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Acknowledgements.

As an undergraduate, I took a course called 'Cognitive and Neuropsychology' run by my Supervisor, Bill Phillips. When asked by another student how the course was, I could only liken it to being shot at by an 'intellectual scatter-gun'. The torrent of ideas was fascinating and bewildering. During my Ph.D. studentship one or two things have become clearer. Some of the material and some of Bill's ideas! However, one other thing became clearer too - that Bill did exactly what a good teacher should do. That is, excite and motivate someone so that they enjoy learning about a subject themselves. I am grateful to Bill for that and I don't think he knows how much his ideas have sustained me.

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Neuropsychology. (in press) and Phillips, W. A. & Goodall, W. C. , Lexical writing can be non-semantic and it can be fluent without practice. *Cognitive Neuropsychology*. (in press). I am grateful to the anonymous reviewers of these papers who contributed helpful comments. During my Ph.D. studentship Max Coltheart, Rosalyn McCarthy, Tony Marcel, Karalyn Patterson, Tim Shallice and Phillip Smith all took the time to comment on this work and I thank them for doing so.

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Abstract

This thesis investigates the reading and writing of two patients with brain injuries due to cerebro-vascular accidents. Background tests show both patients to be moderately anomic and to have severe impairments in reading and writing nonwords. Investigations of the locus of impairment in AN's nonword reading showed her to have normal orthographic analysis capabilities but impairments in converting single and multiple graphemes into phonemes and in phonemic blending. The central issue studied was the role of lexical but non-semantic processes in reading aloud, writing to dictation and copying. For this purpose a "familiar nonword" paradigm was developed in which the patients learned to read or write a small set of nonwords either with or without any associated semantics. Both AN and AM were able to learn to read nonwords to which no meanings were attached but they could still not read novel nonwords. Both patients were unable to report any meanings for the familiar nonwords when they read them and there was no evidence that learning to read them improved their sub-lexical processing abilities. These results are evidence for a direct lexical route from print to sound that is dedicated to processing whole familiar words. It was also shown with AN that if nonwords are given meanings then learning is faster than if they are not given meanings. Experiments designed to test the hypothesis that nonwords are read by analogy to words found no support for it.

Both patients have severe impairments in writing novel nonwords to dictation. As they can repeat spoken nonwords after they have failed to write them, this is not due to a short-term memory impairment. Despite their nonword writing impairments, both patients were able to write to dictation the meaningless nonwords that they had previously learned to read at the first attempt, and AN did so one month after learning to read them. Neither patient however, could write novel nonwords made by reordering the letters of the familiar nonwords. Furthermore, the familiar nonwords used spellings that are of *a priori* low

probability. The familiar nonwords must therefore have been written using lexical knowledge. Tests of semantic association showed that the familiar nonwords evoked no semantic information that the patients could report. Function words dictated to AN evoked little semantic information but she wrote them to dictation significantly better than nonwords made by reordering their letters. These results are evidence for a direct lexical route for writing to dictation.

Copying was studied both with and without a five second delay between presentation and response. AN was better at delayed copying of meaningless but familiar nonwords than she was at copying novel nonwords. She was also better at delayed copying of six-letter, bi-syllabic nonwords that she had been trained to copy than she was at copying novel nonwords made by recombining the first and second halves of the familiar nonwords such that these halves retained their positions from the parent nonwords. AN was better at copying function words than nonwords made by reordering their letters. She was also better at copying function words than she was at reading or writing them to dictation. These results are evidence for a direct lexical route for copying.

AN and AM were both able to write to dictation nonwords that they had never heard or written before but with which they had been made visually familiar during a visual discrimination task. They must have used lexical knowledge to do so because the spellings used were of a priori very low probability. The creation of lexical orthographic information which can be retrieved from novel auditory input raises difficulties for current models and various possible interpretations are discussed.

Finally, some of the possible implications of the re-learning abilities shown by these patients, for rehabilitation procedures are discussed briefly.

1 The Cognitive Neuropsychological Approach.

1.1. The Basic Aims.

Contemplation and study of the relationship between the human brain and behaviour have a long documented history, e.g. Plato (420-347 BC.) suggested that as our brains are nearest to heaven, then this is where the rational part of our tripartite soul is located. Since then, the nature of this relationship has formed part of the research domain of many scientific disciplines, e.g. pharmacology, biology, cognitive psychology, biophysics, philosophy, neurology and neuropsychology. Although *cognitive neuropsychology* as it is currently practised is considered to be a comparatively new field, there are many aspects of this history that are part of its heritage. It is probably most firmly rooted in the work of the 19th century neurologists, often referred to as the diagram-makers.[1]

Broca (1861), Bastian (1869), Wernicke (1874), and Lichteim (1885) were all key figures in whose work the seeds of modern cognitive neuropsychology can be found. Their approach to the study of the relationship between the brain and behaviour closely corresponded to present-day neuropsychology in that a core activity was the precise cerebral localisation of function. The principle method of anatomical localisation involved the correlation of clinically observed symptoms with damaged neural structures, identified at post-mortem. Two classic aphasia (language disorder) syndromes, Broca's (1861) and Wernicke's (1874), were born in just this way. However, it was this activity that proved to be the diagram-makers 'Achilles heel'. As more cases were described, it was found that Broca's type aphasia could arise in patients with lesions outside of the inferior posterior

[1] For a more thorough historical review of the origins of cognitive neuropsychology, see Kolb and Whishaw (1985) and Shallice (1988) .

third of the left frontal gyrus, the area which, when damaged, was identified by Broca as being responsible for the disorder. It has even been argued that a classic case of Broca's aphasia must involve extensive frontal lesions, reaching back to the Rolandic fissure, as well as underlying white matter (Mohr, Pessin, Finkelstein, Funkenstein, Duncan, & Davis, 1978; Naeser, Palumbo, Helm-Estabrooks, Stiassny-Eder, & Albert, 1989). When Broca's own classic patients, Tan and Lelong, were re-assessed by Marie in 1906, Tan was found to have additional damage to posterior cortical areas while it was claimed that Lelong had non-specific atrophy of the brain (Joynt, 1964). Such weakening of the evidence for functional localisation contributed to the demise of the early diagram-makers approach and led to an anti-localisation sentiment in the early decades of the 20th century. The rejection of functional localisation as a valid enterprise within modern cognitive neuropsychology (e.g. Morton, 1984) led Shallice (1988) to describe the approach as *ultra* cognitive neuropsychology (although see McCarthy & Warrington, 1990, where "anatomical considerations" are part of the approach).

The most positively influential aspect of these early researchers work for cognitive neuropsychology was that they studied the cognitive problems (particularly language disorders) of patients suffering neurological disease or brain injury and produced schematic drawings to represent the mental processes involved. These drawings were hypothetical functional architectures with processing centres and transmission pathways which served as theoretical frameworks to explain observed cognitive impairments. Despite there being important differences between the approach of the diagram-makers and today's cognitive neuropsychologists (e.g. the difference in emphasis on anatomical localisation, outlined above), the use of diagrams to map out mental machinery is central to both. Furthermore, Morton (1984) pointed out in his review of language models that some rival models from the turn of the century embodied the same contrasting theoretical viewpoints as some current models.

Another major source of influence for cognitive neuropsychology, as the name suggests, has been cognitive psychology. Ellis and Young (1988) suggested that the vigour of cognitive *neuro*psychology is largely due to the crosstalk between the two disciplines. It is certainly the case that the areas where modern-day cognitive neuropsychology first made important theoretical advances (e.g. Shallice & Warrington's 1970 study of memory impairments; Marshall & Newcombe's 1973 study of acquired reading disorders), were those where cognitive psychology had already developed viable theories of normal functioning. Furthermore, many of the phenomena discovered in experiments in laboratories have proved useful as tools to investigate cognitive disorders in patients. Even computing science has had an influence through cognitive psychology. The widely accepted information-processing paradigm as a conceptual tool has legitimised modern-day diagram making.

Cognitive neuropsychology then, can be thought of as a convergence of two disciplines: (a) cognitive psychology, which studies in normal subjects, the mental processes involved in problem solving, speaking, reading, writing, recognising objects, remembering information and generally living our daily lives and (b) neuropsychology, which attempts to identify the particular brain structures involved in cognitive tasks by studying the deficits in brain injured patients. There are then two main aims of cognitive neuropsychology. The first is to examine the impaired and intact cognitive skills of brain injured patients and interpret them in terms of damage to the components of a model of the underlying cognitive processes. The second is to infer from these patterns of impaired and intact cognitive processes what the normal organisation of the mental machinery is (Coltheart, 1985; Ellis & Young, 1988). As McCarthy and Warrington (1990) said, it is the belief that "the functional analysis of patients with selective deficits provides a very clear window through which one can observe the organisation and procedures of normal cognition" that is at the heart of the discipline. The methods by which this enterprise is undertaken and some of the issues and assumptions involved are outlined below.

1.2. The Single-Case Approach.

Another aspect of the methodological approach of cognitive neuropsychology common to the 19th century diagram makers, is the use of single patients as the source of data. The investigation of a patient's particular area of cognitive disturbance is guided by current theoretical models. Based on such models, predictions about certain aspects of performance can be made. If a patient shows a pattern of performance that cannot be accommodated by the current models then modifications need to be made which will accommodate both the pre-existing and the new data. In this way each patient is treated as a test of current theory. The use of in-depth studies of single patients to make inferences to normal functional organisation is widely accepted (e.g. Coltheart, Patterson & Marshall, 1980; Patterson, Marshall & Coltheart, 1985; Ellis & Young, 1988; Denes, Semenza & Bisiacchi, 1988; McCarthy & Warrington, 1990). In fact, Caramazza (1986) and Caramazza and McCloskey (1988) went as far as to argue that *only* the single-case approach permits valid inferences about the structure of normal cognitive processes from the analysis of cognitive disorders. The alternative approach, and one dismissed by Caramazza and McCloskey, is to study the performance of groups of patients and make inferences on the basis of group performance. Their objection is that the criterion for assignment to a group has to be homogeneity. This cannot be homogeneity of some aspect of performance however, because this may arise from different functional impairments. Homogeneity must be in respect of the component(s) of processing that is impaired in each member of the group and this has to be assessed by reference to models derived from single patients. Thus they argue that single-case studies must precede group studies. Shallice (1979) and Caramazza and McCloskey (1988), have also argued that the single-case approach avoids the loss of theoretically informative differences between the performance of individuals, that can occur in the statistical analysis of group data.

This 'strong' single-case position is not universally accepted however. Caplan (1988) argued that Caramazza and McCloskey's concern about the masking of individual performance inappropriately stresses the theoretical importance of individual exceptions and gives them a significance that they do not have in normal studies. Newcombe and Marshall (1988) suggested that the general dichotomy between single vs. group studies is probably misconceived. They, like Wilson (1991), argued that both approaches are valid sources of data and the suitability of one or the other depends very much on the theoretical issues under consideration. Wilson particularly, argues that a problem of the single-case approach is that an individual may represent an atypical functional organisation but that this may be dealt with by studying groups of individuals. Even Caramazza (1986), outlined circumstances in which he considers group studies to be appropriate. For discussions of the strengths and weaknesses of both approaches see Shallice (1979, 1988, & 1991 with open peer commentary), Caramazza (1984; 1986), Caramazza and McCloskey (1988), Bub and Bub (1988).

1.3. The Models and Modularity.

The influence of other disciplines distinguishes the functional diagrams of today from those of the 19th century. Cognitive neuropsychology is defined by the information-processing paradigm. Because an information-processing approach has been used to model cognitive processes in normal subjects, this has encouraged a degree of cross-fertilisation between theories based on neuropathological and normal findings. The approach is not without detractors however (e.g. Dreyfus, 1979; Parisi & Burani, 1988) and it is criticised both for being an incomplete explanation and for gratuitously making analogies between the human brain and computers. It seems though that these criticisms arise because of an epistemological confusion. The information-processing paradigm is merely the conceptual framework within which cognitive neuropsychology operates and does not constitute a scientific theory. It is the assumption of modularity (outlined below) that the information-processing approach makes, to which the criticisms are more properly directed. Information-processing is merely a tool to conceptualise one level of description (Marr, 1982). Before attempting a description or hypothesis of *how* a cognitive task is carried out, it is necessary to specify the sub-goals or problems inherent in the execution of that task. These problems determine the sequence of operations inherent in the task but not *how* they are carried out. Furthermore, they say nothing about the hardware on which these processes are implemented. In other words, the primary goal is to determine the overall organisation of the major computational sub-components of a cognitive system. Nevertheless, cognitive neuropsychology needs to be prepared to try to "unpack the contents of the boxes" (Ellis, 1987) and as Sartori (1988) pointed out, detailed error analyses of patients' performances maybe better suited to specifying the procedures or the *how* of cognitive tasks.

The hallmark of information-processing diagrams is the assumption of modularity. Modularity of cognition posits that mental processes are carried out by the orchestrated activities of a collection of smaller, functionally meaningful processing components or modules. Modularity, as a general design principle in complex systems was explicitly considered by Simon (1982) and Marr (1976, 1982). A further source of influence was Fodor (1983) who outlined a series of defining characteristics and properties of modularity with respect to cognition. Marr's argument was a computational one. He argued that the more computationally complex a task becomes, the more likely it is that it will evolve towards a modular organisation of sub-goals. If these modules are functionally autonomous, this has an important consequence for the system. Namely that modifications can be made to the computational goals of specified parts of the system without incurring compensatory changes elsewhere.

Fodor was more explicit about the properties of cognitive modules. He said that modules would be computationally autonomous, informationally encapsulated, innately specified, hard-wired, domain specific and not composed of simpler elements. This is often considered too rigid a prescription for use in explaining human cognition. Many cognitive systems such as reading are considered to be modular but would violate some of these criteria. For other views on the issue of modularity see Schwartz and Schwartz (1984), and Shallice (1984) for suggestions of how to relax Fodor's specifications.

The concept of cognitive modules would not have been adopted so enthusiastically had it not received enormous empirical support. An array of highly selective and often counter-intuitive impairments have now been reported from the study of brain injured patients (e.g. Ellis & Young, 1988). Converging evidence comes from visual neuroscience. Zeki (1978) argued that the cytoarchitecture of monkey visual cortex contains anatomically distinct sub-systems and that these support distinct micro-functions (e.g. motion and orientation detection and colour processing). Experimental data from normal subjects provides further support. Allport (1980) interpreted the ability of subjects in dual-task experiments, to perform two demanding tasks simultaneously, both to normal levels of performance, as evidence for the operation of separate cognitive modules.

The extent to which hypothesised modules actually are independent or what the criteria for assessing independence should be, are open questions. Most cognitive neuropsychologists would probably agree that the essential evidence for a cognitive module is the requirement that it can be selectively impaired or preserved.

1.4. Dissociations and Associations.

The basic aims of cognitive neuropsychology are to interpret a patient's performance within a model of the functional architecture and to modify the model where appropriate. Given that the model will be an information-processing diagram embodying assumptions of modularity, the aim can be re-defined as identifying processing components that can be shown to act independently of each other or be extensively capable of selective preservation or impairment. In other words, the aim is to seek functional dissociations. Dissociations are critical in the inferential procedure involved in using patterns of performance to refine current models (Shallice, 1979, 1988). If, within a complicated pattern of preserved and impaired abilities, a patient can be shown to perform normally on one task (e.g. recognising faces) but to be impaired on another (e.g. repeating spoken words), a dissociation has occurred. Another example would be if a patient was found to perform normally on all tasks except one, say, recognising familiar objects. In both cases a *single dissociation* has occurred and many researchers may be prepared to conclude that these patterns suggest functional modularity. In the first example this would be that the cognitive processes involved in face recognition are separate from those involved in word repetition and in the second example that the cognitive processes involved in object recognition are separate from all others. However, the same researchers may not feel as comfortable about drawing the same conclusions of modularity from single dissociations in other circumstances. Consider a patient who can read familiar words normally but is impaired at reading novel words. In this situation assumptions about modularity are much more dangerous. The difference in performance on the two tasks might be just as easily explained as the result of a difference in task demands, i.e. novel words are harder to read than familiar words. The interpretation could now be that the same cognitive processes are involved in both tasks but that the patient's brain injury has reduced the overall level of resources available leaving the patient capable of only doing simple tasks. For this reason inferences of modularity are more safely based on *double dissociations*.

A double dissociation occurs when two patients are found, one of whom is impaired on task 1 but performs normally on task 2 and the other performs normally on task 1 but is impaired on task 2. It can be shown that normal performance on one of the tasks is not required for either patient. As long as both patients perform significantly better on one task than on the other and that these are the opposite tasks for each patient, then modularity is usually assumed (See Shallice, 1988, for a thorough review of the use of dissociations as a basis for inferences of modularity).

Neuropsychology has a tradition of describing patients on the basis of co-occurrence of cognitive deficits. That is, in terms of *associations.* It is not unusual for authors to suggest that associations have little place in cognitive neuropsychology and that they should be treated with caution. Shallice (1988) argued that this stems from an inferential asymmetry between dissociations and associations. The problem with making inferences of modularity from associated deficits is that their co-occurrence may be nothing to do with them being subserved by the same functional module. It could simply be that a constellation of functional deficits arises because of an anatomical lesion that is large enough to affect more than one functional module. Future investigations may reveal a patient in whom only one of the deficits occurs, i.e. a single dissociation. The inverse pattern in another patient would then produce a double dissociation. What may have appeared to be one functional module would now have fractionated into two or more separate modules.

Whilst these arguments about the relative utility of associations and dissociations have considerable empirical support, they do oversimplify the real inferential procedure. A patient's pattern of impaired and intact abilities can sometimes be of labyrinthine complexity. There will usually be numerous symptoms to be explained and it is likely that this will involve the uncovering of functional *dissociations*. However, it would be a mistake not to recognise that this process itself may well involve recognising an *association* of symptoms and then using this as a corroborative tool. Consider the following example. A patient may present with an impairment in understanding spoken words. Normal performance on an auditory lexical decision task (a task that involves judging whether a sequence of phonemes is a real word or not) would show that word recognition was still intact. This would mean that a dissociation between word recognition and word comprehension had been uncovered. After further tests we might wish to conclude that the comprehension problem arises because the semantic representations of the words themselves are damaged. This conclusion would receive considerable support if the patient was also shown to have an impairment in understanding the same written words, i.e. if there is a co-occurrence of spoken and written word comprehension problems. Thus inferring modularity of auditory word recognition procedures would have involved both a dissociation and an association of symptoms.

The apparent dichotomy between dissociations and associations, like that between single-case and group studies, is somewhat artificial. It depends on the type of information being sought. Dissociations are well suited to single-case studies and inferences of modularity. However, if questions are being asked about which deficits typically co-occur then associations are naturally the focus of investigation. Furthermore, groups of patients, not single-cases, are more suitable for answering these types of questions.

1.5. Syndromes or Patient Descriptions?

The distinctions between single-case studies involving dissociations and group studies involving associations arise because the two approaches are suited to answering different questions. A closely related issue is that of patient classification. In the biological sciences, taxonomic categories are based upon co-occurrences of features or attributes. What these features might be depends upon the kinds of generalisations that a biologist may want to make about a particular group. Nevertheless, relationships and associations are the bases for categorisation. It is not surprising then that traditional neuropsychology has used associations of symptoms to define syndrome classifications under which patients sharing the symptoms can be grouped e.g. Broca's and Wernicke's aphasia. This 'syndrome approach' is not unique to neuropsychology however. Marshall and Newcombe (1973) proposed a model of normal reading processes on the basis of having identified three different varieties of reading disorder. These patterns of impairment were defined as deep, surface and visual dyslexia. The major criticism of the syndrome approach is that there is a history of regarding patients grouped together under a syndrome label as interchangeable. Research into the acquired dyslexias has proved the folly of this. Important dissociations between symptoms have been found in patients classified under the same syndrome label, e.g. deep dyslexia (Coltheart, Patterson & Marshall, 1980) and surface dyslexia (Patterson, Marshall & Coltheart, 1985). Ellis (1987), commenting on the fractionation of symptoms in surface dyslexia said that "the syndrome is dissolving before our very eyes".

One reaction to the problem of the continuing fractionation of syndromes has been to suggest that broad categories should simply be replaced with newer, more refined syndromes. Shallice (1979), advocated this approach as one that would allow the progressive identification of theoretically relevant syndromes of increasing purity. More recently (1988), Shallice has acknowledged that whilst this approach is "appropriate as far as theory discovery is concerned it should not be rigidly applied". This, he argued, is because even single-component syndromes, (which supposedly reflect damage to a single sub-system) can appear to fractionate in terms of performance (Sartori, 1988), and the procedure thus runs the risk of eliminating potentially pure syndromes. Coltheart (1987) suggested that syndrome labels had aided in a ground clearing exercise but that they should now be supplanted. More rigorous rejections were provided by Caramazza (1984) and Ellis (1987). Caramazza (1984), said "unequivocally" that classifications based on the statistically reliable co-occurrence of symptoms (e.g. the classical aphasia syndromes) have no place in psycholinguistic research. However, he did not reject the concept of syndromes altogether. He argued that the development of theoretically and empirically coherent aphasia categories are a necessary part of cognitive neuropsychology *but* that the syndromes should be defined by symptoms that *necessarily* co-occur because they are sub-served by a single processing mechanism. Ellis (1987) argued very strongly for a *total* rejection of syndrome labelling in cognitive neuropsychology because, he claimed, nothing can be gained from it. He advocated a simple two-step methodology. Firstly, the researcher should perform a rigorous study and produce a precise description of the patient's pattern of preserved and impaired abilities. Secondly, the researcher should evaluate the implications of the results for the theoretical understanding of the cognitive system in question and "that is all that matters". Saffran (1984), whilst supporting a similar position to Caramazza and Ellis, said that "much of the disharmony with syndrome labels arises because they are a misguided attempt to utilise a single classificatory scheme to achieve a variety of non-complimentary ends". In other words it is not syndromes labels *per se* that are a problem but cognitive neuropsychologists' use of them.

The use of syndrome labels as a shorthand for communication purposes is probably the extent of their utility. This requires that there is conventional recognition of what the primary symptoms subsumed by the heading are. Even then such a heading would have no explanatory weight in theoretical terms because a single symptom may arise because of several different functional lesions. The view taken in this thesis is that for the purposes of cognitive neuropsychology, a description of the pattern of actual impaired abilities by which a patient can be *characterised* is more useful than assuming the probabalistically associated deficits by which they have been *categorised*.

1.6. Other Assumptions.

It should be emphasised that the preceding discussions of methodology (although 'modularity' is more properly thought of as a paradigm *assumption*) are superficial treatments of complex issues. These issues provide fertile ground for debate and there is plenty of room for researchers to switch allegiances between the different sides of the arguments without catastrophic consequences for cognitive neuropsychology as a discipline. Underlying these issues however, is a set of assumptions upon which the procedure of drawing inferences about the normal cognitive system from damaged cognitive systems rests. Some of these assumptions are pivotal to the discipline. Others are less critical but have consequences for the methodology of the discipline.

A crucial assumption is that which Caramazza (1986) referred to as the *assumption* *of universality*. This is the assumption that there is consistency in the organisation and operation of cognitive systems across normal human beings. If this were not true then cognitive neuropsychology would not be possible. However, universality need not be held to refer to the whole human race. It may depend upon the cognitive system under consideration. As Caramazza pointed out, it would be wise to avoid pre-theoretical assumptions of cognitive homogeneity in domains where the internal structure of the information being processed varies between cultures, e.g. the differences in structure between Chinese language (where words are monomorphemic) and English language (which contains inflected words).

Dependent upon the notion of modularity, (itself an assumption which Caramazza said is not clearly open to empirical refutation), is the *fractionation assumption* (Caramazza, 1984, 1986). This is simply the belief that brain damage can result in the selective impairment of cognitive modules or processes (of course this carries no implication that impairment should be restricted to one module or even one domain). It is further assumed (the "*transparency condition*", Caramazza, 1984) that after brain injury "the pathological performance observed will provide a basis for discerning which component or module of the system is disrupted". In other words, the normal cognitive system can be fractionated by brain injury along theoretically significant lines and the remaining pattern of performance bears a transparent relationship to the organisation and processes of that normal system (although see Semenza, Bisiacchi, & Rosenthal, 1988, for a discussion of problems with this assumption). Caramazza added some caveats to this assumption, such as the effect of normally occurring individual differences in performance and the possibility of patients having developed compensatory strategies but concludes that these can be dealt with in a principled way. Caramazza (1986) extended the transparency condition to be explicit about yet another assumption. This has been called the *subtractivity assumption* (Saffran, 1982) and is related to the assumption of modularity. The subtractivity assumption says that the cognitive system of a brain- injured patient is the same as the normal system except for local modifications which involve the removal, either partial or total, of cognitive modules or processes. In other words, after injury the brain does not develop new cognitive modules. It may develop new strategies to compensate for any impairment but it must use pre-existing structures to carry them out. For further discussion of these assumptions and others embedded within them, see Shallice (1988).

