue Depreciation word set**

The underlined letter in each word along with the first letter of the word constitute a unique fragment of the word. Taken from Peynircioglu and Watkins (1986).

<table>
<thead>
<tr>
<th>Acquaint</th>
<th>Embezzle</th>
<th>Inscribe</th>
<th>Magazine</th>
<th>Pastrami</th>
<th>Unkindly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>Envelope</td>
<td>Inwardly</td>
<td>Mischief</td>
<td>Quaintly</td>
<td>Unlawful</td>
</tr>
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<td>Amethyst</td>
<td>Ethereal</td>
<td>Jaundice</td>
<td>Mobilise</td>
<td>Quantity</td>
<td>Unlikely</td>
</tr>
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<td>Anywhere</td>
<td>Euphoria</td>
<td>Jealously</td>
<td>Mosquito</td>
<td>Quotient</td>
<td>Unvoiced</td>
</tr>
<tr>
<td>Antelope</td>
<td>Eventful</td>
<td>Jeopardy</td>
<td>Motivate</td>
<td>Raindrop</td>
<td>Upheaval</td>
</tr>
<tr>
<td>Approval</td>
<td>Eyesight</td>
<td>Jettison</td>
<td>Mystique</td>
<td>Receptor</td>
<td>Vagabond</td>
</tr>
<tr>
<td>Atomizer</td>
<td>Festival</td>
<td>Joyfully</td>
<td>Namesake</td>
<td>Rehearse</td>
<td>Vehement</td>
</tr>
<tr>
<td>Beverage</td>
<td>Fiftieth</td>
<td>Jubilant</td>
<td>Navigate</td>
<td>Reviewer</td>
<td>Vermouth</td>
</tr>
<tr>
<td>Bequeath</td>
<td>Frequent</td>
<td>Judicial</td>
<td>Needless</td>
<td>Rightful</td>
<td>Vexation</td>
</tr>
<tr>
<td>Boutique</td>
<td>Genocide</td>
<td>Kangaroo</td>
<td>Negative</td>
<td>Sequence</td>
<td>Vineyard</td>
</tr>
<tr>
<td>Bungalow</td>
<td>Gigantic</td>
<td>Kerchief</td>
<td>Nightcap</td>
<td>Sideways</td>
<td>Volcanic</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Gullible</td>
<td>Keyboard</td>
<td>November</td>
<td>Smallpox</td>
<td>Wardrobe</td>
</tr>
<tr>
<td>Confetti</td>
<td>Halfback</td>
<td>Kilogram</td>
<td>Nowadays</td>
<td>Theorize</td>
<td>Wickedly</td>
</tr>
<tr>
<td>Conquest</td>
<td>Handcuff</td>
<td>Knapsack</td>
<td>Numbness</td>
<td>Township</td>
<td>Windmill</td>
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<td>Dejected</td>
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<td>Knockout</td>
<td>Oblivion</td>
<td>Tranquil</td>
<td>Wreckage</td>
</tr>
<tr>
<td>Delivery</td>
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<td>Laziness</td>
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<td>Overkill</td>
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Corpora Table 1: Word set Peynircioglu and Watkins (1986)
Non words and Words used in Experiment 2 (CH. 5)

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<th>Low Frequency Words</th>
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<td>TWBE</td>
<td>NAWT</td>
<td>BOOK</td>
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<td>LOVBF</td>
<td>YURD</td>
<td>CASE</td>
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<td>AMOTY</td>
<td>DOOR</td>
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<td>THFES</td>
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<td>EARTH</td>
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<td>KJDR</td>
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<td>FACE</td>
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<td>HGTKI</td>
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<td>RTOYT</td>
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<td>EBCYD</td>
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Corpora Table 2: Nonwords and words used in Experiment 2 (CH. 5)
The four sets of words and non-words in the two tables below were taken from Besner & McCann (1987).