This chapter has attempted to provide an overview of some of the methodological issues and assumptions that are part of the cognitive neuropsychological approach to the study of human behaviour. The work that is reported in the following chapters is typical of this approach and involved the investigation of disorders of reading and writing (particularly of novel or non-words) sustained by two patients, as a result of brain injury. Their general patterns of preserved and impaired reading and writing abilities and their performances on specially designed tasks, are interpreted within the framework of current competing theories of normal function. All investigations involved testing the patients' processing of single words or non-words. The specific issues to which the investigations of the reading disorders are relevant are presented in Chapter 2 and the corresponding experimental data are presented in Chapter 4. The writing investigations are presented in Chapters 5 and 6. Chapter 3 is relevant to both investigations and presents case histories, background language investigations and general patient descriptions.

2 Disorders of Reading Single Words and Non-Words.

2.1. Introduction.

Reading disorders, consequent upon brain injury, are known as *acquired dyslexias*. Their investigation has a long history, from the rather general descriptions produced by the 19th century neurologists to the very detailed descriptions of the single-patient studies of current cognitive neuropsychology. Such studies have provided a wealth of data which have been used to develop models of the normal reading system.

Historically, it has been common for models of the reading system to be incorporated within models of the functional architecture of the overall language system, i.e. the processes involved in reading, writing, listening and speaking.[2] There are two main reasons for this. The first is that up until as recently as 1970 (e.g. Luria), there was a common, intuitive belief that writing was necessarily parasitic upon the phonological output system involved in pronouncing words (either as internal sound forms 'spoken' in one's head or normal overt pronunciations). This view was bolstered by the empirical observation that reading and writing impairments commonly co-occurred. However, cognitive neuropsychological investigations have now rendered "phonic mediation theory" untenable. Evidence from patients shows that accurate writing can be performed not only when a patient is unable to produce overt pronunciations but also when they appear to have no inner speech either, e.g. patient EB, Levine, Calvanio and Popovics, (1982). Thus writing can be performed independently of speech processes (for brief reviews of other evidence see Patterson, 1988; Ellis & Young, 1988).

2 Although Wernicke (1886), was not content to do this. As well as drawing a composite model of the organisation of the system responsible for reading and writing, he also drew separate models of the systems responsible for reading, writing and writing to dictation.

Secondly, it was assumed that the sub-system responsible for the visual recognition of a written word was the same sub-system from which the spelling of that word was retrieved prior to written production (e.g. Morton's logogen model, 1970, 1979a). Although there is not the same weight of evidence to refute this view as there is to refute phonic mediation theory, this assumption is no longer shared by everyone.[3] Morton (1979b, 1980, in developed versions of the logogen model), Monsell (1987) and Campbell (1987), are amongst those who have suggested that the evidence is best accommodated by a model which incorporates independent sub-systems for visual word recognition and spelling production. Therefore, although it is no longer *necessary* to incorporate models of reading within models of the overall language system, it is still common to do so within cognitive neuropsychology. One motivation for this, as with the models of the past, is that patients commonly suffer impairments in more than one language domain. A comprehensive study of a patient's impairments may therefore require a model of the overall system to permit a description of the theoretical motivation for the tasks employed and an interpretation of the results.

One such model is that shown in Fig. 2.1. This model, which represents something of a consensus view, describes the functional architecture of the processes involved in the recognition, comprehension and production of written and spoken single words and non-words and is adapted from Patterson (1986). This model, as Patterson (1988) acknowledges, is a descendent of Morton's (1970, 1979a) logogen model. Modifications to the early version produced something similar to that in Fig. 2.1. (Morton, 1979b, 1980). The model is sufficiently general that most researchers would not be too antagonised by it, or variants of it (e.g. Coltheart, 1987; Ellis & Young, 1988; Coslett, 1991). Nevertheless, it specifies the organisation of processes sufficiently well to provide a theoretical framework within which the data from the patients reported here can be interpreted.

[3] Although this issue is not a main focus of this thesis, it is one to which data from the investigation reported here are relevant. It is therefore referred to only briefly here and will be dealt with in more depth later.

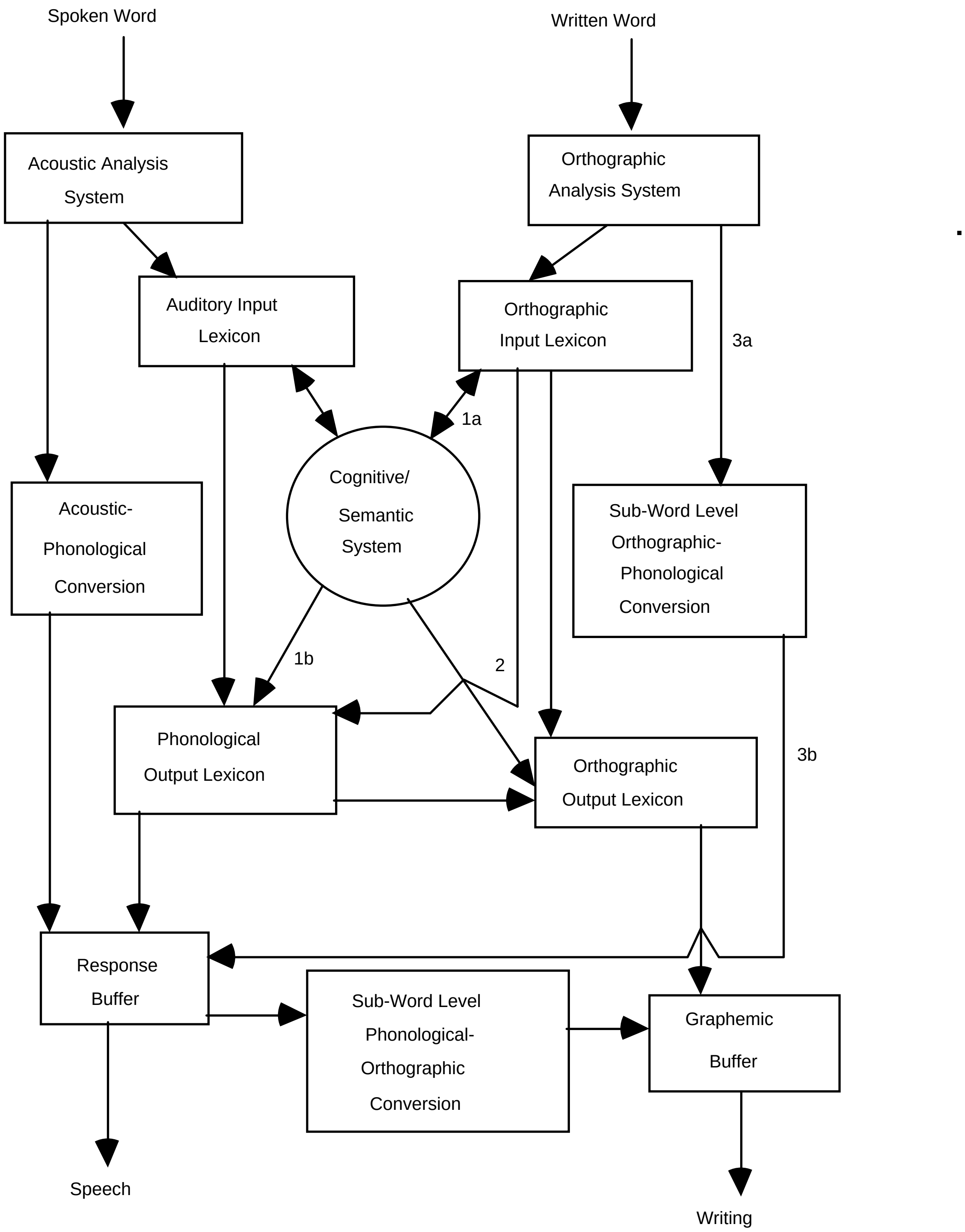

FIG 2.1. A Simple Process Model for the Recognition, Comprehension and Production of Spoken and Written, Single Words and Nonwords (Reproduced from Patterson, 1986). Routes 1a and 1b Comprise the Indirect Semantic Route. Route 2 is the Lexical Direct Route. Routes 3a and 3b Comprise the Sub-Lexical Direct Route.

Cognitive neuropsychological studies of language disorders received real impetus in 1973 when Marshall and Newcombe produced a seminal article, "Patterns of Paralexia", in which they identified and described three different acquired dyslexic disorders. They termed these visual, surface and deep dyslexia. Over the following years, reading disorders were to play a central role in cognitive neuropsychology and the syndromes of deep dyslexia (e.g. Coltheart, Patterson & Marshall, 1980), surface dyslexia (e.g. Patterson, Marshall & Coltheart, 1985), and an additional syndrome of phonological dyslexia (e.g. Beauvois & Derouesné, 1979; Shallice & Warrington, 1980; Bub, Black, Howell Kertesz, 1987), came to be much better understood. A review of several other reading disorders that have been identified and described, in addition to those mentioned above, can be found in Ellis and Young (1988). The body of literature on language and specifically reading disorders, is now immense and models like that in Fig. 2.1. are testimony to the advances that have been made in our understanding of how language processes are organised. Nevertheless, important theoretical issues remain unresolved and prominent among these are issues concerned with the processes and routes involved in reading aloud. These issues are important theoretically because the different solutions proposed imply different criteria for functional specialisation in human cognition.

2.2. Routes from Print To Sound.

It is generally agreed that there is an indirect route from print to sound via the semantic system (see Fig. 2.1). Semantic mediation is clearly necessary to explain our ability to produce contextually appropriate pronunciations for heterophonic homographs (words which have more than one possible pronunciation) like *lead*. It is also generally accepted that there are routes or processes that achieve the mapping directly (i.e. non-semantically). However, there is no general agreement on the nature and organisation of these direct mapping processes.

Many cognitive neuropsychologists propose that there are two distinct direct routes (e.g. Coltheart, 1978, 1985; Ellis & Young, 1988; Morton & Patterson, 1980; Patterson and Morton, 1985; Patterson & Shewell, 1987; Coslett, 1991). One route deals with familiar whole words or root morphemes (e.g. Bub, Cancelliere, & Kertesz, 1985; Funnell, 1983; Schwartz, Saffran, & Marin, 1980). The other route deals with segments smaller than the whole word such as graphemes and their corresponding phonemes (e.g. *s* - /s/, *ea* - /i/). These two proposed routes will be referred to as the lexical direct route and the sub-lexical direct route respectively (see Fig. 2.1). Other theories deny this dichotomy and propose that there is just a single direct route (e.g. Shallice, Warrington & McCarthy, 1983; Shallice & McCarthy, 1985; McCarthy & Warrington, 1986; Hillis & Caramazza, 1991; Seidenberg & McClelland, 1989; Hinton, Plaut & Shallice, 1993). Theories which include two non-semantic routes will be referred to as dual direct-route theories, and those with just one will be referred to as single direct-route theories.

2.2.1. Dual Direct-Route Theories.

Dual direct-route theories have many proponents. There are various possibilities with respect to the precise specification of the entities that are dealt with by each route. For example, the sub-lexical direct route is proposed to involve the application of orthography-to-phonology conversion (OPC) procedures to segments smaller than the whole word. It has been suggested (Coltheart, Masterson, Byng, Prior & Riddoch, 1983) that this route maps between single graphemes ("functional spelling units", Venezky, 1970) and the phonemes to which they correspond (e.g. *s* - /s/, *ea* - /i/). Alternatively, it has been suggested that it may also map between larger segments, such as the body *ove* of the nonword *pove* (Patterson & Morton, 1985). Our ability to read unfamiliar letter-strings and nonwords is the primary evidence cited in support of this route. This route is also considered to be sufficient for reading familiar words with regular pronunciations but it would misread irregularly pronounced words by regularising them, i.e. by reading *pint* to rhyme with *hint*. Phonological dyslexia , where the central characteristic is severely impaired reading of novel words or non-words accompanied by comparatively preserved or unimpaired reading of familiar real words, is often explained as arising from damage to this route (e.g. Funnel, 1983; Bub *et al*, 1987).

A major motivation for proposing a distinct lexical direct route was the discovery of patients who could accurately read aloud, many irregularly pronounced words (e.g. *swan*, *leopard*) despite severely impaired comprehension of those same words. Since sub-lexical OPC procedures would not yield correct pronunciations for such words and the semantic route for these words appeared not to be available to these patients, their performance was interpreted as evidence for a lexical direct route. This was proposed to involve direct connections between phonological output representations and their corresponding orthographic input representations (e.g. Schwartz et al, 1980; Bub et al, 1985; Coslett, 1991). This route is assumed to be capable of processing all familiar words but incapable of processing novel letter-strings or non-words.

2.2.2. Single Direct-Route Theories.

Single direct-route theories take a variety of forms. They can be put into three broad groups: 1. Lexical single direct-route theories; 2. Sub-lexical single direct-route theories; 3. Multi-level single direct-route theories. The major contenders of each of these approaches will be briefly outlined in turn.

2.2.2.1. Lexical Single Direct-Route Theories.

A well specified single direct-route theory is Seidenberg and McClelland's (1989) connectionist model, in which the translation of all print to phonology is performed within what amounts to just one functional route. It is lexical only in the sense that the procedures for converting print to sound are trained by pairings of specific whole printed words with their specific whole pronunciations. The 'knowledge' gained from such procedures generalises to produce pronunciations for unfamiliar items. The phonology for regular words, exception words and nonwords is computed directly from their orthographic representations by a single procedure that uses a layer of hidden units which receive activity from orthographic units and transmit activity on to the phonological units. This particular single-route architecture has an important theoretical consequence for the explanation of the functional impairments involved in phonological dyslexia. There is no sense in which words and nonwords can be distinguished by the system. It has no lexical representations and deals with all orthographic input in the same way. Because a common procedure is used for producing the phonology for all letter-strings, lesioning cannot produce a severe impairment to nonword reading whilst leaving familiar word reading largely preserved. The implication of this, as Seidenberg and McClelland made explicit, is that phonological dyslexia "would follow if the patient's capacity to compute pronunciations from orthography were impaired but the indirect route from orthography to meaning to phonology were not" (p.558). In other words, phonological dyslexics are dependent on the semantic route for reading single words.

Analogy theory also proposes a single direct route that is lexical (e.g. Glushko, 1979; Marcel, 1980; Kay and Marcel, 1981; Friedman & Kohn, 1991). To account for our ability to read novel items, this theory proposes that their pronunciations are assigned by analogy with known lexical items. A crucial characteristic of this model is that there are no distinct sub-lexical processes for assigning phonology to sub-lexical orthographic segments. Instead, pronunciations for unfamiliar words and nonwords are assembled after the segmentation of any matching segments from any lexical orthographic and phonological representations which contain them. In this model, a severe impairment to nonword reading does not necessarily imply that phonological dyslexics are semantic readers. Instead, intact reading of familiar words could be performed non-semantically with the non-word reading deficit arising because of impaired segmentation processes.

2.2.2.2. Sub-Lexical Single Direct-Route Theories.

Hillis & Caramazza (1991) proposed a single direct-route theory in which the non-semantic route is sub-lexical. They proposed that in an intact system, the semantic route is adequate for the pronunciation of known words and that novel words and nonwords are read aloud via OPC procedures. As outlined above, one problem for this proposal is to explain the ability of some patients to read irregular words despite severely impaired comprehension of them. Hillis & Caramazza (1991) re-examined the data from such patients, and concluded that it does not provide good evidence for a lexical direct route. They noted that patients such as WLP (Schwartz, Saffran, & Marin, 1980), who read irregular words despite impaired comprehension of the same words, did not have *total loss* of semantic information. WLP’s errors on picture/word matching tasks were predominantly within-category semantic errors, suggesting some residual semantic information. Hillis & Caramazza (1991) reported their own patient, JJ, who shows precisely this pattern of performance. They showed that JJ read *only* those irregular words for which he showed *some* comprehension. Words for which JJ showed no comprehension produced phonologically plausible errors (e.g. *soot* being read as "suit"). Hillis & Caramazza accounted for these results by proposing that "accurate oral reading could result from the summation of (even partial) information from OPC mechanisms and (even partial) semantic information which together activate corresponding entries in the phonological output lexicon to threshold levels". Although this summation hypothesis accounts well for much of the data, Hillis & Caramazza did not rule out the possibility of a lexical direct route, but noted that evidence for it requires data that cannot easily be explained as the result of the combined operation of a lexical semantic route and a sub-lexical direct route. Hillis & Caramazza (1991) suggested that an example of such data would be the accurate reading of irregular words in the face of impaired semantics and total inability to use OPC procedures.

2.2.2.3. Multi-Level Single Direct-Route Theory.

A third form of single direct-route theory, the multiple-levels approach, has been proposed by Shallice, Warrington and McCarthy (1983) and Shallice and McCarthy (1985). This theory, modelled in Fig. 2.2, proposes that spelling-to-sound correspondences for units of various sizes such as letters, graphemes, sub-syllabic segments such as heads and bodies, syllables and morphemes are generated after a letter-string is analysed by a visual word-form system. This single but "broad" route is proposed to be sufficient for reading all words and nonwords. The primary motivation for this proposal was the observation that spelling regularity is a continuous rather than a dichotomous variable and thus does not seem to provide an adequate basis for just two distinct direct-routes. Specifically, they

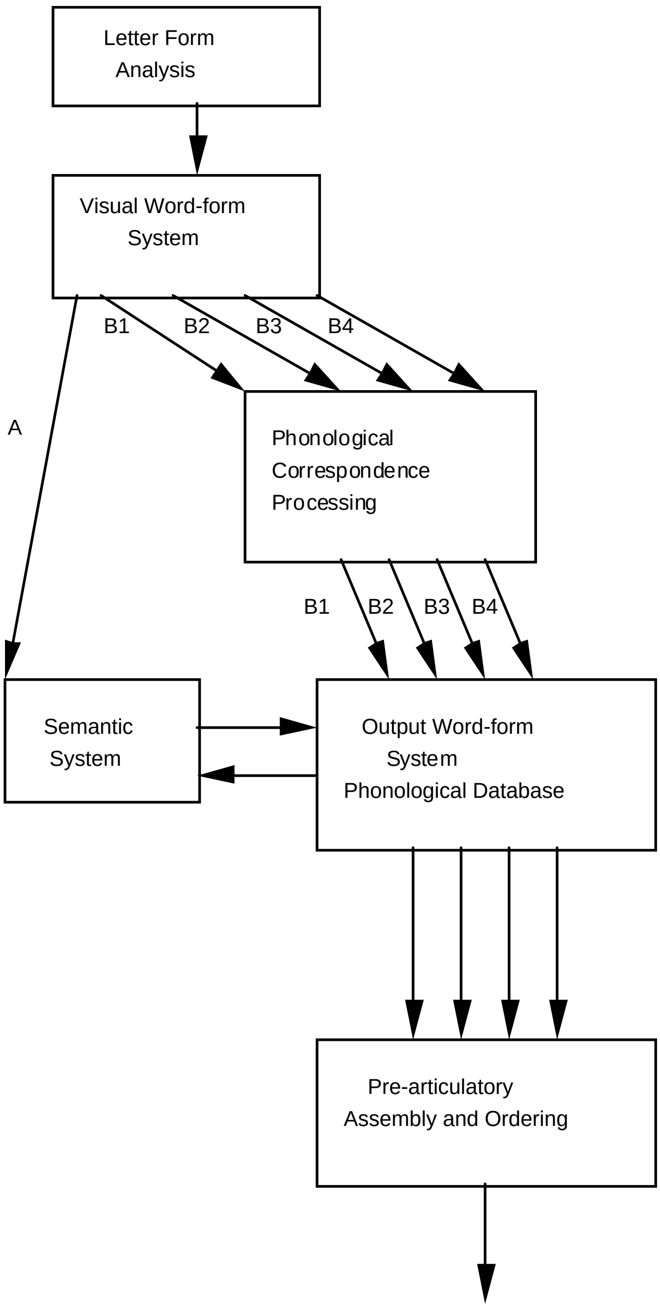

FIG 2.2. A Model of the Word-Form Multiple-Levels Approach to the Reading Process. A = the Semantic "Route" and B = the Phonological "Route". B1 - B4 Represent Different Levels of Operation or Different Sizes of Orthographic/ Phonological Units Represented in the System. (Adapted from Shallice and McCarthy, 1985).

reported a patient, HTR, (Shallice, Warrington and McCarthy, 1983) who could read mildly irregular words better than highly irregular words. This pattern of performance is not readily explained by any version of dual-route theory that distinguishes between two routes on the basis of whether they can deal with irregular words or not, or where OPC procedures depend only on grapheme-phoneme conversion. To account for these effects of the 'degree of irregularity', Shallice, Warrington and McCarthy (1983) suggested that correspondences based upon larger sized units are more vulnerable to damage than those based upon smaller ones, and that the more highly irregular words depend upon larger units. No basis for the reverse form of selective damage, with smaller units being more vulnerable than larger ones, was proposed. A failure to read nonwords would therefore imply that all levels of this single route are impaired. The ability of phonological dyslexics to read familiar words despite severely impaired nonword reading is therefore explained as being due to the use of the semantic route, "If a patient cannot utilise grapheme-phoneme correspondences, the phonological recoding mechanisms would be so impaired that all forms of phonological reading would be impossible. Any observed reading abilities must then depend on the 'direct' semantic route alone" (Shallice & Warrington, 1980).

2.3. Peripheral Issues and an Outline of Investigations.

This thesis reports two patients, AN and AM who both have, amongst other difficulties, impairments in non-word reading that are severe relative to their impairment in reading words. Aside from the main issue of the number of routes from print to sound, data from these patients are relevant to other issues. Patients with a non-word reading deficit have typically been classified as either deep dyslexics, e.g. patient PW (Patterson, 1980) or phonological dyslexics, e.g. patient WB (Funnell, 1983). In particular, AN shows a mixture of the symptoms associated with these two conditions, but has more in common with those called phonological dyslexics. She is a good example of why many authors argue that syndrome labels provide inadequate descriptions of individual patients (see chapter 1.5).

In many areas of cognitive modelling, a distinction is made between procedures that access stored knowledge and the knowledge structures themselves (e.g. Tulving & Pearlstone, 1966; Meyer, 1970). Specifically with regard to impaired cognitive systems, Warrington and Shallice (1979) proposed that deficits of access to stored information can be distinguished from deficits affecting the stored representations themselves by certain characteristics of a patient's performance. To account for the differences between the performances of patients AR and EM, who both had impaired semantic processing, they proposed that inconsistency in retrieval of knowledge of specific items, lack of significant frequency effects and the effectiveness of priming or cueing were all indicative of a deficit in accessing semantic information. The opposite pattern of symptoms, high consistency, significant frequency effects and no effect of cueing, were argued to be characteristic of a loss of the semantic representations themselves. Shallice (1988) has gone on to suggest that these criteria should apply as general principles across cognitive theories and domains, regardless of the proposed nature of the access mechanisms or the actual representations. However, Rapp and Caramazza (1993) argue that whether or not some pattern of impaired performance is indicative of a deficit of access or storage "relies crucially and absolutely" upon assumptions regarding the nature of access and storage. Although the following investigations were not designed specifically to address the issue, some of the data reported here are relevant to the distinction.

After the case reports and general descriptions of the patients' language deficits, the possible loci of AN's nonword reading deficit is explored.[4] A mechanism for translating an unknown letter-string to sound could suffer functional impairment at any of at least three stages: (1) orthographic analysis, e.g. patient MS (Newcombe & Marshall, 1985); (2) the assignment of phonemes to graphemes, e.g. patient WB (Funnell, 1983); and (3) phonological assembly, e.g. patient MV (Bub, Black, Howell & Kertesz, 1987). Studies with AN reveal that she has impairments in the assignment of phonemes to graphemes and in phonological assembly. Reported next, as a test of analogy theory, are studies of orthographic and phonological segmentation, and of the reading of nonwords that are close neighbours of words that AN can read without difficulty. No evidence was found for reading by analogy. Finally, to investigate the role of semantics in the reading of familiar items, her ability to learn to read nonwords was studied. The method for doing this has been

[4] In terms of both the general descriptions of language abilities and the specific investigations, there are less data from AM than from AN. This is partly because AM is less willing to take part in neuropsychological testing than AN. However, it is also because AM has found great difficulty in coming to terms with the effects of his stroke and he reacts strongly to 'failing' in tests, sometimes by abandoning testing and sometimes by failing at everything 'for a joke'. Data obtained from such sessions have not been reported and re-testing was carried out on other occasions when the patient was willing.

called the 'familiar nonword paradigm'. This technique showed that AN and AM could learn to read the nonwords on which they were trained even if they were given no distinctive meanings. With AN it was found that learning was significantly faster if the nonwords were given distinctive meanings. This was not tested with AM. Studies are also reported of the semantic associations evoked in both patients by both words and learned nonwords, and of the effects of the nonword training on their sub-lexical performance. The results of these studies support the hypothesis that in AN and AM, there is a lexical direct route from print to sound available and that it is used to learn to read meaningless nonwords.

Studies of learning are theoretically important because they provide evidence on issues of functional organisation, in this case the issues of the number of routes involved in reading and the nature of the representations handled by such routes. They can also be used to test interpretations of deficits and the models upon which these interpretations are made (e.g. Aliminosa, McCloskey, Goodman-Schulman & Sokol, 1993). Studies of remedial techniques with aphasics are also of wider relevance to issues of assessment and rehabilitation (de Partz, 1986; Bachy-Langedock & de Partz, 1989; Nickels, 1992; Gonzalez-Rothi, 1993). Finally, such studies are also important because theoretical studies of reading by simulated neural networks emphasise learning (e.g. Seidenberg and McClelland, 1989; Plaut, 1992; Plaut and Shallice, 1991) which in turn may help evolve crucial constraints in cognitive modelling.

3 Case Reports and Investigations of General Language Abilities.

3.1. Patient AN.

AN is a right-handed, ex-restaurant manageress, born in October, 1932. In August 1979 she was admitted to hospital complaining of a right occipital headache and a general feeling of weakness and dizziness. Her previous medical history was unremarkable but there was a family history of cerebrovascular accidents (CVAs) at a relatively young age. Upon first examination she reported intermittent cramping pains in the legs and an upper limb weakness. Four days after admission her condition worsened and she was found to have developed a complete motor aphasia and a left-sided hemiparesis. A right-side carotid bruit (an abnormal noise in the cortical vascular system) was also found. Examination the following day found continued left-sided hemiplegia and a carotid bruit. A CT scan showed a right-hemisphere capsular infarct. AN opened her eyes to speech and gave disoriented verbal responses limited to yes/no confusions and curses. She was diagnosed as suffering from severe diffuse ischaemic vascular disorder. This has since necessitated amputation of the toes of the right foot in 1983 and of the left leg below the knee in 1991. Four weeks after admission AN's speech began to return and there was a slight improvement in her hemiplegia. Nine weeks after admission she was discharged. For most of the time since then she has continued to live at home alone, but with the aid of a home-help and of her daughter. Her main remaining neurological disabilities are left-sided hemiplegia, moderate nominal dysphasia, dyslexia and dysgraphia.

There is no indication in AN's medical records of any birth disorder or developmental disorder that might have led to right-hemisphere language representation. It was therefore suggested by a clinician, that AN's linguistic deficits may be due to left hemisphere lesions that are not detected on the CT scan, but which are consistent with the diagnosis of diffuse vascular disorder. However, although aphasia is rare following right hemisphere lesions in right-handers, it does occur (Habib, Joanette, Ali-Cherif & Pence, 1983; Brust, Plank, Burke, Goudadia & Healton, 1986). It therefore seems equally probable, given AN's associated symptoms, that she is one of the rare cases.

Pre-morbidly AN's occupation involved considerable administrative duties in a busy restaurant. She read frequently and took an active interest in politics. Post-morbidly she rarely attempts to read books although she does attempt to read the newspaper daily even though she claims to find this difficult because her reading is not fluent. She maintains an enthusiastic interest in politics, and frequently watches television. She is a mail-order catalogue agent and is knowledgeable of current affairs. AN no longer smokes but pre-morbidly she smoked about 25 cigarettes per day. She currently has reasonable mobility around her flat and walks short distances with the aid of a cane and prosthesis. She attends three social groups for stroke victims each week. AN is a willing and cheerful subject and can be fiercely independent. Her speech production in conversation is fluent with good articulation, normal prosody and speed. She has a moderate word finding difficulty and on occasions, though very rarely, produces semantic paraphasias. There is little obvious impairment in her comprehension during conversation.

The data on which this thesis is based were obtained between March l991 and October 1993, except as follows. Some of the background reading tests carried out on AN for this thesis were also administered in l984/85 by Dr W. A. Phillips of Stirling University. For comparative purposes, the l984/85 data are included as they provide a measure of stability of the patient's condition. Some of the data were obtained as part of an undergraduate project I carried out in 1990 and these tests will be indicated by this symbol §. All other data were obtained specifically as part of this thesis.

3.1.1. Background Tests.

Boston Aphasia Battery.

Formal evaluation with the Boston Diagnostic Aphasia Examination[5] (BDAE, Goodglass & Kaplan, 1972) in August 1991, yielded a severity rating of 4 on a scale of 0 (no usable speech or auditory comprehension) to 5 (minimal discernible handicap) and a Speech Profile typical of Anomic aphasia. Table 3.1 presents a subtest summary profile.

TABLE 3.1

Boston Diagnostic Aphasia Examination Subtest Summary Profile of AN.

Fluency		
	Articulation	7/7
	Phrase Length	7/7
	Verbal Agility	13/14
Auditory Comprehension		
	Word Comprehension	67/72
	Commands	8/15
	Complex Material	11/12
Naming		
	Responsive Naming	27/30
	Confrontation Naming	105/114
Repetition		
	Words	9/10
	High Probability Phrase	7/8
	Low Probability Phrase	3/8

Speech Comprehension.

AN performed auditory commands normally when instructions were short but showed a moderate impairment when instructions were longer. On the Token Test (de Renzi & Vignolo, 1962) she scored 9/10 correct on Part 1 and 6/10 correct on Part 2. Further tests suggest that the moderate impairment on Part 2 reflects a short-term memory impairment rather than a comprehension problem (see below).

[5] This was carried out by staff at Stirling Royal Infirmary Speech Therapy Department. I am grateful to Moira Bankier for allowing me to use these data.

Short-Term Memory.

Auditory-verbal and visual-verbal forward letter and digit spans were between 2 and 3 items. Number and letter names were either spoken aloud or presented visually in printed form at the rate of about one per second. Visual pattern span (Wilson, 1993) was 6 blocks within a square matrix, which is poor.

Copying.

Words and nonwords were printed in lower-case typeface and placed in front of AN for her to copy, which she always did in her own cursive script. Here, and in all subsequent tests, except where stated, the content and function words used were from a matched set supplied by Karalyn Patterson (Of the Applied Psychology Unit at Cambridge), and the high/low imageability, regular/irregular words and the nonwords (fifteen of which are pseudo-homophones[6] and fifteen of which are not) were taken from Coltheart (1981).

AN's performance was as follows, with the number correct being shown over the number of words presented: (a) 58/60 content words and 54/60 function words; (b) 28/28 high-imageability words and 27/28 low-imageability words; (c) 38/39 regular words and 37/39 irregular words; (d) 30/30 nonwords which were each three letters in length; (e) 41/43 four and five letter nonwords (from Glushko, 1979, Table A1); (f) 52/54 newly created six-letter bi-syllabic nonwords (e.g. *fincil, gerson, musger).*

Writing To Dictation.

All stimuli were read to AN at a normal speech rate and she was allowed as long as she wanted for each attempt. All correct real word responses were written immediately and fluently. Only nonword stimuli were reproduced with difficulty.

AN's writing to dictation was as follows: (a) 49/60 content words and 29/60 function words, the difference being significant ($\chi^2 = 13.2$, 1 d.f., $P<.005$); (b) 11/28 high-imageability words and 4/28 low-imageability words, the difference not being significant;

[6] A nonword which when pronounced sounds the same as a real English word.

(c) 16/39 regular words and 16/39 irregular words; (d) 3/15 non-homophonic nonwords[7]; (e) 3/15 newly created non-homophonic three-letter nonwords (e.g. *gan*, *jix*); (f) 1/30 of the non-homophonic nonwords taken from Glushko (1979, Table A1); (g) 0/54 newly created six-letter bi-syllabic nonwords.

Reading.

Words. A summary of the background reading data from 1984/85 and from 1991/92 for various classes of words and nonwords are presented in Table 3.2. All stimuli were presented in lists printed in lower case. An important aspect of the data is that the improvement in AN's reading across all six word classes during this time is significant ($t [5] = 3.105, P < .05$) whilst there was no improvement in her reading of nonwords. An error analysis for the 1991 data is shown in Table 3.3.

Monosyllabic nonwords of 3 letters. When presented with Coltheart's (1981) list there was no facilitating effect of homophony. Of the 10/30 nonwords AN read correctly, 4/15 were pseudohomophones and 6/15 were non-homophonic nonwords. Repeat testing produced 9/30 read correctly, comprising 5/15 pseudohomophones and 4/15 non-homophonic nonwords. There was little evidence of lexicalisation or real-word substitutions. Two were produced to the pseudohomophones, fue - "jews" and oan - "odour". Three were produced to the non-homophonic nonwords: mun - "mum", gue - "gore" and bue - "bow". The predominant characteristic of the errors in reading these stimuli was perseveration of the first phoneme (or sometimes first two phonemes) that was uttered. AN would often correctly produce the first phoneme and then reproduce it up to fourteen times, unable to produce any phonology beyond it (e.g. *noo* - /n/n/n/n/n /n/...../). Sometimes she would stop the perseveration but when re-attempting the letter-string would be unable to produce the correct phoneme and on producing an incorrect one would shake her head in frustration obviously aware of her errors (e.g. *kag* - /k/k/k/k/..../g/).

Monosyllabic nonwords of 4 or 5 letters. A further test of nonword reading used the

[7] A nonword which when pronounced does not sound the same as a real English word .

forty-three regular nonwords from Glushko (1979, Table A1). AN read 5/43 correctly, producing 19 real-word substitutions. This set of nonwords produced a worse overall

TABLE 3.2

Comparison of AN's Reading Performance Data From 1984/85 and 1991 Plus Additional 1991 Data.

		Proportion Correct 1984/85	Proportion Correct 1991/92	Significance of Differences Between Scores on Different Word Types in 1991/1992
Content	N=60	.82	.85	
				χ^2 = 16.52 (p<.005)
Function	N=60	.38	.48	
High Imageability	N=28	.79	.82	
				χ^2 = 7.62 (p<.005)
Low Imageability	N=28	.25	.43	
Regular	N=39	.72	.82	
				N.S.
Irregular	N=39	.67	.67	
Bi-syllabic Nouns (6 letter)	N=54	-	.72	
Nonwords (3 letter)	N=30	.33	.33	
Nonwords (4/5 letter)	N=43	-	.12	
Nonwords Bi-syllabic (6 letter)	N=54	-	.00	
Schonell Graded Word List		8 yrs 7 months	8 yrs 10 months	
Neale Analysis of Reading				
: Rate		-	7 yrs 6 months	
: Accuracy		-	7 yrs 11 months	

The improvement in reading words between 1984/85 and 1991/92 is statistically significant, t [5] = 3.105, p<.05.

performance (11.6% correct) than the Coltheart list (30% correct). They also induced different error types. Both real-word substitutions (e.g. *nust* - "nun", *beld* - "fell", *dold* - "bottle") and nonsense syllables (e.g. *dreed* - /bri/, *taze* - /tæt/, *brobe* - /pr/) were more common in the Glushko list. Only one nonword produced perseveration of the first phoneme. It is not clear why the error types are different for the two sets of stimuli. It is unlikely that it is because the Glushko nonwords are more 'word-like' because the Coltheart nonwords, like the Glushko nonwords, can all be made into real words by changing one letter. In AN's attempts to produce the appropriate phonology, the piecemeal building of the phonological form seems to happen in 'slow motion' and very inefficiently. She would often make laborious attempts at articulating the appropriate phonemes one at a time and then attempt to produce a combination. On going back to the beginning of the letter-string she would often produce incorrect phonemes where she had previously produced correct phonemes (e.g. *dreed* - /d/f/d/j/j/r/r/ri/ri/bri/; *doon* - /d/d/ju/jum/pjut/).

Bi-syllabic words and nonwords of 6 letters. This test was designed to provide a close comparison of AN's word and nonword reading where the sub-word segments and their positions relative to the letter-string as a whole, were the same in the two sets. A new set of nonwords was created by recombining the syllables of thirty-four bi-syllabic nouns (e.g. *napkin*, *musket*) to produce a closely matched set of thirty-four bi-syllabic nonwords (e.g. *napket*, *muskin*). Words and nonwords were presented as separate lists, words at the beginning of a one hour testing session and nonwords at the end. AN read 20/34 of the words (40/68 syllables) correctly taking 83 seconds to do so. After trying for 8 minutes she had read 0/34 of the nonwords and 3/68 syllables correctly. The test was later repeated using the twenty words that AN had read correctly and twenty new nonwords formed from them. She read 19/20 words correctly (39/40 syllables) in 55 seconds. After 8 minutes she had read 0/20 nonwords and 0/40 of their syllables correctly.

3.1.2. Summary of Language Impairments.

The above tests reveal AN to have a moderate anomic aphasia. Her auditory comprehension is good. On the BDAE her comprehension was in the 80th percentile or above except for the 'commands' section where her performance was in the 40th percentile. That impairment is probably due to her short-term memory deficit. AN's spontaneous speech is fluent and her articulation is normal. She copies words fluently with her preferred right hand. AN suffers two clear impairments. She has reading and writing impairments which are more severe for nonwords than for words. In both reading and writing she shows a syntactic category effect with an impairment that is more severe for function words than content words, and for abstract words than for concrete words. There are no effects of regularity on either reading or writing and there is no evidence of semantic paralexias.

TABLE 3.3

Error Analysis of AN's Reading Responses from 1991/92 by Stimulus Type.

	All Words N=308	All Non-Words N=127	Content Words N=114	Function Words N=60	Regular Words N=39	Irregular Words N=39	High Imageablility N=28	Low Imageability N=28
Number Of Errors	n=96	n=112	n=24	n=31	n=7	n=13	n=5	n=16
Proportion of Error Types:								
Visual:	.42	-	.54	.26	.44	.54	.40	.44
Derivational:	.09	-	.29	-	.14	.08	-	.06
Nonsense:	.24	.33	.08	.16	.29	.31	.40	.50
Omission:	.03	.26	-	.03	.14	.08	-	-
Unrelated Response:	.05	-	.08	.03	-	-	.20	-
Function Word Substitution:	.17	-	-	.52	-	-	-	-
Real-Word Substitution:	-	.21	-	-	-	-	-	-
Perseveration of First Phoneme:	-	.20	-	-	-	-	-	-
Semantic:	-	-	-	-	-	-	-	-

Examples of each error type are given below. An error was classified as visual if the response was a real word and a minimum of 50% of the letters appeared in the same order as in the target. Nonsense syllables occurred to both words and nonwords. Real-word substitutions were real-word responses to nonwords. Unrelated responses were real-word responses to words.

Visual:	found - "fold"; say - "stay".
Nonsense:	been - /twi/; kie - /kel/.
Derivational:	asked - "ask"; eyes - "eye".
Unrelated:	profile - "accord".
Function Word Substitutions:	who - "ever"; than - "and".
Perseveration of First Phoneme:	nue - /n/n/n/n/n/...; kag - /k/k/k/k/.....
Real-Word Substitutions:	oan - "odour"; fue - "jews".

Of 308 different words, 212 were read correctly (68.8%), but of 127 different nonwords, only 15 were read correctly (11.8%). This difference is highly significant ($\chi^2 = 115.01$, 1 d.f., $P < .001$). The results of the last test (reading bi-syllabic words and nonwords) show that AN can read familiar, whole words but not novel combinations of their sub-word segments, even when those segments occur in the same position as they do in the words that she can read. The segments of which words are composed, can therefore be processed when they occur as parts of a familiar whole but not when they occur as parts of an unfamiliar whole.

3.2. Patient AM.

AM is the nephew of AN. He is a left-handed, ex-graphic designer, born in June, 1955. At around mid-day on the 26th December 1990, AM had complained of a "strange" feeling in his right arm. Over the next two hours a numbness developed and he began to feel generally unwell. Around 2pm he drove three miles to his mother's house. After drinking a cup of tea he went to lie down and slept until next morning. He awoke at 8am to find he had difficulty in getting out of bed because of a weakness in his right leg and a completely numb right arm. He attempted to call his mother but found difficulty in doing so. He was admitted to hospital within an hour, with a sudden onset of severe right-sided hemiparesis and difficulty speaking. Apart from the family history of CVAs, AM's previous medical history was unremarkable.

Upon examination, AM had a pulse of 72/minute, blood pressure of 130/80 and his heart sounded normal. He opened his eyes to speech and intermittently obeyed commands. He showed a predominantly expressive dysphasia and a right-sided hemiparesis which was severe on the upper limb but slight on the lower limb. An ECG was normal. A CT scan of AM's brain, performed that day, showed a vague reduction in attenuation in the region of the left temporal parietal lobe, in keeping with an early infarct. He was diagnosed as having suffered a left hemisphere CVA. AM's condition worsened and he was unconscious for most of the two days immediately after admission. After two days his condition began to improve. He remained in hospital for six weeks, during which time his hemiparesis, particularly of his lower limb, gradually improved with physiotherapy and upon discharge he was walking independently and his speech had improved. AM's main remaining neurological disabilities are a moderate nominal dysphasia, dyslexia, dysgraphia and a right-sided hemiplegia of the upper limb.

AM was educated to Grammar School level and then went on to a Technical and Arts College graphic design course. Pre-morbidly, AM's job involved him producing artwork for local authority letterheads and publicity campaign materials. The quality of his artwork meant that he held a senior position in the department. His responsibilities involved reading documents produced by, and producing written documents for other council departments as well as giving face-to-face presentations to council executives. He was a gregarious person who had a passion for contemporary music and hi-fi equipment, about both of which he is very knowledgeable. He frequently read music and hi-fi industry magazines and occasionally novels.

Post-morbidly, AM never reads books. He attempts to read music magazines but claims to get discouraged doing so because of a difficulty in reading fluently. To my knowledge, he never attempts to write or draw. AM lives at home with his mother. He currently smokes about 40 cigarettes per day. Pre-morbidly he had smoked about 30 per day since he was sixteen years old. He occasionally watches television and is knowledgeable about current affairs. His main interest is listening to music and watching films. Six months after the CVA, AM's engagement broke up and he has received psychological counselling for depression. AM abandoned speech therapy after two years and goes out infrequently. When he does go out, it is usually to a pub with his brother and two ex-colleagues from work. He finds these outings frustrating because the fluency of his spontaneous speech is impaired by a word-finding problem. He has been encouraged to go back to work on an informal basis and produce artwork for the council. He has not done this because of his reluctance to face his colleagues with his word-finding problem.

AM enjoys the social interaction during testing sessions but is not always willing to continue testing when he fails at a task. His speech production in conversation is reasonably fluent with good articulation. Prosody and speed are normal. He has a moderate word finding difficulty but never produces semantic paraphasias. There is no obvious impairment in his comprehension during conversation.

3.2.1. Background Tests.

Boston Aphasia Battery.

Formal evaluation with the BDAE[8] in November 1992, yielded a severity rating of 2/3 on a scale of 0 to 5 and a Speech Profile typical of Anomic aphasia. Table 3.4 presents a subtest summary profile.

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[8] This was carried out by staff at Stirling Royal Infirmary Speech Therapy Department.

TABLE 3.4

Boston Diagnostic Aphasia Examination Subtest Summary Profile of AM.

Fluency	
Articulation	6/7
Phrase Length	7/7
Verbal Agility	13/14
Auditory Comprehension	
Body Part Identification	30/30
Word Comprehension	72/72
Commands	13/15
Complex Material	11/12
Naming	
Responsive Naming	27/30
Confrontation Naming	94/114
Repetition	
Words	10/10
High Probability Phrase	6/8
Low Probability Phrase	5/8

Speech Comprehension.

The clinical impression was that AM's auditory comprehension was good. He performed commands normally when instructions were short and only showed a mild impairment when instructions were longer.

Short-Term Memory.

Auditory-verbal and visual-verbal forward letter and digit spans were 4 items. Number and letter names were either spoken aloud or presented visually in printed form at the rate of about one per second. Visual pattern span (Wilson, 1993) was 8/9 blocks within a square matrix which is within normal limits.

Copying.

Words and nonwords were printed in lower-case typeface and placed in front of AM for him to copy, which he always did in his own cursive script. The materials used in all tests are the same as those used with patient AN unless indicated otherwise. AM's performance was as follows, with the number correct being shown over the number of words presented: (a) 60/60 content words and 60/60 function words; (b) 27/28 high-imageability words and

27/28 low-imageability words; (c) 39/39 regular words and 38/39 irregular words; (d) 30/30 nonwords which were each three letters in length; (e) 43/43 four and five-letter nonwords (from Glushko, 1979, Table A1); (f) 52/54 newly created six-letter bi-syllabic nonwords.

Writing To Dictation.

AM's writing to dictation was as follows: (a) 51/60 content words and 36/60 function words, the difference being significant ($\chi^2 = 8.20$, 1 d.f., $P<.005$); (b) 18/28 high-imageability words and 12/28 low-imageability words, the difference not being significant; (c) 27/39 regular words and 29/39 irregular words; (d) 2/15 non-homophonic nonwords; (e) 3/15 newly created non-homophonic three-letter nonwords; (f) 3/30 of the non-homophonic nonwords taken from Glushko (1979, Table A1); (g) AM declined to attempt the 54 newly created six-letter bi-syllabic nonwords.

Reading.

Words. A summary of the background reading data for various classes of words and nonwords are presented in Table 3.5. An error analysis of the data is shown in Table 3.6.

Monosyllabic nonwords of 3 letters. When presented with Coltheart's (1981) list there was no *significant* facilitating effect of homophony. However, of the 7/30 nonwords read correctly, 5/15 were pseudohomophones and 2/15 were non-homophonic nonwords. The errors were predominantly lexicalisations or real-word substitutions. Nine were produced to the pseudohomophones (e.g. *sed* - "seed", *nue* - "nut"). Eight were produced to the non-homophonic nonwords (e.g. *mun* - "mum", *kag* - "bag"). Apart from one omission, the remaining errors were nonsense syllables which differed from the target by one phoneme (e.g. *noo* - "koo"). All responses were produced fluently and without hesitation. Although the difference in reading performance between pseudohomophones and non-homophonic nonwords was not significant, a further test was made to see if a real difference would emerge when the stimulus set was larger.

TABLE 3.5

Summary of AM's 1992 Reading Performance Data.

		Proportion Correct	Significance of Differences Between Scores
Content	N=60	.90	
			N.S.
Function	N=60	.78	
High Imageability	N=28	.93	
			N.S.
Low Imageability	N=28	.82	
Regular	N=39	.87	
			N.S.
Irregular	N=39	.82	
Bi-syllabic Nouns (6 letter)	N=34	.97	
Nonwords (3 letter)	N=30	.23	
Nonwords (4/5 letter)	N=123	.10	
Nonwords Bi-syllabic (6 letter)	N=34	.09	

Monosyllabic pseudohomophones and non-homophonic nonwords. A further test for an effect of homophony in nonword reading used eighty, four or five-letter nonwords, some of which were taken from the irregular list of Glushko (1979, Table A1) and some of which were newly constructed (e.g. *plick*, *borl*). AM read 7/80 correctly. This set of nonwords produced a worse overall performance (8.8% correct) than the Coltheart list (23.3% correct). Again, there was no facilitating effect of homophony, 4/40 pseudohomophones and 3/40 non-homophonic nonwords being read correctly.

The pattern of AM's errors was very striking. Although 50/73 errors involved the production of real English words, they were not all straightforward real-word substitutions of the type that occurred in the previous test (although in the error analysis in Table 3.6 they are all classified as such). A more fine-grained classification of the type of lexicalisation and their frequencies is as follows. (a) If a letter-string had a real English word embedded within it, this was segmented out and pronounced correctly. This was accompanied by the spoken letter-name(s) (e.g. *gode* - "god"+/i/ ; *sost* - "so"+/ɛsti/) or an appropriate or an inappropriate sounding-out, of the remaining grapheme(s) (e.g. *prace* - /pri/+ "ace"). In each case the word and accompanying phonemes were uttered fluently as single, whole pronunciations. AM produced 22 of this type of response. (b) AM produced 15 real-word substitutions where the response was either a single or a pair of English words which did not appear in the letter-string (e.g. *moop* - "mops" ; praze - "try"+"zoo"). Where a response was a pair of English words, they were pronounced fluently as a single item. (c) Another type of response involved the production of a single English word (one which was not embedded within the letter-string) accompanied by either a letter-name(s) (e.g. *clart* - /si/+"lard"; *greak* - "great"+/ɛm/) or an appropriate or an inappropriate sounding-out of some of the grapheme(s) (e.g. *wote* - "woman"+/tju/). There were 13 errors of this type. The majority of the remaining errors were nonsense syllables which sometimes included a partial translation of the letter-string.