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<td>MALT</td>
</tr>
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<td>HEAP</td>
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<td>MINK</td>
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<td>RIOT</td>
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<td>CROW</td>
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<td>SKIT</td>
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<td>MOAN</td>
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<td>FAKE</td>
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Corpora Table 3: Non-words and words used in Experiment 3, 4 and 7 (CH. 5)
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<td>LOBE</td>
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<td>SASH</td>
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<tr>
<td>GAME</td>
<td>TOOT</td>
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<tr>
<td>LACK</td>
<td>STAB</td>
</tr>
<tr>
<td>HOUR</td>
<td>NOOB</td>
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<td>PULP</td>
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<td>WILT</td>
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<td>STUB</td>
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Corpora Table 4: Nonwords and words used in Experiment 3, 4 and 7 (CH. 5)
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<tr>
<td>MATE</td>
<td>COLD</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>DEBT</td>
<td>DINE</td>
</tr>
<tr>
<td>HOLY</td>
<td>NECK</td>
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<td>COLD</td>
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<td>F</td>
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<td>DINE</td>
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<td>NECK</td>
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<td>COLD</td>
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<td>F</td>
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<td>DINE</td>
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<tr>
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Corpora Table 5: Words used in Experiment 5 (CH. 5)
## Words used in Experiment 6 (CH. 5)

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<tr>
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<td>Job Three Audience Lad Shrub Twilight</td>
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Corpora Table 6: High Image words used in Experiment 6 (CH. 5)
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*Corpora Table 7: Low Image words used in Experiment 6 (CH. 5)*
## Error corpus

Target words are in the shaded columns, and the corresponding error in the adjacent column.

Corpora Table 8: Error corpus.

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<td>ruben</td>
<td>bard</td>
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<td>prohibit</td>
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<td>answer</td>
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<td>hear</td>
<td>want</td>
<td>many</td>
<td>poem</td>
<td>postey</td>
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</table>
Survey of Cue Depreciation results

Note on survey tables.