Monosyllabic nonwords of 4 or 5 letters. A further test used the regular nonwords from Glushko (1979, Table A1). Before this test was performed, it was explained to AM that he was not expected to look for real words embedded within the letter-strings and to pronounce them pre-fixed or suffixed by letter names. Appropriate pronunciations for some of the nonwords were read to him and when he appeared to understand the difference between these and his lexicalisations, the list of nonwords was presented to him for reading. AM read 5/43 correctly. The pattern of errors was consistent with that of the two previous tests. AM produced 31 real-word substitutions of mixed types.

Bi-syllabic words and nonwords of 6 letters. This test was performed to provide a close comparison of AM's word and nonword reading where the sub-word segments and their positions relative to the word as a whole are the same in the two sets. Words and nonwords were presented as separate lists. AM read 33/34 of the words correctly (66/68 syllables) taking 50 seconds to do so. He read only 3/34 of the nonwords correctly (28/68 syllables) in 69 seconds. The number of correct syllables reflects the fact that the predominant error in reading the nonwords was lexicalisation. Of the 31 errors, 26 were English words which were visually similar to the nonsense word and shared one syllable (e.g. *botpon* - "bottle"; *wincil* - "winner").

TABLE 3.6
Error Analysis of AM's 1992 Reading Responses by Stimulus Type.

	All Words N=288	All Non-words N=187	Content Words N=94	Function Words N=60	Regular Words N=39	Irregular Words N=39	High Imageability N=28	Low Imageability N=28
Number Of Errors	n=39	n=165	n=7	n=13	n=5	n=7	n=2	n=5
Proportion of Error Types:								
Visual:	.26	-	.14	.23	.40	.28	-	.40
Derivational:	.28	-	.57	.08	.40	.43	.50	-
Nonsense:	.03	.22	-	-	-	-	.50	-
Omission:	.23	.03	.14	.15	.20	.28	-	.60
Unrelated Response:	-	-	-	-	-	-	-	-
Function Word Substitution:	.18	-	-	.54	-	-	-	-
Real-Word Substitution:*	-	.75	-	-	-	-	-	-
Perseveration of First Phoneme:	-	-	-	-	-	-	-	-
Semantic:	.03	-	.14	-	-	-	-	-

Table 3.3 for the criteria used for the error classifications and examples of each error type.

* See the text on nonword reading for an explanation of the different types of real-word substitutions.

3.2.2. Summary of Language Impairments.

AM has a moderate anomic aphasia. His auditory comprehension is good. On the BDAE his comprehension was in the 80th percentile or above. AM's spontaneous speech is fluent with good articulation. He copies written material fluently, in cursive script with his preferred left-hand. AM suffers two clear impairments. He has reading and writing impairments which are more severe for nonwords than for words. In reading, AM shows no significant effects of syntactic category, imageability or spelling regularity. In writing to dictation there are no significant effects of imageability or spelling regularity but there is a significant effect of syntactic category with function words being more impaired than content words. There is no evidence of semantic paralexias.

On the background tests, the status of AM's residual language abilities is remarkably similar to AN's. Furthermore, this similarity appears to have arisen from CVAs to different hemispheres in the two patients. Both patient's have an advantage for real words vs nonwords in reading, a pattern of abilities that has commonly been described as phonological dyslexia. Despite the similarities between the two patients, the absence of word class effects in reading mean that AM could be considered a purer case of a nonword reading disorder than AN. AM read 249/288 (86.1%) words correctly but only 22/187 (11.8%) nonwords correctly. This difference is highly significant ($\chi^2 = 255.20$, 1 d.f., $P < .001$). (AN read 68.8% and 11.8% respectively). The results of the last test show that AM, like AN, can read familiar, whole words but not novel combinations of their sub-word segments. The segments of which words are composed can therefore be processed when they occur as parts of familiar wholes but not when they occur as parts of unfamiliar wholes.

4 Experimental Investigations of Reading.

4.1. Loci of AN's Nonword Reading Impairment.

One proposal of how nonwords are read is embodied in Fig. 2.1. The sequence of processing stages begins with orthographic analysis. Firstly, the system has to identify the printed letters of a nonword. Since the system has to respond to all fonts and cases of a particular letter (e.g. *A* , a, A or *a*), it has been proposed that recognition involves the activation of abstract letter identities (Coltheart, 1981) stored within the system. Once the letters are identified, the letter-string is parsed into orthographic segments and their corresponding phonological segments are retrieved by accessing a system of orthographic-to-phonological conversion rules. The resulting string of phonological segments is held in an output buffer where it is blended into a complete phonological specification ready for pronunciation. Disruption at any point in this sequence will produce a nonword reading impairment. The investigations into the cause of this impairment in AN were organised to test processing at each of three stages: (1) orthographic analysis, involving the visual recognition of letters, words, and graphemic spelling patterns; (2) assignment of phonology to graphemic segments; (3) phonological assembly and articulation.

4.1.1. Orthographic Analysis and Graphemic Parsing.

Test 1: *Cross-case matching*. One hundred and four pairs of letters, one in upper case, one in lower case, were constructed. In fifty-two pairs the letters were the same, half with the first letter in upper case (e.g. *Aa*) and half with the second letter in upper case (e.g. *bB*). The other fifty-two pairs were randomly chosen different letters, half with the first letter in upper case (e.g. *Xy*), half with the second letter in upper case (e.g. *cH*). Half of each pair type were hand-written and the other half typewritten. The pairs were randomly presented and required a verbal judgement of whether the letters of each pair were the "same" or "different". AN judged 104/104 correctly. This suggests that abstract letter identities are intact but it is not necessarily evidence that AN knows what these letters are.

§*Test 2: Letter naming.* The letters of the alphabet, typewritten in upper case, were randomly presented three times for naming. Naming accuracy was 20/26, 21/26 and 13/26[9] for tests one, two and three respectively. Of the 24 incorrect responses, 11 were attempts to sound-out the letter, rather than name it. As it was not always obvious that AN had remembered that she was supposed to respond with the letter name, only 13 of the responses were treated as clear errors. Table 4.1 presents a confusion matrix and shows that the errors were not consistent between trials. Only one letter (T) was misnamed more than once and on each occasion the response was different. Despite the overall impaired performance (54/78), the inconsistency of the errors suggests that letter recognition mechanisms are intact because all letters were named correctly at some point during the three trials. The impairment could be at a subsequent stage of processing such as assigning phonology to the letters or in articulating the assigned phonology. The following test was designed to test letter recognition without involving the assignment of phonology or articulatory mechanisms.

§*Test 3: Word completion.* Twenty high frequency, concrete nouns were hand-written in a list. Each word was also written on a plain white 6" x 4" card but with a dash in place of the initial letter. So, *WINDOW* in the list became -*INDOW* on the card. To ensure that AN was familiar with all the stimuli, she was presented with the list to read at the beginning of one of the test sessions. AN read 20/20 correctly. During the test phase, the cards with the incomplete words were laid one at a time in front of her. Each 6"x 4" card was accompanied by four smaller cards, upon each of which was printed a letter. Only one small card contained a letter that would complete the word, the others having been randomly selected from the alphabet. When all five cards were laid in front of the subject, she was instructed to point at the letter that would complete the word. AN selected the

[9] It is unclear why AN's impairment was greater on the third trial than on the other two but it appears to have been a temporary problem because subsequently her level of performance has been around 77%.

critical letter on 20/20 occasions.

TABLE 4.1

Confusion Matrix for Letter Naming.

Response :	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Target																										
A																		1								
B				1																						
C											1															
D																										
E																								1		
F																										
G																										
H			1																							
I																										
J																										
K																										
L																										
M														1												
N																										
O																										
P																										
Q																										
R																										
S																										
T				1				1																		
U															1											
V																	1									
W																										
X																	1									
Y										1																
Z					1																					

Test 4: Graphemic parsing.[10] If AN suffered an impairment to graphemic parsing mechanisms without any impairment to phonological assignment or to assembly and output mechanisms, she should be unable to convert a letter-string into graphemic units but be able to convert the graphemic units into phonemes if the letter-string is parsed for her. Forty, four-letter, nonwords were constructed. Each contained two adjacent vowels surrounded by two consonants. In twenty of the nonwords, the vowel segment corresponded to a single

[10] The design of this experiment is taken from Derouesné and Beauvois (1985).

grapheme (e.g. *ee* pronounced /i/). The other twenty nonwords contained a vowel segment that corresponded to two graphemes (e.g. *iu* pronounced /i/Λ/). In the first stage of the test, the forty nonwords were presented as a random list. AN was instructed to inspect each letter-string and to say whether the vowel segments corresponded to one phoneme or to two. She scored 38/40 correct, there being one error to each vowel segment type. In the second stage, AN was asked to read aloud the nonwords from the list. She read only 8/40 correctly, four of each vowel segment type. Finally, AN was asked to read aloud the nonwords again but this time from two lists, each of which consisted of words of all the same type of vowel segment. She was told prior to testing whether the list was of the one or two phoneme type letter-string. She again read only 8/40 correctly. Three correct responses were from the /C/V/V/C/ list and five from the /C/VV/C/ list. Thus having the letter-string parsed for her produced no facilitating effect on pronunciation.

4.1.2. Assignment Of Phonemes to Graphemes.

The following three tests were designed to test the ability of AN to assign phonemes to letter-strings of various lengths.

Test 1: Letter sounding-out. Each letter of the alphabet, except X, was written on a 2" x 2" card and randomly presented to AN twelve times. A generous criterion for scoring was used, and any plausible sounding-out was accepted. Errors occurred nevertheless. AN produced an appropriate sound for 201/300 letters (67.0%). Perseveration of incorrect phonemes was common. Of the 99 error responses, 24 were the names of the letters being attempted. The remaining 75 errors are shown in the confusion matrix of Table 4.2, where erroneous soundings are listed under the letter for which they would be the most likely sound. There appears to be no reliable relationship between target letters and their assigned incorrect phonemes or target phonemes and their assigned incorrect phonemes although six of the letters that produced more than one error always produced the same error.

§Test 2: Paired letter sounding-out. Twenty pairs of letters were constructed. Ten pairs were consonants, half of which required the assignment of one phoneme (e.g. sh - /ʃ/) whilst the other half required the assignment of two phonemes (e.g. *cl* - /k/l/). The other

ten pairs were vowels, half of which required the assignment of one phoneme (e.g. *oo* - /u/) whilst the other half required the assignment of two phonemes (e.g. *ua* - /ju/æ/ or /u/æ/). The twenty hand-written two-letter items were presented randomly. AN gave an acceptable sound for 12 of the 20 items, 3 from each of the four types.

TABLE 4.2
Confusion Matrix for Letter Sounding-Out.

Response:	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	Y	Z
Target																									
A										1															
B				1												1	1								
C										3		1													
D							1								2										
E						1								1											
F										4			1												
G																				1					
H					1										1										
I	1				1									1	1			1			1				
J						3																			
K		1						1																	
L	1					1															1				
M														2										2	
N													1					1							
O								3																	
P														2									2		
Q	1			1																					
R																			1					1	1
S		3																							
T			1				1																		
U													3												
V						3																			
W													4												
Y								1									1								3
Z					1													1							

Test 3: Silent judgement of homophony. This test was taken from Coltheart (1981) and is designed to test knowledge of phonology without the involvement of assembly or articulatory mechanisms. The test involves presenting the subject with fifty regular word pairs, fifty pairs of words where one is regular and one is irregular and fifty pairs of nonwords. Each word type contains twenty-five pairs which are homophonic (e.g. *lacks/lax*, *pair/pear*, *afe/aif*) and twenty-five which are non-homophonic (e.g. *loan/long*, *cry/quay*,

bauze/bams). The subject's task is to sort each pair according to whether they receive the same or different pronunciations. The word pairs were printed in lower case on 3" x 2" white cards which were randomly ordered and given to AN who was told to place them on either a pile marked "different" or "same". AN made correct judgements for 50/50 regular word pairs, 46/50 irregular words and 37/50 nonwords, all scores being significantly better than chance. The difference between word and nonwords judgements is significant (χ^2 = 13.8, 1 d.f., P<.005).

4.1.3. Articulation and Phonological Assembly.

Test 1: Single word repetition. The stimuli were taken from McCarthy and Warrington (1984). These words are balanced for frequency and number of syllables (one, two or three). Of one hundred and eighty words, half were high frequency with equal numbers (thirty) of one, two and three syllable words, and the other half, low frequency with matched syllable variables. The words were presented randomly and AN was asked to repeat them immediately. AN repeated 167/180 (93%) correctly. Table 4.3 shows the proportions correct. Overall the effects of frequency and length are not significant, but three-syllable low frequency words were repeated significantly worse than one- or two-syllable low frequency words (χ^2 = 11.13, 2 d.f., P<.005).

TABLE 4.3
Proportion of Words of Varying Frequency and Syllable Length Correctly Rpeated.

	Number of Syllables			Proportion Correct
	1	2	3	N=90
High Frequency N=90	1.00	1.00	.90	.97
Low Frequency N=90	.97	.97	.73	.89

Test 2: Nonword repetition. AN was presented with twenty /CV/ syllables and repeated 20/20 correctly. In another presentation, the /CV/ syllables were randomly combined to form forty, two-syllable nonwords. AN repeated 39/40 correctly. In a further test, AN was presented with thirty-six randomly ordered nonwords for repetition. There

were twelve each of one, two or three syllables. AN's repetition was again quite good, although there was a non-significant syllable length effect. AN scored 12/12 on monosyllabic items, 10/12 on bi-syllabic items and 8/12 on tri-syllabic items. Table 4.4 shows the greater impairment in performance on the repetition of nonwords than real words, although the difference is not significant.

TABLE 4.4

Proportion of Correct Responses for Repetition of Word and Nonword Stimuli of Varying Syllabic Length.

		Number of Syllables 1	2	3	Proportion Correct
Words	N=180	.98	.98	.82	.93
Non-Words	N=36	1.00	.83	.67	.83

§Test 3: Repeating letter names. Whilst facing away from the experimenter to remove any visual clues, AN was asked to repeat the names of fifty-two letters (the alphabet twice) presented randomly. AN repeated 52/52 correctly. This performance is considerably better than naming letters orally from written stimuli.

§Test 4: Repeating letter sounds. Under the same conditions as in the preceding test, but without using the letter X, AN repeated 50/50 letter sounds correctly.

Test 5: Reading and repeating non-homophonic nonwords. A list of twenty, three-, four- and five-letter nonwords was constructed by using examples from Funnell (1983) and Coltheart (1981). Forty random presentations were made to AN, each nonword being used twice, once for reading and once for repetition. In the repetition condition AN was asked to repeat immediately. AN repeated 19/20 correctly, the one error being one omitted phoneme. She read only 5/20 correctly, the error types being AN's characteristic mixture of nonsense syllables and repeated first phonemes. AN was significantly better at repeating nonwords than reading them (McNemar $\chi^2 = 10.6$, 1 d.f., $P<.005$).

Test 6: Reading pseudohomophones and their lexical equivalents. Twenty, three-, four- and five-letter pseudohomophones were constructed and printed in lower case on 2" x 2" plain white cards. Randomly mixed with these were the lexical equivalents of the pseudohomophones (e.g. *toad* - *tode*). AN was presented with the forty stimuli and instructed to read them. She read only 5/20 of the nonwords but 18/20 of their lexical equivalents. This difference in performance is significant (χ^2=14.7, 1 d.f., P<.005).

Test 7: Phonological blending of words and nonwords. Ten nonwords and ten words were selected for repetition, half of each type being four letters long and half five letters long. In one condition all stimuli were spoken as complete phonological specifications (e.g. *fekt* - /fɛkt/) to AN and she was instructed to repeat them immediately. In another condition both sets of stimuli were segmented into two or three phonological units (e.g. /fɛk / t/) and presented to AN at the approximate rate of one unit per second. She was instructed to repeat the segments as a single whole word. After several trials to ensure AN understood the nature of the task, the twenty stimuli were randomly ordered, as was the form of presentation (whole or segmented).

AN's repetition accuracy of stimuli presented as complete specifications was 10/10 for words and 9/10 for nonwords. However, when segmented phonology was presented for assembly prior to repetition, AN performed significantly worse scoring 3/10 on words and 4/10 on nonwords (χ^2 = 13.3,1 d.f., P<.005). She correctly reproduced 3/10 two-unit stimuli and 4/10 three-unit stimuli. AN's failures at repetition usually involved being able to repeat the first phonological unit but either omitting the subsequent units or substituting some incorrect phonology. Her errors were often accompanied by an explanation such as, "Oh, it's gone.....no it's this here........it's not that......er......oh, leave it.....that's queer. . . ."

This test was repeated using thirty concrete nouns that AN had read successfully on a previous test session and sixty new non-homophonic nonwords. When the stimuli were presented as complete pronunciations, AN correctly repeated 30/30 and 51/60 respectively. When the stimuli were presented as phonological segments for AN to blend before repeating she scored 17/30 and 28/60. The difference between the two conditions is highly significant (χ^2 = 32.4, 1 d.f., P<.005).

4.1.4. Discussion.

AN's perfect cross-case matching confirms that she can recognise different forms of the same letter whether typewritten or hand-written and whether upper or lower case. She can also select the correct letter needed to complete a word even though those letters include ones on which she had made naming errors. Naming errors are therefore not due to a failure of visual letter recognition.

On the graphemic parsing task, AN's success at deciding whether a pair of vowels normally corresponds to one or two phonemes suggests that her graphemic parsing abilities are intact. Furthermore, there is no evidence that a graphemic parsing problem contributes to AN's nonword reading deficit because whether AN has to parse a letter-string herself of not, has no effect on her ability to read it. Her performance in reading nonwords when they were effectively parsed for her (20%), was identical to when she had to parse them herself and is consistent with her reading performance on other four-letter nonwords. The conclusion that letter recognition, word recognition, and graphemic parsing, are unimpaired is further supported by tests of orthographic segmentation reported in the next section (Section 4.2.1). AN's nonword reading impairment must be due to difficulties at some stage later than visual processing.

AN successfully sounded out only 67.0% of the single letters and 60% of the letter pairs regardless of whether these required the assignment of one or two phonemes and despite being able to repeat such stimuli accurately. This is evidence for an impairment in the assignment of phonemes to graphemes. Further evidence for this is AN's poor performance on the nonword section of the silent rhyme judgement task. When no articulation was involved, AN still only judged 74% correctly. However, AN's deficit in assigning phonemes to graphemes is not due to the *absolute* loss of specific correspondences. Over the twelve trials of the letter sounding-out task, every letter received an appropriate sounding at some point. A better explanation is that there is some source of unreliability in the system that affects all correspondences.

AN's performance on the phonological blending tasks suggests that she has a deficit in phonological assembly. There are several aspects of her performance that suggest that articulatory mechanisms are not the source of her deficits. Firstly, her repetition of words and single letters is excellent. Secondly she can repeat short nonwords that she cannot read.

Thirdly, she is significantly better at reading words than she is at reading their corresponding pseudohomophones, so articulation of the particular phonemes cannot be a problem. It is possible that her difficulties in the phonological blending task are in part due to verbal STM impairments, which are also seen in her reduced digit span. The conclusion is that AN's nonword reading difficulties are due to impairments in assigning phonemes to graphemes and in blending those phonemes into a complete articulatory specification.

4.2. Reading by Analogy?

Analogy Theory (e.g. Marcel, 1980; Kay & Marcel, 1981) proposes that novel letter-strings and nonwords are pronounced by using a lexical direct route. Nonword phonology is derived from stored orthographic and phonological representations. This involves the letter-string being parsed into segments for which there are lexical entries. These segments could be complete real words (e.g. *tap* and *pen* as in *tappen*) or just segments that occur in known words. All matching orthographic segments are activated and they in turn activate their corresponding pronunciations segmented from lexical phonology. The pronunciation produced is the most commonly assigned phonological value. Thus if orthographic segmentation, phonological segmentation and lexical reading are all largely intact then nonword reading should also be largely intact.

4.2.1. Orthographic Segmentation.

The design of the tests used to investigate orthographic segmentation were taken from Funnell (1983).

Test 1: Orthographic segmentation of compound words in which morpheme and syllable boundaries coincide. The fifteen words chosen for this test were real words that could be segmented into two further real words (e.g. *doorknob*, *carpet*). The words were chosen such that the phonology of the constituent morphemes corresponded closely with the phonology they received in the pronunciation of the whole word and therefore with the syllable boundaries of the whole word. When presented with the words printed in a list, AN read 12/15 correctly. She was then told that each of these words contained two separate words which could be seen and pronounced as two separate real words. When asked to read them aloud AN read 28/30 correctly. She also took the pen from the experimenter's hand and drew a slash between the two segments of all the compound words. Furthermore, she noticed that one of the words could be segmented into four different words (i.e. *be*/*tray* or *bet*/*ray*).

Test 2 : *Orthographic segmentation of compound words in which morpheme and syllable boundaries differ*. The design of this test was identical to that of the above except that the syllable boundaries of the compound words did not correspond to the constituent morphemes (e.g. *door*, *heathen*). Consequently, whole word phonology was not the same as the sum of the two parts. AN read 6/14 of the compound words and 9/28 of the segmented words. This poor performance on reading the constituent words was not however, due to an inability to segment the parent word into two separate words. AN again showed this by drawing a slash between the two constituent words in each of the fourteen parent words. Reading of constituent morphemes was worse in this test than in Test 1 where morpheme and syllable boundaries coincide. However, this appears to be due to the characteristics of the constituent words (e.g. seven of them were function words which AN finds difficult to read) and not to a failure of orthographic segmentation which was flawless in both tests.

§Test 3: Orthographic segmentation of hidden words. Fifteen nonwords were constructed that contained a hidden word and AN was instructed to read aloud any word she might see contained within the string (e.g. *not* from *tinoth*). AN read the hidden word from 14/15 of the nonwords.

Analogy theories propose that the derivation of phonology for nonwords occurs via the *automatic* segmentation of orthography and phonology. The three segmentation tests reported so far suggest that orthographic segmentation processes are intact in AN. However, in each of these tests AN was instructed to segment the letter-string to perform the task. The following test was used because success at reading the words would suggest that orthographic segmentation had been both successful and automatic.

Test 4: Orthographic segmentation and reading of compound nonwords. In this test each nonword was a compound of two real words (e.g., *tugant, attype*). Ten such nonwords were presented in a list, typed in lower case, Geneva font, fourteen point size, and AN was asked to read them aloud. The stimuli used are from Funnell (1983) and are presented in Table 4.5.

TABLE 4.5
Nonwords for Segmentation Test. (Funnell, 1983)

tugant	attype
fistam	pother
hispat	hatein
biteto	pigham
nothat	topain

AN balked immediately at the stimuli, exclaiming, "Oh, no, no, I can't do that......Oh God, no, they're no words......they're, you know". When asked to read as much as she could, she attempted each string with her characteristic one-phoneme-at-a-time strategy. After five minutes AN had failed to read any of the nonwords correctly and became agitated. It was then explained to her that there was a simple way to read the nonwords if she could find it. She continued to fail for some time. She was then told that it was possible to read the nonwords by breaking them up somehow. Her response was, "Oh aye, I can see that......oh aye, like we did before...... I know that, that's pot........that's pain, that's pat, that's fist.......oh aye, I know that but they're no words (indicating the whole string). You want me to say that rubbish...... the wee ones are words but those big ones.......aye, that’s bite......but I can’t say that". AN had clearly recognised that there were real words in the letter-strings and had segmented the orthography adequately at some point and had accessed the appropriate phonology for these segments. It had not occurred to her to use this phonology to pronounce the whole letter-string, however. Rather, it seemed that the orthographic analysis system detected the non-lexical status of the stimulus and then attempted to implement a severely impaired non-lexical procedure. When put under pressure to try and read the complete string, AN recognised real words but balked at the idea of using real words to read what she obviously recognised as non-lexical material and still failed to read to produce any of the letter-strings as a complete pronunciation.

4.2.2. Phonological Segmentation.

§Test 1: Segmentation of whole word phonology. The fifteen compound words from Test 1 of orthographic segmentation (Section 4.2.1.) were orally presented as complete phonological specifications to AN and she was asked to repeat separately the two constituent morphemes (e.g. "understand" - "under".."stand"). AN scored 30/30.

§Test 2: Segmentation and repetition of partial whole-word phonology. On another test session the same stimuli as in the preceding test were presented orally to AN and she was asked only to repeat the second morpheme. AN scored 15/15.

§Test 3: Segmentation of initial phoneme from spoken word. Fifteen nouns were orally presented to AN and she was asked to repeat the first phoneme of each one. AN produced 14/15 correct responses.

Test 4: Segmenting spoken phonology into syllables. Fifteen nouns were spoken individually at a normal rate to AN and she was asked to count the syllables in each word, which ranged from one to four. AN counted the syllables correctly for all 15 words.

In this test and the preceding three tests of phonological segmentation, the phonology was presented to AN orally. However, this is probably not a good analogue of how a phonological segmentation process would work during nonword reading where the system has to generate its own phonology. The following test was designed so that the patient had to generate her own phonology and then segment it before responding.

Test 4: Segmenting internally generated real word phonology. Twenty pictures of common objects were cut from colour magazines. They were selected such that the spoken name of each object consisted of two syllables with the added criterion that the second syllable was not phonologically identical to a real English word (e.g. anchor, orange, scissors). The pictures were glued onto white cards shown individually to AN. She was instructed not to speak the name of the object aloud but to say only the second syllable. Before testing, three training trials were performed with three additional stimuli to ensure that AN understood the task. AN produced 17/20 appropriate phonological segments. The three failures, which were omissions, were not because of a failure of segmentation, but because AN was unable to retrieve the object names. When given cues until she could name the three objects, AN was able to produce each of the second syllables.

4.2.3. Reading Nonwords with Close Lexical Neighbours.

§Test 1: Reading nonwords with close lexical neighbours. For this experiment the parent stimuli were seven concrete nouns that AN could read without difficulty. From these, two sets of nonwords were generated. One set was the lexical form with one letter changed and the other set had two letters changed. The stimuli, which were all printed in upper case are shown in Table 4.6.

TABLE 4.6
Lexical and Non-Word Forms of Stimuli For Reading by Analogy.

Lexical Form	Single-Letter Distortion	Two-Letter Distortion
HOSPITAL	HOSPIMAL	HOSPAMAL
HORSE	HIRSE	TIRSE
YACHT	VACHT	VOCHT
THEATRE	THEATRO	THEABRO
HELICOPTER	HEDICOPTER	HODICOPTER
POLICEMAN	POLICTMAN	POLINTMAN
ELEPHANT	OLEPHANT	OLEPHAND

The seven words were presented to AN in a printed list and she read 7/7 correctly. The distorted forms were printed randomly in a list and presented to AN for reading, the only instruction being "read what is on the list". AN's reaction was one of weary disdain as she exclaimed, "Oh no, not again, they're nae words....". She persevered for some time but read only 1/14 correctly, *polintman*. AN's attempts at reading the letter-strings sometimes involved several repetitions of a single phoneme, sometimes the correct first phoneme, sometimes an incorrect one. Occasionally she would attempt to add a second phoneme to a correct first one but be unable to utter the two fluently and would bang her fist on the table in agitation. Sometimes she moved up and down the list producing strings of isolated phonemes, some right, some wrong. She attempted all of the stimuli except *vocht*. At a point where it became obvious that AN was not even going to produce a close approximation of any of the letter-strings, she snatched a pen from the tester's hand, saying, "Look, there's something missing". She proceeded to score a line through every one of the twenty one 'letter impostors' and write the correct letter above! On substituting the proper letter, AN exclaimed, "Now it's helicopter, now it's horse ", etc. and produced the correct lexical form to all 14 of the altered nonwords.

In the second phase, a list was constructed using the lexical forms printed in the first half of the list followed by the one-letter distorted forms in the same order in the second half. AN was instructed to read the list. She read 6/7 of the real words correctly, the one error being only one phoneme off target and read 0/7 of the nonwords correctly.

Test 2: Reading 3-letter nonwords together with their close lexical neighbours. Ten orthographically simple three-letter nonwords were constructed such that each had several 'close' lexical analogies. Each nonword was analogous to several real words in that it was both orthographically and phonologically similar, differing by only one letter (e.g. *TAF* - *TAG, TAN, TAP*). The 10 nonwords were presented for reading in two conditions. In the first condition, each nonword was assigned to a group of four nonwords. The other three members of each group were randomly chosen from a pool of 30 nonwords in which each of the 10 appeared three times. The only stipulation was that none of the nonwords could appear in any group more than once. Thus, 10 groups of four different nonwords were created (e.g. *TAF, HAB, MUN, GEN*). The groups were printed in upper case, on 6"x 4" cards and randomly presented to AN for reading. In the second condition, each of the 10 nonwords was again assigned to a group of four stimuli. On this occasion, the other three group members were all close lexical analogies of the nonwords (e.g. *BAN, BAT, BAG, BAZ; and SOW, VOW, COW, FOW)*. In half of the groups the real words were variants of the nonword with the initial letter changed (e.g. *MEN, TEN, PEN, GEN*) and in the other half the final letter was changed (e.g.. *HAM, HAT, HAD, HAB*). The nonwords always appeared as the last member of the group. The all nonword groups were presented at the beginning of one of the test sessions and the lexical analogy/nonword combination groups at the end of the session. On a previous occasion AN had read 27/30 (90%) of the real words correctly.

In the condition with the nonwords alone, AN read 7/40 (17.5%) correctly, two being read correctly twice, *MUN* and *FOW*. In the condition where the nonwords were presented in a list together with their close lexical neighbours she read 2/10 (20%) of the nonwords and 27/30 (90.0%) of the real words correctly. There was no significant difference in AN's reading of nonwords between the two conditions. Of the 8 nonwords AN failed to pronounce in the analogy/nonwords combination condition, 4 had been read correctly in the all nonwords condition. There was no effect of the position of the letter distortion, one correct response being to each type of nonwords, i.e., initial or last letter being changed.

Test 3: Reading 4-letter nonwords together with their close lexical neighbours. As a test of the reliability of the results of the last test (Test 2), the design of this test was identical except that the words and nonwords used were all four letters long (e.g. *BORN*, *TORN*, *WORN*, *RORN*). In the all nonword condition, AN read 11/40 (27.5%) correctly. In the nonword/lexical analogy combination condition AN read only 3/10 (30.0%) of the nonwords correctly despite reading 29/30 of the real words.

4.2.4. Discussion.

In Test 4 of Section 4.1.1, AN's ability to decide whether the vowel segments in nonwords corresponded to one or two phonemes suggests that AN's graphemic parsing is intact. Tests of orthographic segmentation in Section 4.2.1. confirm this. AN can segment morphemes from words that are compounds of two morphemes whether syllable boundaries coincide or not (e.g. *doorknob*; *heathen*) and she can segment and read real words embedded in nonwords that she cannot read (e.g. *not* from *tinoth*). Furthermore, she can segment and read as two individual items, morphemes (e.g. *hate* and *in*) which comprise a nonword which she cannot read as one single item!

AN's segmentation of phonology seems similarly intact. She can segment and repeat one or two constituent morphemes (e.g. "under" and "stand") from an orally presented compound word. She can segment and repeat the initial phonemes from, and count the number of syllables in, orally presented words. More convincingly, she can produce the second syllables of object names that she has generated herself.

If segmentation processes are intact and AN can read 68% of real words, it is difficult to explain why AN can read aloud only 11.8% of nonwords if indeed they are read by lexical analogy processes. However, in the background reading tests no formal investigation was made to see whether the nonwords chosen were very close to real words that AN was now no longer able to read i.e. were from the 32% of words that AN could not read. If this were the case, and it was assumed that phonological segments need to achieve a threshold level of activation before they are available for articulation, failure to read a nonword could be because the appropriate phonology was now no longer adequately represented in the phonological output lexicon. Difficulties for this explanation arise from several tests where AN was unable to read nonwords which were orthographically similar to real words that she could read. Firstly, AN was no better at reading nonwords preceded by three close lexical neighbours that she could read well, than she was at reading the same nonwords in a list of other nonwords i.e. she could read *map*, *tap* and *gap* correctly but not *vap*. Secondly, AN could read several concrete nouns correctly but not one- or two-letter distorted versions of them e.g. AN could not get close to reading *hedicopter* but had no problem reading *helicopter* even when the phonology for the former should receive considerable activation from the latter. Thirdly, AN was unable to read nonwords that were composed of two real words that she could read individually, and for which therefore, all the constituent phonemes were both available and capable of being activated. These results therefore provide no evidence for the reading aloud of nonwords by analogy with familiar words. We cannot conclude that lexical analogy plays no role in reading but these results are evidence that it is not an automatic or necessary consequence of lexical processing, and they weaken the view that lexical analogy procedures account for all nonword reading.

4.3. The Functional Routes Involved in Learning to Read Nonwords.

One consequence of a severe nonword reading impairment for the single direct-route architectures of Seidenberg and McClelland (1989) and Shallice, Warrington and McCarthy

(1983), is that the residual reading of words can only occur via an indirect semantic route. However, the claim that all of AN's word reading is now mediated by semantics does not fit well with some of the data. A comparison between her reading performance in 1984/5 and 1991/2, for the word classes reported in Table 3.2, shows a significant improvement ($t [5] = 3.105$, $P < .05$). The largest improvement however, was for function words (10.0%) and for content words of low imageability (18.0%), and these types of words are the least likely to depend upon a semantic route (Saffran et al, 1980; Patterson, 1982; Jones, 1985; Plaut & Shallice, 1993). A possible interpretation of this is that some of the change was due to an improvement in a direct route. If this assumption is correct it is evidence in support of dual direct-route theory[11] because AN's reading of nonwords has not improved. (AN's reading of regular words also improved by 10%, which in principle could reflect an improvement in the sub-lexical route, but as there was no improvement in her reading of simple three-letter nonwords, the sub-lexical route is an unlikely source of this improvement). This support for dual direct-route theory is not conclusive, however, because the words on which AN's reading improved, function words and content words of low imageability, do have some meaning that might be used to mediate their pronunciation. An attempt was made therefore, to obtain more direct evidence on this issue and relevant data were obtained from both patients.

4.3.1. Learning to Read Nonwords with and without Semantics: AN.

This technique was devised to investigate AN's ability to learn to read nonwords that either were or were not given distinctive meanings. "Distinctive meanings" refers to meanings that distinguish the nonwords from each other. The various possible interpretations of her improved reading of words lead to the following predictions. If only a semantic route is operative and can learn then reading should improve only for the nonwords given distinctive meanings. If only a direct route is operative and can learn then reading should improve for both sets of nonwords at the same rate. If a semantic and a direct route are both

[11] Or at least an architecture which allows a lexical level to functionally dissociate from sub-lexical levels within a direct route.

operative and can learn then reading should improve for both sets of nonwords but it should be faster for those given distinctive meanings. This experiment was designed to test these predictions.

Method.

Thirty exception nonwords were selected from Glushko's (1979) A1 and A2 lists and each was printed in lower case along the bottom edge of a 6"x 4" white card. In a pilot phase the cards were presented one after another and AN was asked to read each nonword aloud. She was given no assistance in pronunciation but was told to "take your time and try and read each one as if they were words you know". For each nonword, AN was allowed about thirty seconds or until she gave up, whichever was the sooner. She pronounced 4/30 correctly and she was told when she had produced a correct pronunciation.

For the learning phase two sets of fifteen stimuli were created by randomly dividing the twenty-six nonwords that AN had failed to read, into two sets, and then by adding two that were correctly read to each set. Fifteen line drawings of nonsense objects were then selected from the Kroll and Potter (1984) corpus and one was glued above the nonword on each of the fifteen cards of one of the two sets. During another session AN was shown all thirty cards and it was explained that the lone nonwords were in fact nonsense words. When shown the nonwords paired with the nonsense pictures it was explained that they were being made into real words by using them to name the objects on the card. AN would go no further until she understood what the objects were. She was asked what she thought each object resembled and might be used for. These "definitions" were used for the rest of the experiment and AN was asked to remember them. An experimental trial consisted of all thirty cards being shuffled and then presented one at a time for reading for a maximum of about thirty seconds each or until she gave up or appeared to become frustrated. If AN produced a correct response she was told that it was correct. For any nonword that AN failed to read, the experimenter held the card in front of her and explained that he would read it for her. She was told "Look at the card, I'll read out the word and you repeat it". Only when she had correctly repeated the pronunciation given to her, was the next card presented. To ensure that AN was learning the semantic representations, whenever a nonword paired with a nonsense object was presented, she was asked to state what the object could be used for before attempting to pronounce the nonword. These procedures were repeated for each trial but as the experiment progressed and it became obvious that she knew the semantics, she was told that she need only read the nonwords. The number of correct responses for each nonword type was recorded for each trial.

Twenty-five trials were run over eight testing sessions, where each trial involved the presentation of all thirty stimuli. The number of trials performed in each session varied from two to five according to how many AN was comfortable doing. AN is very persistent but finds all nonword reading tasks difficult and so a decision on how many trials to perform was made by AN at the time on each occasion.

Results.

The total number of correct responses produced in the with-semantics condition was 220/375, and in the no-semantics condition it was 157/375. The number expected on the basis of her performance in the pilot phase would be 50/375. Figs. 4.1 and 4.2 show how performance improved in both conditions as the number of trials increased. Fig. 4.1 plots the number correct per trial and Fig. 4.2 plots the mean number correct per session. A Kendall's S test (Jonckheere & Bower, 1967) performed on the data shows the learning trend to be highly significant in both conditions (with-semantics, $Z = 7.01$, $P < .0001$; no-semantics, $Z = 3.85$, $P < .0001$).

In order to test the hypothesis that the average learning gradients in both conditions were equal, a measure of gradient was calculated for each of the thirty words as the difference between the proportion of successes obtained during the first twelve trials and the last thirteen trials respectively. A randomisation test was conducted on these 30 gradients using the programme in Edington (1987)[12]. A two-sided exact P-value of 0.0475 was obtained, suggesting a difference between the two learning rates that is significant but

[12] I am grateful to Dr J Kay who both suggested and wrote the program for this test.

small.

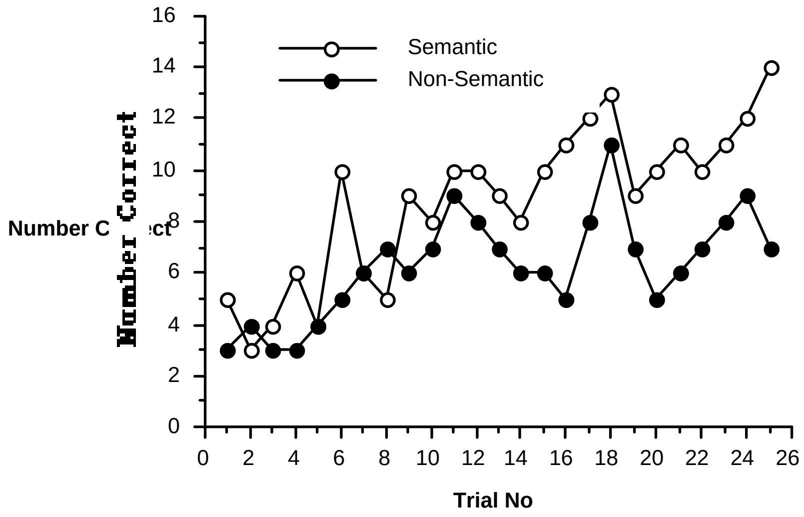

FIG. 4.1. AN's Reading Performance on Four-Letter Nonwords Shown as the Number Correct Per Trial over Twenty-Five Training Trials. In the Semantic Condition each of Fifteen Nonwords was Given a Specific Meaning by always being Presented Together with the Picture of a Specific Novel Object. In the Non-Semantic Condition each of Fifteen Nonwords was Presented on its Own.

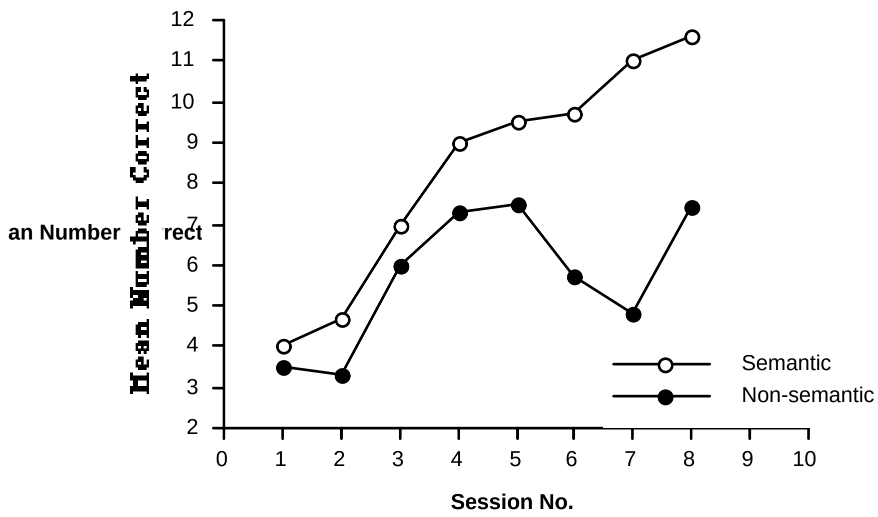

FIG. 4.2. AN's Reading Performance on Four-Letter Nonwords Shown as the Mean Number Correct Per Session over Eight Sessions. In the Semantic Condition, each of Fifteen Nonwords was Given a Specific Meaning by always being Presented Together with the Picture of a Specific Novel Object. In the Non-Semantic Condition each of Fifteen Nonwords was Presented on its Own.

An error analysis was performed on three of the twenty-five trials (trials 9, 10 and 11). Of the ninety responses, forty-one were errors. Most of these errors were partially correct attempts at the nonword. Four were substitutions by a word; *doot* was twice read as "boot", *heaf* was read as "leaf", and *cose* was read as "cost". She immediately rejected each of these substitutions after having said them. None of these errors involved the substitution of one familiar nonword for another.

Discussion.

The gradients of the learning curves show that the training produced a significant improvement in reading performance in both conditions. The significantly greater improvement in the with-semantics condition suggests that semantic mediation contributes to the reading of these nonwords. Further support for this is provided by a characteristic of AN's attempts at reading with-semantic nonwords. On occasions, AN had difficulty in reading a nonword paired with a nonsense object that she had read correctly on a previous trial. During the attempt she would indicate that she had recognised the object and provide her 'definition' saying something like "Oh aye, it's for crushing fruit....aye.... and ....er...pressing oranges...but I don't know the word, it's not there". She would then repeat the definition one or more times and suddenly produce the trained pronunciation (e.g. *heaf* - /hif/), spoken fluently as a complete item at normal speed. On trials nine, ten and eleven this happened on all of the twelve occasions on which there was a delay in producing the pronunciation. On these occasions semantic access always preceded pronunciation.

Another characteristic of AN's attempts to read all of the nonwords was that in the early trials of the experiment she would produce her usual string of phonemes, some correct and some incorrect, but in the later trials when she read a nonword successfully it would be read fluently as a complete item. Interestingly, this happened even when there was a delay in pronunciation. If it was a non-semantic nonword, during the delay AN would typically look intently at the card, shake her head and exclaim "oh, it's not there....no...no....nearly". It seemed that once the pronunciation of a nonword became familiar she made no overt attempt at converting it bit-by-bit even when she had difficulty retrieving it. If she did subsequently manage to read the nonword it was always fluently as a complete item.

The improvement in AN's reading of the nonwords in the non-semantic condition was highly significant. One possible explanation for this is that a lexical direct route is operative in this patient and can still learn new representations. This assumes however, that such items evoke no useful semantic associations under these conditions.

4.3.2. The Semantic Associations of Words and Familiar Nonwords: AN.

This test was designed to test the assumption that when presented one at a time for reading aloud, concrete nouns and familiar nonwords that have been given meanings will evoke semantic associations, whilst function words and familiar nonwords given no meanings, do not.

The test used five concrete nouns (e.g. *lemonade, gift, ambulance, cigar, hand*); five function words (e.g. *since, while, often, them, quite*); five nonwords (*heaf, wush, pook, pove, mear*) from the with-semantics condition in the previous experiment and five nonwords (*bood, tind, pild, peen, gome*) from the no-semantics condition. Each letter-string was printed on a separate card. Prior to the association test all twenty stimuli were randomly presented for reading. AN read thirteen correctly, three errors being on function words and two on each type of nonword. Each time she made an error the letter-string was read to her by the experimenter and she was instructed to repeat what she heard. On the fourth run through the twenty items AN read all of them correctly.

After a break of about twenty minutes AN was given the following instructions. "I am going to hold up some cards and each one has something printed on it. I want you to read aloud what is printed and then tell me anything that it brings to mind. It doesn't matter what it is. Take as long as you like. I just want you to say anything that comes into your head, anything at all". The order of presentation was randomised. AN read 5/5 concrete words correctly and provided clear evidence of available semantic information for all of them (e.g. *lemonade* - "Lemonade. A drink, in a bottle, clear"; *gift* - "Gift. Christmas or wedding or birthday. Anything"). She read 3/5 function words correctly but gave specific semantic associations for only one of them (*Often* - "Often you go there, often you go away, several visits"). The two other function words that were read correctly and the two that were not attempted produced very similar responses (e.g. *while* - "erm, while, while, no, no, nae a word. That's too hard. Nothing much really. Aye, it has meaning. Just er..no"; *them* -

"Oh God, no. I know the word but I just cannae explain its meaning"). She read 5/5 of the nonwords from the with-semantics condition and gave clear evidence of having available the definitions that she had created herself for each nonword and its associated nonsense picture (e.g. *heaf* - "Heaf. It's for crushing bananas, fruit"; *mear* - "Erm, mear. Aye it's a word. Brass, a brass instrument, toot, toot). AN read 5/5 of the nonwords from the no-semantics condition but failed to show any knowledge of the words other than their pronunciations (e.g. *bood* - "Bood. It's er, nae a word, no, nae a word. I cannae think of anything. It's not a real word. I know it though, oh aye"; *pild* - "Pild. That’s nae a word. God no. It is a word but it's no really, no").

As a final test, three months later, all fifteen of the familiar non-semantic nonwords were presented to AN with the same instructions as above. She read 12/15 correctly and again failed to produce semantic associations for any of them. For example her response to *gome* was "Gome. Gome. That's, er, it's nae a word. It's rubbish. It doesn't mean a thing. You know what? I couldn’t even say how I know that".

4.3.3. The Effect of Nonword Training on Sub-Lexical Processing: AN.

These tests were designed to see if there had been any change in AN's general ability to read non-lexical material as a result of her having learned to read specific nonwords. Any improvement in sub-lexical processing would weaken the claim that AN's learning to read meaningless nonwords was evidence for a lexical direct route.

Test 1: Reading familiar nonwords and closely matched novel nonwords. Of the fifteen non-semantic nonwords, five (i.e. *bost, tave, bood, pild*, and *tost*) were rearranged to create orthographically legal novel nonwords (i.e. *stob, vate, doob, dilp,* and *stot)*. Each of the five parent nonwords and the five re-arranged forms was printed on a separate card. These were presented in random order to AN and she was asked to read what was on each card. AN read 5/5 of the familiar nonwords and 1/5 of the novel nonwords.

Test 2: Reading compound nonwords. If the training improves reading of the components of the nonwords, rather than just the reading of those specific whole items, then it might generalise to new words formed by combining the familiar nonwords that she can read. Five new, eight-letter nonwords were created for this test. This was done by selecting ten of the twelve non-semantic nonwords that AN had read correctly in the final phase of the semantic association test above, and joining together pairs that would make orthographically legal letter-strings (e.g. *boodpeen*). These were printed in a list and presented to AN for reading. AN read none of them correctly nor any of the familiar four-letter components, even though she could read those when they were presented as single whole items. Her strategy was the same as in previous tests of compound nonword reading. She attempted a bit-by-bit conversion of each nonword, attempting the initial phoneme and then moving on to others before attempting a whole pronunciation which was always wrong. After about two minutes she said " You're trying to trick me. I cannae read these. It's terrible but I can't. What I'm trying to say.... I don't have a clue. I've never seen them before. They're no real words. Oh aye, these are, well, aye" (indicating the two familiar elements). She then proceeded to cover up one half of each nonword and read the other half. She read 9/10 of the familiar components in this way.

Test 3: Letter sounding-out. The sixty letters making up the fifteen familiar four-letter non-semantic nonwords were printed individually on separate cards and presented in random order for AN to sound out. She produced an appropriate sound for 42/60, (70%). In the same session she read 13/15 of the familiar nonwords correctly. This would not be possible if their individual components had only a 70% chance of being correct. Using the original letter sounding-out data, obtained prior to training and given in Table 4.2, it was possible to calculate a probability value for each letter of it being given an acceptable pronunciation. By multiplying this probability by the frequency occurrence of each letter, an expected level of performance was calculated for these sixty letters. The expected score is 46.6/60 (77.7%), so her sub-lexical processing of these letters shows no sign of improvement.