The sources are referred to by authors (PW = Peynircioglu & Watkins; P = Peynircioglu; LS = Luo & Snodgrass; T = Thapar; TG = Thapar & Greene; GW = Gibson & Watkins; SM = Snodgrass & Mintzer) then the year of publication, and the number of the experiment. (LS94-3 refers to Luo & Snodgrass (1994), Experiment 3.) The LS and SM experiments use the Fragmentation task, and PW, P, T, TG, and GW used the component letter task. An * indicates a reliable effect, and incr. is an abbreviation of incremental. Mixed experiments are ones in which the subjects complete mixed, randomly presented primed and unprimed fragments. Blocked experiments are ones in which subjects are aware of the source of fragments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Procedural notes</th>
<th>Standard</th>
<th>Incr.</th>
<th>Effect</th>
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</thead>
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<tr>
<td>LS94-3</td>
<td>Normal fragmentation task procedure</td>
<td>72.7</td>
<td>57</td>
<td>15.7 *</td>
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<tr>
<td>GW90-2</td>
<td>Auditory study and fragments tested immediately after list</td>
<td>63</td>
<td>50</td>
<td>13 *</td>
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<tr>
<td>Pw86-5</td>
<td>3 seconds instead of 4 seconds</td>
<td>77.1</td>
<td>65.2</td>
<td>11.9 *</td>
</tr>
<tr>
<td>Pw86-4</td>
<td>Normal component letter task procedure</td>
<td>83</td>
<td>72.7</td>
<td>10.3 *</td>
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<td>Normal fragmentation task procedure</td>
<td>75.5</td>
<td>66.5</td>
<td>9 *</td>
</tr>
<tr>
<td>P90a-1</td>
<td>5 s and study exposure repeated 5 times</td>
<td>70.6</td>
<td>62.6</td>
<td>8 *</td>
</tr>
<tr>
<td>Pw86-5</td>
<td>60 seconds to complete after last fragment</td>
<td>96.5</td>
<td>88.7</td>
<td>7.8 *</td>
</tr>
<tr>
<td>P90a-2</td>
<td>5 s deep processing (LOP) AND Remember instructions</td>
<td>64.4</td>
<td>56.9</td>
<td>7.5 *</td>
</tr>
<tr>
<td>P90a-1</td>
<td>5 s and study exposure repeated 1 time</td>
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<tr>
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<td>48.1</td>
<td>46.1</td>
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<td>GW90-2d</td>
<td>Auditory study and fragments tested 48 hours after list</td>
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<td>60</td>
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<td>Normal fragmentation task procedure</td>
<td>46.3</td>
<td>46.7</td>
<td>-0.4</td>
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<table>
<thead>
<tr>
<th>Experiment</th>
<th>Procedural notes</th>
<th>Standard</th>
<th>Incr.</th>
<th>Effect</th>
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</thead>
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<tr>
<td>LS94-5</td>
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<td>53.1</td>
<td>7.6 *</td>
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<td>Normal component letter task procedure</td>
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<td>50.6</td>
<td>1.2</td>
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<td>Auditory study and fragments tested immediately after list</td>
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<td>Fragmentation task procedure</td>
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<td>GW90-3D</td>
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<td>47</td>
<td>-1</td>
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<td>Pw86-5</td>
<td>60 seconds to complete after last fragment</td>
<td>80.9</td>
<td>81.1</td>
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Reviews Table 1: Mixed sets in the cue depreciation experiments.
<table>
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<th>Standard</th>
<th>Incr.</th>
<th>Effect</th>
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</thead>
<tbody>
<tr>
<td>P90b-2</td>
<td>Direct instructions (use fragments to recall studied words)</td>
<td>68.8</td>
<td>56.3</td>
<td>12.5</td>
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<tr>
<td>P90b-1</td>
<td>6 letter fragments / Low F / 5s S's told hard to solve</td>
<td>54.4</td>
<td>43.3</td>
<td>11.1</td>
</tr>
<tr>
<td>TG95</td>
<td>Passive (do not attempt completion before last fragment)</td>
<td>83</td>
<td>72</td>
<td>11</td>
</tr>
<tr>
<td>P87-3</td>
<td>5 s English words with Turkish students i.e. limited set</td>
<td>50</td>
<td>42</td>
<td>8</td>
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<tr>
<td>Pw86-1</td>
<td>Studied words normal procedure</td>
<td>84.6</td>
<td>78.1</td>
<td>6.5</td>
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<tr>
<td>GW90-1</td>
<td>Auditory fragments of recently heard words</td>
<td>56.9</td>
<td>50.4</td>
<td>6.5</td>
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<tr>
<td>T92-1</td>
<td>No first letter in the fragments</td>
<td>85.2</td>
<td>79.3</td>
<td>5.9</td>
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<td>TG95</td>
<td>Active (think of as many possible solutions to unique cue)</td>
<td>86</td>
<td>81</td>
<td>5</td>
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<td>Pw86-3</td>
<td>6 letter fragments instead of the usual 5</td>
<td>94</td>
<td>89.5</td>
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<td>P87-1</td>
<td>Subjects informed of fragments category (e.g. all fruit)</td>
<td>56.7</td>
<td>52.5</td>
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<td>P87-2</td>
<td>Subjects informed of fragments category (e.g. all fruit)</td>
<td>66.2</td>
<td>62.3</td>
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<td>P90b-2</td>
<td>Indirect instructions (words that come to mind)</td>
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<td>6 letters / High F / 5s S's told easy to solve</td>
<td>81.9</td>
<td>78.8</td>
<td>3.1</td>
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<td>P90b-4</td>
<td>Only 1 point scored compared to 5 points on others</td>
<td>54.1</td>
<td>54.9</td>
<td>-0.8</td>
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**BLOCKED UNPRIMED**

<table>
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<td>T92-2</td>
<td>S's informed that fragments not from preceding study list</td>
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<td>P90b-3</td>
<td>S's told fragment completion was an IQ test</td>
<td>38.1</td>
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<td>Passive (do not attempt completion before last fragment)</td>
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<td>57</td>
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<td>P90b-4</td>
<td>5 point cue indicated by an orange dot and so blocked</td>
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<td>Active (think of as many possible solutions to unique cue)</td>
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<td>T92-1</td>
<td>No first letter in the fragments</td>
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<td>6 letter fragments instead of the usual 5</td>
<td>79.9</td>
<td>83.1</td>
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<td>S's told fragment completion was an practice test</td>
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<td>Subjects not informed of category of fragments</td>
<td>31.1</td>
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Reviews Table 2: Blocked sets in the Cue Depreciation experiments