4.3.4. Learning to Read Nonwords Without Semantics: AM.

AM's nonword reading deficit provided an opportunity to test the replicability of AN's apparent ability to learn to read nonwords for which she could give no associated semantic information.

Method.

The procedures and design of the experiment were the same as those used in 4.3.1. except that only a 'no-semantic' condition was run. AM was thus presented with the same fifteen nonwords as AN, printed individually on blank cards and asked to read them aloud. He agreed to continue with the experiment until such time as he could read all fifteen correctly in any one trial. In fact, the experiment was terminated after forty trials by which time AM had read 14/15 correctly for the last three consecutive trials.

Results.

AM read 4/15 nonwords correctly on the first trial and 14/15 correctly on the last trial. He read 411/600 correctly over the forty trials. Predicted performance levels based on the first trial would be 160/600 over the forty trials. Figs. 4.3 and 4.4 show how performance improved as the number of trials increased. Fig. 4.3 plots the number correct per trial and Fig. 4.4 plots the mean number correct per session. A Kendall's S test (Jonckheere & Bower, 1967) performed on the data shows the learning trend to be highly significant ($Z = 9.24$, $P < .0001$).

An analysis of the responses on trials one to four inclusive, shows that of the thirty-nine errors, twenty-five involved real-word substitutions of both the simple and the complex types described in the background tests of nonword reading in Section 3.2.1 (p.37). Throughout the experiment, when AM produced a lexicalisation to any particular nonword on more than one trial, it was almost always the same lexicalisation (eleven of the fifteen nonwords produced lexicalisations on the first trial and only three of these subsequently produced a different one). So on trial one, *wone* was read as "won"+/i/, a response which was produced thirty-two times over the forty trials. However, for most nonwords, there was a 'transition' from lexicalisation to correct response with errors becoming phonologically closer over time. All correct responses were pronounced fluently as complete pronunciations. None of the lexicalisation errors involved the substitution of one familiar nonword for another.

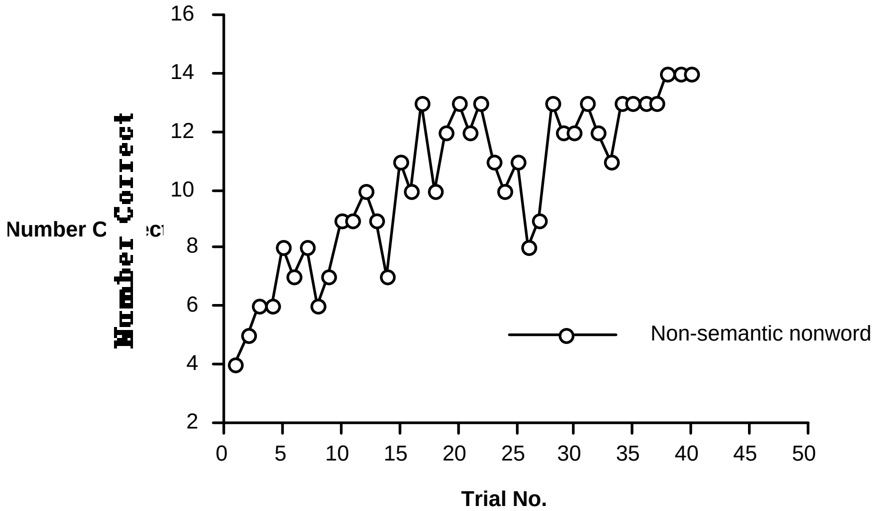

FIG. 4.3. AM's Reading Performance on Fifteen Four-Letter Nonwords, Shown as the Number Correct Per Trial over Forty Training Trials. Each Nonword was Printed on a Blank Card and Presented Individually for Reading.

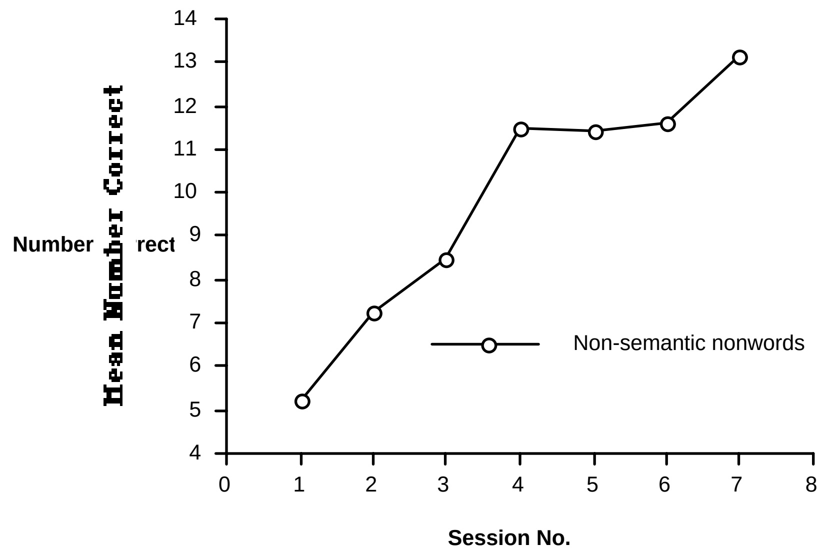

FIG. 4.4. AM's Reading Performance on Fifteen Four-Letter Nonwords, Shown as the Mean Number Correct Per Session over Seven Training Sessions. Each Nonword was Printed on a Blank Card and Presented Individually for Reading.

Discussion.

The gradient of the learning curve shows that the training produced a highly significant improvement in reading performance. As these nonwords had no distinctive meanings that would distinguish one from another, AM's learning suggests that a lexical direct route is both operative in this patient and can learn new representations. Again , this assumes that the patient had not generated his own semantic associations which aided his improved reading. An attempt was therefore made to see whether being presented with the nonwords for reading, evoked any semantic associations.

4.3.5. The Semantic Associations of Words and Familiar Nonwords: AM.

This test used fifteen concrete nouns (e.g. *house*, *blood*) and the fifteen familiar nonwords from the last experiment (e.g. *bost*, *wone* and *tave*). Each letter-string was printed on a separate card and the cards were randomly presented to AM. He was given the same instructions as AN in the corresponding experiment (Section 4.3.2.). AM read 15/15 concrete nouns correctly and provided appropriate semantic associations for all of them (e.g. *house* - "House. Where we are.....now. Here. Home; *blood* - " Blood. What went wrong in my head!). AM read 13/15 of the familiar nonwords correctly but provided semantic associations for none of them. His persistent response was that he didn't understand the "word" e.g. "It doesn't mean anything. It can't. It's just something...... a word I can say".

4.3.6. The Effect of Nonword Training on Sub-Lexical Processing: AM.

One test was performed to see if AM appeared to be generally better at sub-lexical processing after the training on specific nonwords, than he was before. This involved testing AM's reading of the familiar nonwords and closely matched novel nonwords made from the same elements. Of the fifteen nonwords, thirteen were re-arranged to create orthographically legal novel nonwords. Each of the thirteen parent nonwords and the thirteen re-arranged forms was printed on a separate card and the cards were presented in random order to AM who was asked to read what was on each. AM read 12/13 of the familiar nonwords and 2/13 of the novel nonwords.

4.4. General Discussion of Routes from Print to Sound.

Both an interpretation of AN's and AM's reading performances and the implications for the main issue of the nature of the functional organisation of routes from print to sound, will be dealt with in this discussion. Other issues to which the data are relevant will be dealt with in a general discussion at the end of the thesis.

4.4.1. Contribution of the Semantic Route.

Three main results provide evidence that the semantic route contributes to reading aloud by AN. (a) Content words are read better than function words; (b) Highly imageable nouns are read better than nouns of low imageability and; (c) Nonword pronunciations are learned significantly faster if they are given distinctive meanings than if they are not.

The extent of this contribution is unclear, however. It is not possible to tell from the data whether this route by itself is adequate for the reading of some words by this patient, or whether it exerts its influence only in combination with other routes. Nor is it possible to tell whether this route contributes to the reading of function words. One possibility is that function words are read only via the non-semantic direct route or routes. Patterson (1982), for example, suggests that function words are read by the sub-lexical route. Another possibility is that the semantic route contributes to, but is not sufficient for the reading of function words. Both possibilities could explain why function words are affected by damage that is restricted to the direct route.

There is no evidence of semantic impairments relevant to the comprehension of single words whether presented orally or in writing, nor did AN ever make a semantic paralexia in any of the reading tests. Semantic errors in spontaneous speech and writing to dictation have occurred but very rarely. Her deficits in reading single words aloud, do not therefore seem to be due to impairments of comprehension. AN suffers nominal aphasia however, so it is possible that the contribution of the semantic route to reading is reduced by impairments in the processes that retrieve phonological output representations from meaning. This might help explain the word class effects, because her nominal aphasia appears to be greatest for abstract words, although this has not been formally assessed. Other explanations for her impaired reading of many familiar words are also possible, however. One is that these words are especially dependent upon a contribution from the sub-lexical direct route. Another is that such words are especially dependent upon a lexical direct route that is partially impaired in AN.

The data from AM provide little evidence about the role of a semantic route in his reading aloud. Content words are read better than function words and highly imageable nouns are read better than nouns of low imageability although these differences are not significant. This lack of significance in no way implies that a semantic route is not operative, however. It might be that the differences in reading performances between the word classes are smaller because of a greater contribution from a direct route or routes in reading function words and words of low imageability. Even if it was accepted that the differences are suggestive of a semantic contribution to reading, the extent of the contribution is again unclear. Nevertheless, there is no evidence of a semantic impairment that compromises AM's comprehension of spoken or written words. During testing sessions, AM has never made a semantic error in spontaneous speech and has only ever made one semantic paralexia. It therefore seems unlikely that failures of comprehension contribute to AM's word reading deficit. Like that for AN, a plausible explanation is that AM may have a deficit in activating phonological output representations from meaning, a problem which might underlie his anomia.

4.4.2. Contribution of the Direct Route or Routes.

Three main results provide evidence that a direct route, or routes, contributes to reading aloud by AN; (a) She can sound-out single letters with an accuracy of approximately 70%; (b) She can read three-letter nonwords with an accuracy of approximately 30% and; (c) She can learn to read nonwords even if they are given no distinctive meanings. Furthermore, she can read more than a third of function words correctly, but the accessible semantic associations evoked by isolated function words are minimal. Therefore, either adequate semantic associations are evoked but cannot be expressed, or a direct route contributes to the reading of function words. Two aspects of AM 's reading provide evidence for a direct route, or routes: (a) He can read 23% of three-letter nonwords and 10% of four-letter nonwords and; (b) He can learn to read nonwords even if they are given no distinctive meanings.

4.4.2.1. Evidence for a Sub-Lexical Direct Route.

The ability to read unfamiliar words or novel nonwords is prima facie evidence for a sub-lexical direct route. Analogy theory (Glushko, 1979; Marcel, 1980; Kay and Marcel, 1981) suggests an alternative interpretation by proposing that unfamiliar items are read by analogy to whole familiar words. However, AN’s severe impairment at reading nonwords that are close lexical neighbours of words that she can read well and her severe impairment at reading compound nonwords composed of two real words that she can read individually, provides no support for this proposal. This pattern of performance could be explained within analogy theory as a failure of orthographic or phonological segmentation but AN’s ability to segment both orthography and phonology appear to be unimpaired. AN’s nonword reading is therefore worse than it should be according to analogy theory, given the words that she can read. By contrast, normal readers are better than they should be when compared with the computational version of single direct-route theory proposed by Seidenberg and McClelland 1989; Besner, Twilley, Seergobin & McCann, 1990; Coltheart, Curtis and Atkins, in press). Phillips, Hay & Smith (1993) show that by modifying the architecture of the Seidenberg and McClelland net, its ability to read nonwords can be improved but not to a level comparable with humans. Phillips, Hay & Smith (1993) suggest that this limitation is due to the lack of a sub-lexical route. The data from AN are best accommodated by an architecture that includes a distinct sub-lexical route that makes a special contribution to the reading of novel letter-strings in normal readers, and which is severely impaired in AN. AN’s persistent attempts at reading novel items by using a sub-lexical strategy may reflect a lifetime's experience of being able to use sub-lexical processes to read such items. This strategy persists even though the sub-lexical route on which it depends is no longer adequate for the task. Perhaps it does so because recognition and segmentation are well preserved in both graphic and phonic domains.

AM's ability to read some novel nonwords is prima facie evidence for a sub-lexical direct route, although again, analogy theory would propose that these items are read by analogy to whole familiar words. With the available data it is impossible to adjudicate between these two accounts, although AM's serious impairment at reading bi-syllabic nonwords (.09%) which are re-combinations of syllables from familiar words that he can read well (97.0%), is difficult for analogy theory to explain. However, the absence of any formal tests of AM's orthographic or phonological segmentation abilities means that analogy processes cannot be refuted in this patient.

4.4.2.2. Evidence for a Lexical Direct Route.

In Hillis & Caramazza’s (1991) single direct-route model, reading of familiar words is normally achieved via lexical semantics. Novel words and nonwords are read by sub-lexical OPC procedures. This model would account for both AN’s and AM's nonword reading impairment simply by proposing damage to OPC procedures. Hillis & Caramazza also propose that poorly understood irregular words can be read within their model by the sub-lexical direct route working in conjunction with the semantic route, thereby eradicating the need to postulate a lexical direct route. Residual semantic information coupled with residual OPC procedures was, according to Hillis & Caramazza, what was supporting the reading of orthophonically irregular words in patients like WLP (Schwarz et al, 1980) and JJ (Hillis & Caramazza, 1991). AN’s semantic word class effects are difficult to explain within this framework, however. Although not formally documented, AN would often show, by mime or circumlocution, comprehension of abstract words that she failed to read. It is therefore difficult to explain why when AN has residual OPC procedures, she fails to read some abstract words that she understands well.

The crucial aspect of both AN’s and AM's performance for this model is their successful reading of nonwords of which they appear to have no distinctive semantic knowledge, and whose components they cannot adequately read. Hillis & Caramazza

(1991) tested patient JJ’s semantic knowledge by asking him to define a word and then read it.[13] They found that JJ read aloud correctly *only* those irregular words for which he showed *some* comprehension. JJ never correctly read a word for which he could not provide any semantic information and that could not be correctly read by sub-lexical processes. In contrast, AN and AM correctly read familiar nonwords for which they showed no semantic knowledge and for which their seriously impaired OPC procedure were inadequate. Furthermore, although both patients can read these familiar nonwords they cannot adequately read their components when presented alone or in unfamiliar combinations.[14] In addition AN's reading of function words, though poor, is better than her reading of unfamiliar nonwords, and has improved over the last few years whereas her sub-lexical reading has not. In the absence of a contribution from a semantic route and with no adequate sub-lexical procedures it is difficult to explain AN’s reading of familiar nonwords and of function words other than by proposing processes that are lexical but not semantic.

AN's and AM's reading performances also pose difficulties for the single-route, computational model of Seidenberg and McClelland (1989). A consequence of a severe impairment in nonword reading of this model is that a patient relies on semantic mediation for the successful reading of real words. In other words, a single route that will no longer read nonwords will not read whole real words either. A simple *prima facie* single direct-route interpretation that accounts for most of both patients' reading abilities and disabilities, is that they have suffered damage to the direct route as a whole and consequently are semantic readers. Thus there are semantic word-class effects, nonwords are particularly affected, and in AN, there is better learning for new words that are given distinctive meanings than for meaningless nonwords. The key problem for this interpretation, however, as for Hillis & Caramazza’s (1991) single-route approach is that both patients can read nonwords of which they appear to have no distinctive semantic knowledge, and whose components they cannot adequately read. The significant improvement in AN’s reading of

[13] The procedure that was used with AN and AM was similar but was perhaps more open-ended with respect to the specification of what semantics are relevant.
[14] It is acknowledged that this claim is stronger for AN than for AM because fewer tests of reading of the nonword components were carried out with AM.

function words and low imageability words between 1984/85 and 1991/92, whilst there was no improvement in the reading of content and high imageability words is difficult for this model too. Both of these phenomena suggest that reading can occur via a lexical/non-semantic route. Support for this conclusion is that the improvement in word reading and the learning to read specific nonwords produced no observable improvement in the reading of novel nonwords or general sub-lexical processes. In the Seidenberg and McClelland (1989) model the ability to read novel nonwords is an automatic and necessary consequence of learning to read words and within certain constraints depends upon the number of words learned. On this theory, therefore, the performance on novel nonwords should improve as lexical performance improves.

Although a lexical direct route seems the most parsimonious explanation of the data, they do not imply that there <u>must</u> be a lexical direct route. This is because the lexical but non-semantic contribution might occur within the phonological domain using whatever information is transmitted from print over the sub-lexical route. The idea of a representation being established in the phonological output lexicon through training, which can then be accessed by sub-lexical graphemic processes, has interesting theoretical implications. However, they are not pursued here because certain aspects of the data, particularly from AN, appear to militate against this interpretation. Firstly, performance would be limited by the sub-lexical route, which is unreliable and of very limited capacity in AN. Test items would therefore frequently be mistaken for familiar items to which they are similar. The tests of analogy theory show that in general, this is not the case. Thus if such a process was postulated, we would need to explain why it does not occur in those tests. Furthermore, the error analysis performed in the 'familiar nonword' paradigm show that when both AN and AM were learning to read nonwords, they did not substitute one familiar nonword for another (they did occasionally substitute real words for the familiar nonwords (this was certainly more common for AM, although as learning progressed the tendency of both patients to erroneously select lexical items decreased). This shows that when reading the familiar nonwords the patients are not restricting their responses to a small set of familiar nonwords from which they select a using their minimal sub-lexical abilities. It is therefore concluded that the lexical but non-semantic contribution to these patients' performances is due to a lexical direct route.

4.4.3. Evidence for a Distinction between Lexical and Sub-lexical Direct Routes.

The preceding sections argue that these patients' performances provides evidence for both lexical and sub-lexical levels of a direct route from print to sound. These results might therefore support a multi-level version of single-route theory (e.g. Shallice, Warrington and McCarthy, 1983; Shallice and McCarthy, 1985). The main difficulty raised for that interpretation however, is to explain why both patients can learn the pronunciations of whole nonwords but not the pronunciations of the smaller units of which they are composed when (a) the latter must be paired with their pronunciations much more often and (b) the morphemic level within the broad route is considered to be the most susceptible to damage. These results suggest that for both patients, the learning of sub-lexical print-to-sound correspondences is much more impaired than is the learning of direct whole-word print-to-sound correspondences. If so, this provides evidence for a double dissociation when combined with other cases that are interpreted as showing better preservation of the sub-lexical than of the lexical levels (Shallice, 1988).

The pattern of data reported here is best accommodated by a dual-route architecture which incorporates a lexical direct route and a sub-lexical route which uses OPC procedures. Although these data provide no evidence about the size of the segments upon which OPC procedures might operate, considerable evidence exists that it is not just at the level of the grapheme (e.g. Shallice, Warrington and McCarthy, 1983; Glushko, 1979; Marcel, 1980; Kay and Marcel, 1981; Patterson and Morton, 1985). Shallice, Warrington and McCarthy, (1983) proposed their multi-level word-form system to account for these data. The same model could explain AN’s pattern of impaired and preserved abilities if the ‘top’ level of the system that deals with morphemes or whole words was functionally dissociable from the other sub-lexical levels. This would mean that these patients have suffered greater damage to the levels dealing with units smaller than morphemes than to the level dealing with whole morphemes. Thus nonword reading is particularly impaired and learning can occur at a lexical level without any improvement at the sub-lexical levels.

4.4.3.1. What distinguishes the Lexical and the Sub-lexical Direct Routes?

If there are two distinct direct routes then it is important to discover what the fundamental differences between them are because we want to know why there are two routes and whether this illustrates any general principles of cortical organisation. At least five different contrasts might be relevant. Each is discussed in relation to the evidence reported above.

1. *Words vs nonwords.* Is one route reserved for words? Both AN and AM can learn to read nonwords as specific familiar wholes so the route by which they do so is not reserved for items that have a role in the normal communicative language of the subject.

2. *Novel letter-strings vs familiar letter-strings.* The sub-lexical route can deal with novel letter-strings but the lexical route cannot. This does not imply that familiarity *per se* is a key distinguishing factor, however, because the lexical level may be able to deal with novel combinations of words and the sub-lexical level may not be able to deal with novel combinations of letter features[15]. Furthermore, these patients' sub-lexical deficits include the inability to learn sub-lexical correspondences that occur more frequently than the whole-word correspondences that they can learn. Therefore their sub-lexical deficit shows-up here as a difficulty in learning a frequently repeated mapping, not as a difficulty in generalising knowledge to novel inputs.

3. *Regular vs irregular mappings.* The nonword pronunciations that AN and AM learned were all regular, and regularity plays no role in the evidence reported here for two distinct direct routes. These results, therefore, provide no reason for supposing regularity to be crucial to the distinction i.e. the lexical route being dedicated to reading irregular words. Furthermore, removing regularity from the list of crucial differences has the advantage that it allows for two direct routes in languages with a wholly regular orthography (DeBastiani, Barry & Carreras 1987).

[15] Another way of looking at it is that the sub-lexical level may be able to deal with novel letters-strings but these are merely novel combinations of familiar items.

4. *Dictionary look-up procedures vs rule-based procedures.* Coltheart, Curtis & Atkins (in press) propose that one route uses a dictionary look-up addressing procedure and that the other uses a rule-based assembly procedure. These patients' performances support the view that one route somehow processes letter-strings as coherent wholes and that the other somehow processes them part-by-part. There is nothing in these results, however, that implies that the procedures which map from the parts to their pronunciations must be fundamentally different from the procedures that map from the whole strings to their pronunciations.

5. *Mappings from whole letter-strings (words and nonwords) to whole pronunciations (morphemes and whole nonword pronunciations) vs mappings from parts of letter-strings (single or multiple letters) to part pronunciations (single or multiple phonemes).* These patients can read and learn at a level of a direct route where the sub-word segments are somehow combined to form a particular whole word, but not at a level where the same segments are treated independently. In other words individual orthographic elements can be processed only as part of a relationship with other elements which in total form a whole representation. The relationship of the elements becomes a critical factor, presumably through visual familiarity and, in the case of AN, dictates the processes applied in the reading aloud of a single letter-string. These patients' performances therefore support the view that one route is somehow specialised for the processing of letter-strings as coherent wholes, and the other route is somehow specialised for the more analytic processing of letter strings as sets of independent parts. Thus this emphasises a difference between what it is that the two routes operate upon. They might in addition operate in fundamentally different ways, but we see nothing in our results that suggests that they do.

To re-iterate the preceding argument, the distinguishing characteristic of the lexical direct route or level is that it operates on whole letter-strings, for which it has lexical entries that are familiar combinations of parts that are mutually dependent for processing. The sub-lexical levels must deal with novel combinations of familiar parts. In one final experiment the question was asked as to whether the mutually co-operative parts that form a whole familiar item could be other than those <u>within</u> the boundaries of a single letter-string.

4.5. Can More than One Letter-String be a Single Lexical Item?

This experiment was designed to test whether a whole item can be a combination of two words or letter-strings. This might be the case if two nonwords were only ever encountered together, and so were only familiar to, and processed by the reading system, in combination with each other. If this were the case, a single lexical entry might exist for the two letter-strings and the direct lexical route would not be able to read the component parts individually or in novel combinations.

4.5.1. Reading Familiar and Unfamiliar Combinations of the Same Words.

On the basis of the data in this thesis, the claim that lexical processing involves treating familiar combinations of mutually co-operative parts as whole items, is made only in relation to the lexical direct route (because the relevant tests used 'meaningless' nonwords). The most appropriate way to test whether this distinguishing characteristic extends beyond the boundary of the single letter-string would have been to teach the patients to read pairs of nonwords and then see if they were unable to read the component parts either individually or in novel combinations. However, learning to read nonwords is effortful for both patients and one of the patients was unwilling to learn to read a new body of 'nonword phrases'. The decision was made therefore, to see whether there is any evidence that general lexical processes (whether in the lexical direct or the semantic route) can treat pairs of words as whole items. In this case, a whole item might comprise two words if they don't normally occur in the language independently or in combination with any other word i.e. if they only ever co-exist. If this was the case, it would be predicted that these patients should be able to read familiar combinations of two words but not the component words when they are encountered individually or in combination with other words with which they would not normally occur e.g. it would be predicted that these patients could read Zsa Zsa Gabor and Acker Bilk but not Acker Gabor and Zsa Zsa Bilk .

Method.

The problem with testing this prediction is that there are few, if any, common phrases comprising two words which do not occur independently. The most likely candidates to satisfy this criterion are real names but even then, probably only two of the stimuli chosen (see above) are combinations of unique elements for these patients. This experiment therefore used twenty real name and twenty other two-word phrases (e.g. jellied eel; nursery rhyme) that normally occur in the language. Each of these two phrase types were sub-divided into ten that are combinations of words that rarely appear independently and ten that are combinations of words that commonly occur independently.[16] Within each of these four sets, ten novel phrases were created by randomly combining the twenty constituent words. Thus forty familiar combinations and forty novel combinations (eight sets) were created. These eighty phrases were individually printed on white cards and randomly presented to each patient for reading. The patients were asked to "read what is printed on each card and take as long as you want". A record was made of the number of phrases read correctly in each of the eight sets. Using a stopwatch, the response time for each item was measured as the time between the display of the item and the completion of the spoken response.

Results.

Tables 4.7 (AN) and 4.8 (AM) show the actual stimuli used in each of the eight sets and which phrases received correct pronunciations and which received incorrect pronunciations. They also show the response times measured in seconds, for each item. Table 4.9 is a summary table showing a comparison of the number of items read correctly according to whether they were familiar or novel combinations and whether their

[16] Whether a component word was one that frequently or rarely occurs independently, was judged by four colleagues who were ignorant of the aims of the experiment.

TABLE 4.6.

AN's Response Times and her Correct and Incorrect Pronunciations for Forty Famliar and Forty Novel Combinations of Two-Word Phrases. Half of all these Phrases were Real Names and Half were not. These Two Halves were Equally Sub-Divided into Half Whose Component Words Commonly Appear Independently and Half Whose Component Words Rarely Appear Independently.

Real Names						Non-Real Names					
Familiar Combinations of Common Items	RT	Right/wrong Pronunciation	Familiar Combinations of Rare Items	RT	Right/wrong Pronunciation	Familiar Combinations of Common Items	RT	Right/wrong Pronunciation	Familiar Combinations of Rare Items	RT	Right/wrong Pronunciation
Harold Wilson	5.7	✓	Winston Churchill	3.7	✓	general election	22.0	✓	jumbo jet	3.6	✓
Elizabeth Taylor	2.0	✓	Elvis Presley	3.8	✓	piano player	3.3	✓	rolls royce	36.0	✓
Kenny Ball	3.3	✓	Zsa Zsa Gabor	7.8	✓	boy scout	6.0	✓	lawn mower	3.5	✓
Tom Jones	5.0	✓	Acker bilk	12.6	✓	long trousers	3.8	✓	reader's digest	3.2	✓
Paul Newman	2.1	✓	Perry Como	2.9	✓	daily mail	7.6	✓	nursery rhyme	1.5	✓
George Harrison	4.6	✓	Telly Savalas	23.7	✓	london underground	5.6	✓	jellied eel	6.1	x
Andy Williams	2.9	✓	Ringo Starr	3.0	✓	british rail	6.9	✓	barrier reef	4.8	✓
Jimmy Carter	1.9	✓	Adolf Hitler	3.8	✓	rocking chair	3.1	✓	embassy regal	2.6	✓
Michael Foot	3.6	✓	Idi amin	19.0	✓	carrier bag	1.6	✓	filing cabinet	2.8	✓
Henry Cooper	2.4	✓	Lester Piggott	2.9	✓	mouth organ	2.9	✓	taj mahal	10.5	✓
Total =	33.5	10		83.2	10		62..8	10		74.6	9
Novel Combinations of Common Items			Novel Combinations of Rare Items			Novel Combinations of Common Items			Novel Combinations of Rare Items		
Elizabeth Ball	2.7	✓	Winston Presley	6.4	✓	general player	4.3	✓	lawn jet	2.9	✓
Kenny Wilson	2.2	✓	Elvis Churchill	6.4	✓	boy election	2.6	✓	rolls mower	6.9	x
Harold Taylor	20.2	✓	Zsa Zsa Bilk	15.8	x	long scout	19.7	✓	jumbo royce	22.0	x
Tom Newman	2.0	✓	Acker Gabor	7.9	x	piano trousers	4.0	✓	reader's eel	4.9	✓
Andy Jones	1.9	✓	Perry Starr	5.6	✓	daily underground	34.3	✓	nursery digest	38.0	x
Paul Harrison	16.8	x	Ringo Savalas	28.9	x	london mail	2.8	✓	jellied rhyme	7.8	✓
George Williams	3.9	✓	Telly Hitler	6.6	✓	british organ	14.0	x	barrier cabinet	1.6	✓
Henry Foot	2.1	✓	Adolf Como	14.0	✓	rocking bag	5.1	✓	embassy reef	4.6	✓
Jimmy Cooper	3.1	✓	Idi Piggott	24.5	x	carrier rail	14.5	x	filing mahal	15.3	x
Michael Carter	3.0	✓	Lester amin	2.8	✓	mouth chair	3.4	✓	taj regal	26.7	x
Total =	57.9	9		118.9	6		104.7	8		130.7	5

TABLE 4.7.

AM's Response Times and his Correct and Incorrect Pronunciations for Forty Famliar and Forty Novel Combinations of Two-Word Phrases. Half of all these Phrases were Real Names and Half were not. These Two Halves were Equally Sub-Divided into Half Whose Component Words Commonly Appear Independently and Half Whose Component Words Rarely Appear Independently.

Real Names						Non-Real Names					
Familiar Combinations of Common Items	RT	Right/wrong Pronunciation	Familiar Combinations of Rare Items	RT	Right/wrong Pronunciation	Familiar Combinations of Common Items	RT	Right/wrong Pronunciation	Familiar Combinations of Rare Items	RT	Right/wrong Pronunciation
Harold Wilson	1.2	✓	Winston Churchill	2.6	✓	general election	1.1	✓	jumbo jet	2.7	✓
Elizabeth Taylor	3.9	✓	Elvis Presley	6.0	✓	piano player	2.3	✓	rolls royce	2.4	✓
Kenny Ball	1.9	✓	Zsa Zsa Gabor	2.4	✓	boy scout	1.9	✓	lawn mower	2.4	✓
Tom Jones	2.2	✓	Acker bilk	2.9	✓	long trousers	2.6	✓	reader's digest	4.0	✓
Paul Newman	2.2	✓	Perry Como	1.5	✓	daily mail	2.4	✓	nursery rhyme	2.5	✓
George Harrison	2.2	✓	Telly Savalas	2.1	✓	london underground	4.8	✓	jellied eel	3.8	✓
Andy Williams	2.3	✓	Ringo Starr	1.6	✓	british rail	2.2	✓	barrier reef	1.0	x
Jimmy Carter	4.1	✓	Adolf Hitler	2.9	✓	rocking chair	1.6	x	embassy regal	1.6	✓
Michael Foot	2.3	✓	Idi amin	1.8	✓	carrier bag	5.5	✓	filing cabinet	6.1	✓
Henry Cooper	2.8	✓	Lester Piggott	1.5	✓	mouth organ	1.8	✓	taj mahal	1.5	✓
Total =	25.1	10		25.3	10		26.2	9		28.0	9
Novel Combinations of Common Items			Novel Combinations of Rare Items			Novel Combinations of Common Items			Novel Combinations of Rare Items		
Elizabeth Ball	11.2	✓	Winston Presley	32.9	✓	general player	2.1	✓	lawn jet	2.3	✓
Kenny Wilson	3.3	✓	Elvis Churchill	4.7	✓	boy election	3.7	✓	rolls mower	7.5	x
Harold Taylor	19.8	✓	Zsa Zsa Bilk	3.5	✓	long scout	2.6	✓	jumbo royce	20.5	✓
Tom Newman	19.4	✓	Acker Gabor	51.2	x	piano trousers	30.0	✓	reader's eel	7.8	✓
Andy Jones	5.2	✓	Perry Starr	2.4	✓	daily underground	3.0	✓	nursery digest	7.4	✓
Paul Harrison	6.6	✓	Ringo Savalas	16.8	✓	london mail	2.6	✓	jellied rhyme	20.8	x
George Williams	4.9	✓	Telly Hitler	2.9	✓	british organ	3.4	✓	barrier cabinet	16.9	x
Henry Foot	3.8	✓	Adolf Como	19.7	x	rocking bag	6.3	✓	embassy reef	3.9	✓
Jimmy Cooper	10.3	✓	Idi Piggott	13.4	✓	carrier rail	10.2	✓	filing mahal	21.3	x
Michael Carter	5.3	✓	Lester amin	3.4	✓	mouth chair	2.4	✓	taj regal	18.8	x
Total =	89.8	10		150.9	8		66.3	10		127.2	5

read 17/20 and 20/20 respectively; AM read 20/20 and 19/20 respectively). However, AN and AM were both worse at reading novel combinations of phrases that contained elements that rarely appeared independently than they were at reading familiar combinations of the same elements (AN read 11/20 and 19/20 respectively; AM read 13/20 and 19/20 respectively.

TABLE 4.9

Summary of AN 's and AM's Reading Performances of Eighty, Two-Word Phrases Comprising Forty Familiar Combinations and Forty Novel Combinations. Each of these Two Sets Comprised Twenty Phrases Containing Words that Commonly Appear Independently and Twenty that Rarely Appear Independently.

	AN			AM		
Combination Type	No of Correct Pronunciations	Total Response Time in Sec's	Sig. of Diffs Between Nos Correct	No of Correct Pronunciations	Total Response Time in Sec's	Sig. of Diffs Between Nos Correct
All Familiar N = 40	39	254.1	χ^2=9.19, p<.005	38	104.6	n.s.
All Novel N = 40	28	412.2		33	434.2	
Familiar Common N = 20	20	96.3	n.s.	19	51.3	n.s.
Novel Common N = 20	17	162.6		20	156.1	
Familiar Rare N = 20	19	157.8	χ^2=6.53, p<.025	19	53.3	χ^2=3.90, p<.05
Novel Rare N = 20	11	249.6		13	278.1	

Discussion.

The similarity in performance of both patients at reading novel combinations of common elements and familiar combinations of the same elements is in line with predictions. There should be no difference because lexical entries should exist for all of the elements.

The fact that AN and AM were both worse at reading novel combinations of rare elements than familiar combinations of the same elements also appears to be in line with predictions. A prima facie interpretation of this result is that such elements can only be read when they occur in the context of their normal combination. A difficulty for this interpretation is that neither patient's performance was at zero. AN read 11/20 and AM read 13/20 of the novel combinations. Furthermore, during the attempts at reading the phrases for which the responses were classified as wrong, both patients often produced one of the elements correctly.[17] The data therefore do not provide evidence for single lexical entries consisting of two letter-strings. However, because only two of the phrases considered to have rare elements were judged to have elements unique to those particular combinations, the data are not evidence against single lexical entries consisting of two letter-strings either. Even though the elements rarely occur independently, they may occur frequently enough to be represented as individual items within the lexicon.

The differences between the numbers correct and incorrect and the response times could well be frequency effects and say more about lexical access than about the nature of lexical representations. Probably the only appropriate way to test whether a single lexical item can extend beyond the boundary of the single letter-string is to use pairs of nonwords which can be guaranteed to be unique items.

[17] Unfortunately, more detailed response data were not kept.

5 Disorders of Writing Single Words and Non-Words.

5.1. Introduction.

For most human beings the primary method of communication is the spoken word. In contrast, the amount we communicate by writing is very small. Even for a person writing professionally, it will be by far, the least used of their communication skills. Perhaps because of this, systems of written communication are relatively new inventions, the oldest thought to be only about five thousand years old (Ellis, 1988). Given the 'marginal' nature of writing, it is not surprising that it is a much less studied skill than speech or reading. Certainly the early nineteenth century 'diagram-makers' incorporated writing as an output modality in their models but the processes were grossly under-specified. This is understandable when one considers how much more marginal, writing would have been as a skill over one hundred years ago. The lack of development of models of writing probably also arose because of the prevalent belief that writing was not a skill in its own right. It was thought that writing was necessarily parasitic upon speech and that these phonological influences could be either lexical - "under no circumstances can a direct path be available from the sense images that form the concept to the motor centre, over which the writing movements could be innervated while the sound images were circumvented" (Wernicke, 1874) or sub-lexical - "Psychologically, the writing process involves several steps. The flow of speech is broken down into individual sounds. The phonemic significance of these sounds is identified and the phonemes represented by letters. Finally, the individual letters are integrated to produce the written word" (Luria, 1970, pp 323-324). The prevalence of these phonic mediation explanations of writing were largely responsible for writing disorders to be considered as inevitable, secondary consequences of primary aphasic disorders. Apparent support for this view came from the observation that oral and written communication disorders rarely dissociate. Consequently, until fairly recently, writing disorders arising from brain injury were known simply as *agraphias*.

One of the contributions of contemporary cognitive neuropsychology has been to demonstrate the inadequacy of the traditional phonological theories of handwriting (e.g. Shallice, 1981). Evidence from patients shows that accurate writing can be performed not only when a patient is unable to produce overt pronunciations but also when they appear to have no inner speech either, e.g. patient EB, Levine, Calvanio and Popovics, (1982). It is mainly as a result of cognitive neuropsychological investigations that detailed models of the processes involved in writing now exist.[18] As with reading, an information processing approach has provided a theoretical framework which has helped guide detailed investigations and interpretations of individual patients disorders. One of the most complete models was outlined by Margolin (1984), in a review of neuropsychological data in which he delineated the semantic, phonological, motor and perceptual processes that underlie spelling and particularly handwriting. He argued that both of these forms of output involve the co-operation of many distinct processes and drew a broad distinction between central and peripheral processes. In the model that he proposed, semantic, lexical phonological and sub-lexical phonological processes are all central processes which can act either independently or in an interactive fashion, to generate either oral or written spellings. After the generation of an orthographic code, oral and written spellings depend upon several separate stages of information processing which are the peripheral processes. In terms of writing (writing to dictation, copying and spontaneous writing) central processes specify a letter sequence in some abstract form and peripheral processes translate that spelling pattern into specific motor instructions. Central processes can be divided into three broad domains depending upon whether they deal with graphic structure, phonic structure or meaning. Just as with reading, cognitive neuropsychology can help us discover how

[18] Although neuropsychological studies are not the sole source of data. Modelling has been constrained by some data from normal adult writing errors e.g. Frith, 1980; Hotopf, 1983.

these domains are organised internally, and by what routes of processing, information is transmitted from one domain to another (e.g. Shallice, 1988; Ellis, 1988; Patterson, 1988; McCarthy & Warrington, 1990; Badecker, Hillis, & Caramazza, 1990; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994). As the available data on writing disorders is considerably less than that on reading disorders there are possibly more unresolved issues, several of which are concerned with the routes involved in producing a written transcription from an auditory input and a written copy of a visual input. The model that will be used as a framework to outline the some of the related issues is the same as that in Fig. 2.1 (page 16) from Patterson (1986) and reproduced again here in Fig. 5.1. In terms of writing, this model contains a functional architecture of the central processes. It should be stressed again that it is only one of many models that have been proposed, but it clearly embodies much of what has been generally agreed, and enables the points of disagreement to be clearly expressed.

The investigations of the writing disorders of AN and AM, primarily involved testing their performances on two main tasks. These were writing to dictation, and copying from memory either immediately or after a short delay. The experiments were designed to provide evidence on two main questions: 1. Do lexical but non-semantic processes contribute to writing to dictation? 2. Do lexical but non-semantic processes contribute to copying? A third question is also highlighted by a particular and unexpected result. 3. How is the ability to produce fluent lexical output acquired?

5.2. Routes for Writing to Dictation.

Three possible routes to the spelling pattern, held as an orthographic code in the orthographic output lexicon, have been distinguished.

5.2.1. Sub-Lexical Direct Route from Phonology to Writing.

First, the heard word could be decomposed into elementary speech sounds such as phonemes, each of which is then translated into a spelling pattern. This phonic spelling process could be used for regularly spelled words, novel words and nonwords. It would not be adequate for words with idiosyncratic spellings however, because for them it would

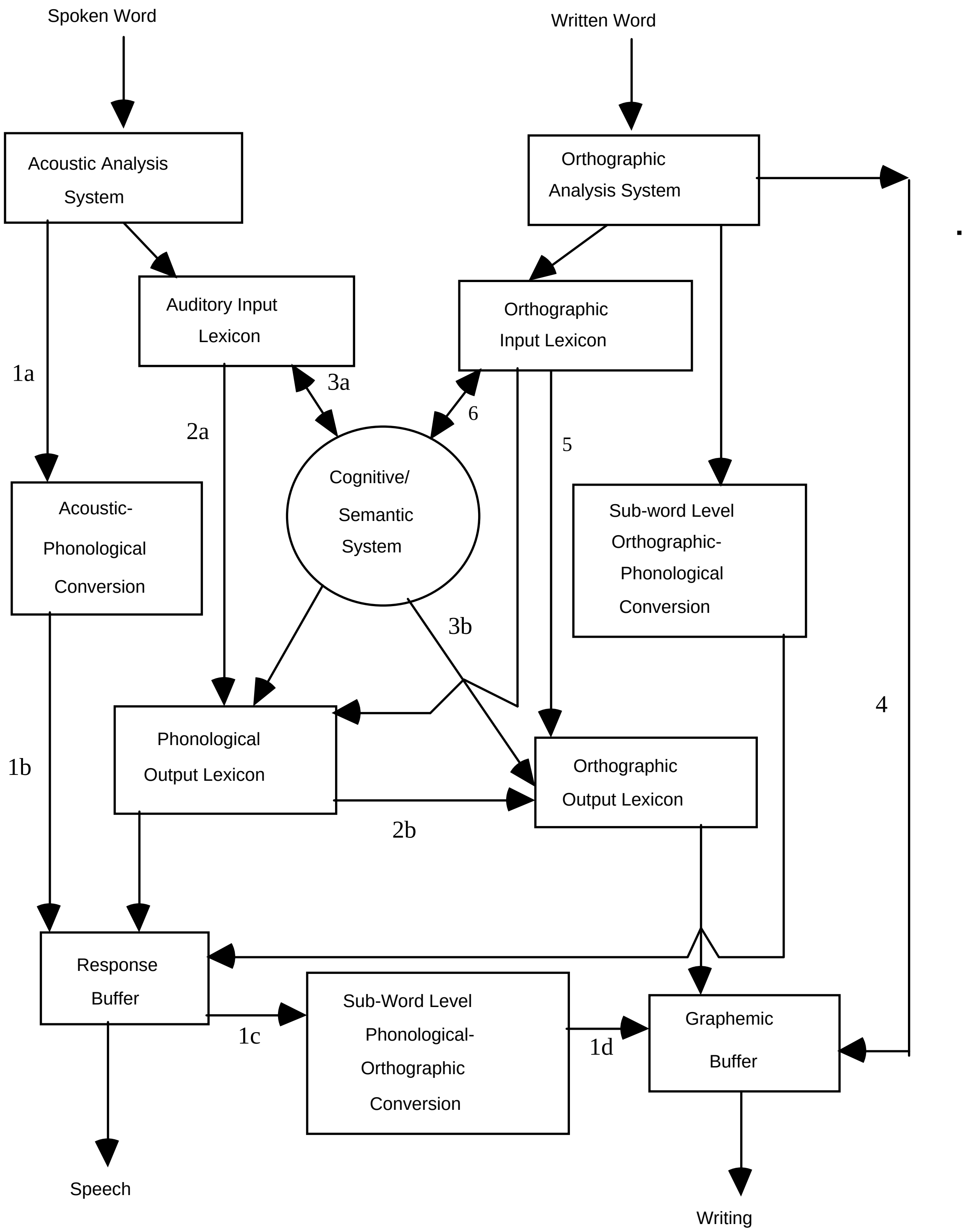

Fig 5.1. A Simple Process Model for the Recognition, Comprehension and Production of Spoken and Written, Single Words and Nonwords (Reproduced from Patterson, 1986). Routes from Phonology to Writing are; 1a - 1d which Comprise the Sub-Lexical Direct Route; 2a and 2b which Comprise the Lexical Direct Route and ; 3a and 3b which Comprise the Indirect Semantic Route. Routes from Print to Writing are; 4 (Not Included in Patterson's Original Model) which is the Sub-Lexical Direct Route; 5 which is the Lexical Direct Route and ; 6 and 3b which Comprise the Indirect Semantic Route.

deliver a regularised spelling. "*Colonel*" might be spelt *kernal*, for example. The sub-word level phonological-to-orthographic conversion procedure (1a - 1d) in Fig. 5.1 is an example of such a phonic spelling route. In that model it connects a phonological response buffer to a graphemic output buffer. The spelling is described as being *assembled* because it is produced by combining the spellings specified independently for each of a number of separate components. This will be referred to as a sub-lexical direct route from phonology to writing.

5.2.2. Lexical Direct Route from Phonology to Writing.

A second possible route from sound to writing involves recognising the heard word, and then somehow using that to look-up the spelling of that specific word. This route would not involve comprehension of the word. It could work for inputs that are familiar, including those whose spelling is idiosyncratic, but it would not work for items that are unfamiliar because no entries would exist for such items in the phonological input or graphemic output lexicons. The route from the auditory input lexicon to the phonological output lexicon and from there to the orthographic output lexicon (2a and 2b) in Fig. 5.1 is an example of such a route. This route is described as using *addressed* spellings. This will be referred to as the lexical direct route from phonology to writing. A direct route from the auditory input lexicon to the orthographic output lexicon is also possible. It is not easily distinguished from that via the phonological output lexicon and there is nothing in the results to be reported here that allows any such distinction to be made. This thesis will therefore refer to lexical direct routes from phonology without prejudice to this issue.

5.2.3. Indirect Semantic Route from Phonology to Writing.

The third possible route involves first recognising the heard word, then accessing any associated meaning and using that to specify the spelling of the word. This route requires that the words evoke distinctive meanings. An example of such a route is that from the auditory input lexicon to the orthographic output lexicon via the cognitive system (3a and 3b in Fig. 5.1). This will referred to as the indirect semantic route from phonology to writing. Note that the term 'semantic' is being used in a broad way to refer to any concrete or abstract meaning or use associated with a single isolated word that could distinguish it from other words. It is assumed, as it was by Margolin (1984), that these three routes are not mutually exclusive, and that they could interact in various ways, depending upon task conditions.

5.3. Routes for Copying.

Copying, as it is used here, means reproducing the spelling pattern of a visually presented item. It does not mean producing a literal copy. The patients whose writing is reported in this thesis always wrote in their own cursive script and as the stimuli were usually presented in typeface, and never in cursive script, literal copying is not involved. Three routes that are analogous to those outlined above have also been proposed for this task.

5.3.1. Sub-Lexical Direct Route from Print to Writing.

The first possible route could transmit information from input to output at a part-by-part level. These parts could be single or multiple letters but would be smaller than the whole letter-string. This could work for all items composed of familiar letters whether the letter-string as a whole is familiar or not. An example of such a route would be a mapping from the orthographic analysis system to the graphemic output buffer. This is shown as route 4 in Fig. 5.1 but was not included in the model of Patterson (1986). This will be referred to as the sub-lexical direct route from print to writing.

5.3.2. Lexical Direct Route from Print to Writing.

A second route could process a letter-string as a specific familiar whole and somehow "address" the whole spelling rather than "assembling" it part-by-part. This route requires the letter-string to be familiar, but does not require it to have any distinctive meaning. The route from the orthographic input lexicon to the orthographic output lexicon (route 5 in Fig. 5.1) is an example of such a route. This will be referred to as the lexical direct route from print to writing.

5.3.3. Indirect Semantic Route from Print to Writing.

A third possible processing route involves first accessing some associated meaning of a word and then using that to specify the written form (6 and 3b comprise this route in Fig. 5.1). This will be referred to as the indirect semantic route from print to writing. As in the case of writing to dictation, the operation of these three routes is not considered to be mutually exclusive.

5.4. The Lexical Direct Routes.

Many cognitive neuropsychological theories include lexical direct routes to writing from both phonological and visual input but the existence of neither route is yet firmly established. Shallice (1988) concludes that it is difficult to establish the existence of a route that is lexical but non-semantic. He was mainly concerned with the difficulty of demonstrating the existence of such a route for the task of writing to dictation. The existence of a lexical but non-semantic route for copying from visual input was assumed, however. In contrast, Ellis and Young (1988) conclude that there is good evidence for such a route for writing to dictation, but not for copying. One simple but major difficulty in establishing the existence of lexical non-semantic processing is that meaning makes a major contribution to writing in both tasks, and does so at a lexical level i.e. in normal subjects, and in many patients, words are usually understood when they are seen or heard. Mappings to writing from sight and sound can thus both occur at a lexical level via meaning. Lexical effects in copying and in writing to dictation can therefore only be used as evidence for lexical direct mappings if it can also be shown that they are not due to an indirect mapping via meaning.

One way to do this is to study the writing of patients who have severe impairments of comprehension. Patterson (1986) reported such a study using a grossly aphasic patient who had a preserved island of writing, including irregularly spelled words. There was evidence that semantic mediation was not adequate to produce the writing observed. Interpretation of these results is difficult, however. Patterson (1986) showed that semantic and sub-lexical processes both contributed to this patient's writing to some extent. Thus, even if it was shown that each of these was not adequate alone to support the writing observed, it would still be necessary to show that they were not adequate in combination (Hillis & Caramazza, 1991). This was not done and it is not easy to do. Furthermore, in reviewing this data Shallice (1988) noted that it is possible that the observed impairment of nonword writing relative to word writing could have been due to a reduced phonemic STM. If so then these results would not be evidence for the selective preservation of a lexical direct route from phonology to writing, even if they are evidence for its existence.

A second source of evidence for a lexical but non-semantic direct route from phonology to writing comes from errors made by normal subjects (e.g. Ellis, 1988). Sometimes these errors are words that are phonemically correct but semantically incorrect, e.g. SCENE may be written where SEEN was appropriate. It is thought that as these errors sometimes include words whose spellings are irregular, they cannot be explained as the result of sub-lexical mediation. This also supports the view that a lexical direct route from phonology to writing exists. It is not conclusive, however, because it assumes that only the semantics that is appropriate to the context can be accessed, and this has not yet been established.

A third source of evidence comes from patients who write familiar words to dictation much better than they can write nonwords. At least 13 such cases have now been reported (for a thorough descriptive review, see Alexander, Friedman, Loverso, & Fischer, 1992). Such patients appear to be essentially lexical writers, and they have been called phonological agraphics. It has been shown that some of these patients can repeat the nonwords that were presented after having failed to write them (Shallice, 1981; Alexander, et al, 1992), thus providing evidence for a selective deficit of the processes that map from sound to writing at a sub-lexical level (Shallice, 1988). In contrast, patients called lexical agraphics have normal nonword writing, but impaired lexical writing as indicated, for example, by a greater impairment in the writing of irregularly spelled words than of regularly spelled words. Together phonological agraphics and lexical agraphics provide a double-dissociation of lexical and sub-lexical processes in writing. This does not however, imply a double-dissociation between the lexical and sub-lexical levels themselves, within a direct route or routes. Lexical agraphics could have damage to a lexical semantic route. If pre-morbidly they also had a lexical direct route adequate for writing all familiar words then that too would have to be damaged. Phonological agraphics could have damage to the direct route or routes as a whole. Evidence for a double-dissociation within the direct route therefore requires a patient with a lexical direct route that is better preserved than the sub-lexical direct route. One way to solve this problem would be to show lexical but non-semantic writing in a phonological dysgraphic.

Both AN and AM have a severe deficit in their writing to dictation of nonwords which is significantly worse than their writing to dictation of real words. They can write content words significantly better than function words and highly imageable words better than words of low imageability, although this difference is not significant. This could be explained by the hypothesis that semantic mediation makes a major contribution to writing but does so less effectively for abstract words. Neither patients' writing depends wholly upon semantic mediation, however. Firstly, they can both write nonwords to some extent. Secondly, AN can also copy animal names better than she can write them when confronted with pictures of the animals even though she has no difficulty in recognising the pictures. The question here is therefore whether there is a lexical component to writing that is not mediated by semantics. To obtain evidence on this, lexical effects and semantic mediation were tested for, using stimuli for which semantic mediation is unlikely to play a major role. Two classes of stimuli were used: familiar nonwords to which no meaning had been given (i.e. a written version of the familiar nonword paradigm) and function words. If lexical effects occur only where there is evidence for semantic mediation then this will support the view that all lexical effects are semantic. If lexical effects occur in the absence of evidence for semantic mediation then this will support the view that there are processes that are lexical but not semantic.

The following studies were designed to provide evidence on two specific questions; 1. Does a lexical direct route contribute to writing to dictation? 2. Does a lexical direct route contribute to copying? One particular result raises a third question.

5.5. How is the Ability to Produce Fluent Written Lexical Output Acquired?

In terms of models such as that in Fig. 5.1 this question becomes, how does the orthographic output lexicon acquire its knowledge of specific words? This question assumes distinct input and output lexicons within the visual domain, and there is good evidence for this view (e.g. Caramazza & Hillis, 1991). Other neuropsychologists suggest that there may be just a single common input/output lexicon, however. Proponents of this latter view include Allport and Funnell (1981), Roeltgen and Heilman (1984), and Coltheart and Funnell (1987). It is possible that input and output lexicons are distinct, but are so closely linked in literate adults that activity in the input lexicon automatically generates corresponding activity in the output lexicon. For a variety of perspectives on the relation between perception and production in language in general see Allport, MacKay, Prinz, and Scheerer (1987). For valuable discussions of the relations between input and output lexicons in particular see Monsell (1987) and Shallice (1988).

The work reported below was not specifically designed to address this third question but the results show that learning to read specific meaningless nonwords aloud enabled both patients to write those specific nonwords fluently to dictation at the first attempt, even though they had never written them before. Further investigations showed that learning to read the nonwords was not necessary but that repeated visual experience alone was adequate to enable nonwords to be written to dictation. These results show that either fluent lexical writing does not require the use of a graphemic output lexicon, or that that lexicon can acquire knowledge without it being used to produce output. Whichever of these is the case, fluent lexical writing without practice highlights the inability of models such as that of Patterson (1986) to explain how the output lexicons acquire their knowledge.

6 Experimental Investigations of Writing.

6.1. General Descriptions of Writing Abilities and Disabilities.

Data from background tests will only be presented briefly here because they are presented more fully in Chapter 3. A summary of those data will be presented for both patients plus some additional data from AN. In all the following tests, the written responses of both patients were in their own cursive script.

6.1.1. Patient AM.

Background writing test results are given below and a summary of the effects of stimulus type on copying, writing to dictation, reading, and repeating is presented in Table 6.1.

Copying.

AM's performance was as follows, with the number correct being shown over the number of words presented: (a) 60/60 content words and 60/60 function words; (b) 27/28 high-imageability words and 27/28 low-imageability words; (c) 39/39 regular words and 38/39 irregular words; (d) 30/30 nonwords which were each three letters in length; (e) 43/43 four and five-letter nonwords (from Glushko, 1979, Table A1); (f) 52/54 newly created six-letter bi-syllabic nonwords.

Writing To Dictation.

AM's writing to dictation was as follows: (a) 51/60 content words and 36/60 function words, the difference being significant (χ^2 = 8.20, 1 d.f., P<.005); (b) 18/28 high-imageability words and 12/28 low-imageability words, the difference not being significant;

(c) 27/39 regular words and 29/39 irregular words; (d) 2/15 non-homophonic nonwords; (e) 3/15 newly created non-homophonic three-letter nonwords; (f) 3/30 of the non-homophonic nonwords taken from Glushko (1979, Table A1); (g) AM declined to attempt the 54 newly created six-letter bi-syllabic nonwords.

TABLE 6.1

Word class effects for AM's Copying, Writing to Dictation, Reading and Repeating Shown as Proportions Correct.

		Copying	Dictation	Reading	Repeating
Content	N=60	1.00	.85	.90	1.00
Function	N=60	1.00	.60	.78	.98
High Imageability	N=28	.96	.64	.93	1.00
Low Imageability	N=28	.96	.42	.82	1.00
Regular	N=39	1.00	.69	.87	.97
Irregular	N=39	.97	.74	.82	1.00
Nonwords (3 Letter)	N=30	1.00	.17	.23	.93
Nonwords (Glushko's 4/5 letter)	N=43	1.00	.10*	.12	.95*
Nonwords (Bi-Syllabic 6 Letter)	N=54	.96	.00	.09¥	.89

* In these cases N=30. The other 13 nonwords from Glushko's corpus could not be used for dictation as they are pseudohomophones. ¥ In this case N=34.

Nonword Repetition Following Attempted Writing to Dictation.

A writing impairment may be greater for nonwords than for words because of a phonic STM deficit, rather than because of a problem in converting the phonemic information into graphemic output. A test was therefore made of AM's ability to repeat nonwords after having attempted to write them. Ten four-letter, single syllable, nonwords were created and dictated to AM for writing. He was given as long as he wished to try and write each nonword and was then asked to repeat it. He produced an adequate spelling for only 2/10, but repeated 10/10 correctly.

Summary.

AM's peripheral writing processes appear to be normal. The words he writes successfully, he does so fluently in cursive script. His ability to write a particular item depends upon whether it is familiar as a whole, and partly on what meaning it has. AM's writing impairments are therefore interpreted as being of central origin. AM has a severe impairment at writing nonwords to dictation. Overall his writing of nonwords (8/114 correct) is significantly worse than his writing of words (173/254 correct; $\chi^2 = 115.22$, 1 d.f., $p<.001$). His ability to repeat the dictated nonwords after failing to write them shows that his nonword writing impairment is not due to problems in auditory perception or phonological short-term memory. It is thus concluded that AM has a deficit in converting phonemes in unfamiliar combinations into appropriate written output. In terms of the model in Fig. 5.1, the locus of this deficit would be in the sub-word level phonological-to-orthographic conversion route (1a - 1d). He could thus be described as a phonological dysgraphic. He could also be described as a lexical writer in the sense that what he writes successfully are nearly always familiar words, and in that lexical variables determine his success.

6.1.2. Patient AN.

AN's background writing test results are given below with some additional data. A summary of the effects of stimulus type on copying, writing to dictation, reading, and repeating is presented in Table 6.2.

Copying.

AN's performance was as follows, with the number correct being shown over the number of words presented: (a) 58/60 content words and 54/60 function words; (b) 28/28 high-imageability words and 27/28 low-imageability words; (c) 38/39 regular words and 37/39 irregular words; (d) 30/30 nonwords which were each three letters in length; (e) 41/43 four and five letter nonwords (from Glushko, 1979, Table A1); (f) 52/54 newly created six-letter bi-syllabic nonwords (e.g. *fincil, gerson, musger).*

TABLE 6.2.
Word class effects for AN's Copying, Writing to Dictation, Reading and Repeating Shown as Proportions Correct.

		Copying	Dictation	Reading	Repeating
Content	N=60	.97	.82	.85	.97
Function	N=60	.90	.48	.48	.95
High Imageability	N=28	1.00	.39	.82	1.00
Low Imageability	N=28	.96	.14	.43	.96
Regular	N=39	.97	.41	.82	.97
Irregular	N=39	.95	.41	.67	1.00
Nonwords (3 Letter)	N=30	1.00	.20	.33	.97
Nonwords (Glushko's 4/5 letter)	N=43	.95	.03*	.12	.95*
Nonwords (Bi-Syllabic 6 Letter)	N=54	.93	.00	.00	.78

* In these cases N=30. The other 13 words from Glushko's corpus could not be used for dictation as they are pseudohomophones.

Writing To Dictation.

AN's writing to dictation was as follows: (a) 49/60 content words and 29/60 function words, the difference being significant ($\chi^2 = 13.2$, 1 d.f., $P<.005$); (b) 11/28 high-imageability words and 4/28 low-imageability words, the difference not being significant; (c) 16/39 regular words and 16/39 irregular words; (d) 3/15 non-homophonic nonwords; (e) 3/15 newly created non-homophonic three-letter nonwords (e.g. *gan*, *jix*); (f) 1/30 of the non-homophonic nonwords taken from Glushko (1979, Table A1); (g) 0/54 newly created six-letter bi-syllabic nonwords.

Nonword Repetition Following Attempted Writing to Dictation.

The test used the same ten, four-letter, single syllable, nonwords used with AM. AN was given as long as she wished to try and write each nonword and was then asked to repeat it. She failed to produce an adequate spelling for any of them, but repeated 10/10 correctly.

Sentence Writing.

Under a two minute time limit AN's narrative description of the "Cookie-jar theft" picture in the Boston Aphasia Battery was as follows: *The boy and girl had be steat the cookie.* (She then changed the -d of "had" to -ve). The dictated descriptive sentences "She can't see them", "The boy is stealing cookies" and "If he is not careful the stool will fall" were written as follows; *She cant see they, the boy is stealing the cookie* and *If he is not careful. he stool will fult* (fall). (The -t of "fult" was crossed out, then "fall" was written.)

6.1.2.1. Writing Animal Names.

One of the subtests of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972) involves the subject verbally producing as many animal names as they can think of in 2 minutes. AN scored only 6 on this sub-test suggesting that access to animal names may be impaired. The writing of animal names to confrontation, dictation, and in immediate copying from memory were therefore studied to provide evidence on the relative effectiveness of these three main routes to the writing of animal names.

Method.

Thirty pictures of animals were randomly selected from the Snodgrass and Vanderwart (1980) corpus and a photocopy of each drawing was glued onto a 6" x 4" white card. The name of each of these animals was hand-written on a similar card. The "animals" were randomly divided into three sets of ten (henceforth referred to as sets A, B, and C) and each set was presented under three conditions. In the first condition, the picture was displayed to AN for one second[19] and she was instructed that there was no need to try and say the name of the animal but only to write the name immediately the picture was removed from display. In the second condition she was shown the printed animal name for one second and then instructed to write it down immediately it was removed from display. In the third condition the animal name was spoken to her and she was instructed to write it down

[19] These timings are approximate because they were made by stopwatch.

immediately. The order of stimuli within each set remained constant across conditions. Testing was carried out in three blocks and Table 6.3. shows the allocation of sets to tasks and the sequence of tasks for each of the three blocks. The blocks were administered in the order 1, 2, 3 , and the sets within blocks were given in the order A, B, C. Two measures of performance were made, the first of these being the number of names written correctly. The second was a measure of the time taken for each task. This was done by subdividing each set of ten stimuli into two subsets of five and measuring the total time taken to write all five stimuli. Thus six times were obtained for each task, each of which was an aggregate of the time taken between the end of the presentation of each of the five stimuli and the completion of each written response. Within each subset, succeeding items were presented immediately she had written the preceding name, or had given up, with no more than 30 seconds being allowed per item.

TABLE 6.3.
Sequence of Tasks Within Experimental Blocks and the Assignment of Stimulus Sets to Tasks.

	Set A N=10 Task	Set B N=10 Task	Set C N=10 Task
Block 1	Writing Picture Name	Copying	Writing to Dictation
Block 2	Writing to Dictation	Writing Picture Name	Copying
Block 3	Copying	Writing to Dictation	Writing Picture Name

Results.

The results were first analysed for order effects across the three blocks. The total number of names written correctly in blocks 1, 2 , and 3 were, 16/30, 20/30, and 19/30 respectively. The total times taken were 437 seconds, 370 seconds and 384 seconds respectively. Thus there was no increase in either the number correct or the speed of writing. These results, contrary to expectations show no evidence for priming effects, even though each word occurred in each block.

AN copied 23/30 names correctly in a total of 234 sec; wrote to dictation 17/30 names correctly in 437 sec; and wrote 15/30 picture names correctly in 520 sec. The differences between writing to dictation and confrontation are not significant. Comparison of copying with confrontation shows that 15 names were correct in both conditions, 7 were wrong in both, 8 were correct for copying but not for confrontation, and none were correct for confrontation but not for copying. Copying is thus significantly more accurate than confrontation naming on a sign test (T = 8, L = 0, P<0.01). Copying times are significantly faster than for writing to dictation (t [5] = 2.95, P<0.05) and for written confrontation naming (t [5] = 3.08, P<0.05). AN wrote 11 of the animal names correctly under all three conditions. The errors produced for the other 19 names are shown in Table 6.4. Florid neologisms such as those shown in Table 6.4. rarely occur in her speech.

TABLE 6.4
Errors Produced by AN when Attempting to Write Animal Names.

Word	Written to Dictation	Copied Name	Written Naming of Picture
crocodile	cro	cradi	croll
tortoise	t	torstoi	*
kangaroo	*	kanagoo	*
fly	✓	✓	fry
frog	✓	✓	fro
deer	✓	✓	*
rhinoceros	lopp	ridommo	*
donkey	monkey	✓	✓
lobster	lobester	✓	lobter
gorilla	goralla	✓	grilla
spider	✓	spister	*
skunk	✓	✓	*
sheep	speep	✓	✓
leopard	l	leotard	leobard
tiger	✓	✓	teger
raccoon	rag	✓	tacoonoo
giraffe	garraa	riffaffe	faffe
camel	camle	✓	✓
elephant	elapa	✓	✓

* No written response offered.
✓ Indicates a correctly written name.

This patient is not agnosic, and has no difficulty recognising the pictures of the animals. This was often clear from her miming or spoken explanations of an animal name that she has difficulty in writing to confrontation (e.g. when shown the picture of a kangaroo she had difficulty writing anything immediately but said "Oh Australia....you know...boing, boing...Waltzing Matilda" but was then unable to offer any written response). Despite good picture recognition, she wrote only 15/30 of the names correctly to confrontation, whereas she copied 23/30 correctly, and did so much more rapidly. This therefore provides evidence for a large non-semantic contribution to her immediate copying of concrete nouns from memory.

The actual responses shown in Table 6.4 are interesting for several reasons. Firstly, there are six responses which are incorrect but which contain the same number of letters as the target i.e. *camle*, *goralla*, *speep*, *leotard*, *leobard* and *teger*. Of these, one involves a transposition of the correct letters i.e. camle. The other five are more interesting because the erroneous letters appear not to be random substitutions. If the target letter was a vowel then so was the substituted letter i.e. the 'e' for an 'i' in *teger* and the 'a' for an 'i' in *goralla*. If the target letter was a consonant then so was the substitution. However, consonant substitutions appear to be even more systematic. In all cases, if the target letter was an ascender (a letter with a vertical stoke which extends upwards above the body of other letters of the same font and size e.g. 't', 'l', and 'd'), or a descender (a letter with a stroke which extends below the body of other letters of the same font and size e.g. 'p' and 'q'), then so was the substituted letter e.g. the 'p' for an 'h' in *speep*. Another observation is that the misspelled responses to words that contain geminate (double) letters, in all cases but one, contain geminate letters themselves. This sometimes resulted in both correct and incorrect letters being erroneously doubled e.g. The written response to the spoken word "gorilla" was *garra* where the 'l' was not written at all but the correct 'r' appeared as 'rr' and 'ff' appeared twice in *riffaffe*, once correctly and once incorrectly.

Similar observations have been made with other patients by Caramazza and Miceli (1990) and McCloskey, Badecker, Goodman-Schulman and Aliminosa (1994) who argue that these phenomena are evidence that stored spelling representations are not simple linear sequences of letter tokens. They propose instead that graphemic representations are multi-dimensional structures that separately encode letter position, letter identity, letter doubling and consonant/vowel status. What Caramazza and Miceli (1990) and McCloskey, Badecker, Goodman-Schulman and Aliminosa (1994) do not include as a dimension of coding, is the ascender/descender information which is suggested by the responses shown above. Future investigations of this patient's writing may be able to provide enough data so that statistical analysis can provide further evidence on these issues.

Partly to see if the above phenomena are robust and partly to see whether re-training of lexical graphemic output for these items was possible, the experiment was repeated exactly as described above until all thirty words were written correctly in all three conditions for two consecutive trials. This took one trial per week over twelve weeks. Tables 6.5 (copying), 6.6 (writing names of animal pictures) and 6.7 (writing animal names to dictation) show the error responses produced across all twelve trials. Copying (227/260 correct) was significantly better than written naming of animal pictures (193/260 correct, McNemar χ^2 = 18.4, 1 d.f., p<.005) and writing animal names to dictation (191/260 correct, McNemar χ^2 = 14.7, 1 d.f., p<.005). When comparing the mean times for writing all thirty responses in each condition, copying (grand mean, 161.0 sec's) was significantly faster than written naming of animal pictures (266.8 sec's, t [11] = 4.51, P<0.001) and writing animal names to dictation (251.3 sec's, t [11] = 5.62, P <.001).

An examination of the responses shows the vowel substitution, consonant substitution, geminate letter and ascender/descender substitution effects to be replicable. There are three difficulties in showing that these effects are significant however. Firstly, there are not enough responses containing each type of error on which to perform statistical analyses. Secondly, the stimuli were not controlled for variables such as length or the number containing geminate letters. Thirdly, although complete response data were not published by McCloskey, Badecker, Goodman-Schulman and Aliminosa (1994), it appears that the responses of their patient , HE, were less distorted and more complete than those of AN. AN's data therefore make analysis involving interpretation of erroneous letters in relation to their target letters, difficult. The detailed analysis of AN's graphic errors and their relationship to the structure of graphemic output representations remains as work to be done. Nevertheless there are several observations that can be made from the data.

1. The simplest observation is that lexical graphemic output can be still be trained in this patient. In all three conditions, performance clearly improves and does so gradually. 2. Although copying performance is significantly better than writing to dictation or written

incorrectly. Six animal names, "crocodile", "tortoise", "kangaroo", "rhinoceros", "leopard" and "giraffe", generated multiple errors in all three conditions. Two more, "gorilla" and "raccoon", generated multiple errors but only in writing to dictation and written confrontation naming. The names which generate multiple errors happen to be the longest names of the set. 4. Over the twelve trials, no animal names generated errors in copying but not in the other two conditions. 5. Despite considerable consistency in the words which generated errors there was no consistency in the errors themselves. No word generated the same error every time. 6. Once a name had been written correctly in a particular condition, it did not guarantee that it would not be written incorrectly again either within the same condition or in the other conditions. 7. The point has already been made that errors involving erroneous geminate letters were usually produced in response to target words containing geminate letters. Several responses would seem to suggest that this is not the case. Consider *crodollo* and *rnillo* from Table 6.7. Neither of their target words contain geminate letters. However, other responses to "crocodile" and 'rhinoceros" suggest how target words without geminate letters could generate responses with geminate letters. To take two examples, 'crocodile' also generated *golligar* when presented for confrontation naming and 'rhinoceros' also generated *rhinoppo* when presented for copying. If it was assumed, as seems reasonable, that the semantic system can influence graphic output, then *golligar* might be expected because the graphic response generated by 'crocodile' is being influenced by the graphic response erroneously generated by 'alligator'. Similarly, *rhinoppo* might be expected because the graphic response to 'rhinoceros' is being influenced by the graphic response to 'hippopotamus'. By the same argument , *crodollo* and *rnillo* might be expected too, the difference being that in the latter two responses, the influence of 'alligator' and 'hippopotamus' includes the coding of geminate letters. In Chapter five it was stated that the operations of the various routes to writing are not considered to be mutually exclusive and the explanation offered for these 'compound' errors is evidence that routes can interact, at least at the level of lexical output. Examples like *rnillo* also show that this interaction can be between different 'levels' of code, ie the word level response to rhinoceros and the geminate letter code of 'll' from alligator.

Summary and Comparison with Similar Patients.

AN's peripheral writing processes appear to be normal. Like AM, the words she writes successfully, she does so fluently in cursive script and her ability to write a particular item depends upon whether it is familiar as a whole, and partly on what meaning it has. AN's writing impairments are therefore interpreted as being of central origin. Also like AM, she has a severe impairment in writing nonwords. Her writing of nonwords (7/114 correct) is significantly worse than her writing of words (125/254 correct; $\chi^2 = 61.80$, 1 d.f., $p<.001$). Her ability to repeat the dictated nonwords after failing to write them shows that her nonword writing impairment is not due to problems in auditory perception or phonic short-term memory. It is thus concluded that AN has a deficit in converting phonemes in unfamiliar combinations into appropriate written output (routes 1a - 1d in Fig. 5.1). She could thus be described as a phonological dysgraphic. She could also be described as a lexical writer in the sense that what she writes successfully are nearly always familiar words, and in that lexical variables determine her success. The frequent neologisms in the writing of animal names show that she is not a lexical writer in the sense of writing only lexical items, however.

Of 13 cases previously described as phonological agraphics (Alexander et al, 1992), nine had spelling impairments for words as well as for nonwords, and these were severe in seven cases . In most cases it was the writing of function and other abstract words that was impaired. Six of the 13 cases were conduction aphasics and at least one was anomic. Reading was impaired in 11 of these other cases. At least 5 were phonological dyslexics. In all of these respects AN and AM are 'typical' members of this cluster of patients. As well as these qualitative similarities, AN's and AM's performances in writing to dictation are quantitatively similar to each other. AN wrote 49.2% of words and 6.1% of nonwords correctly whilst AM wrote 68.1% and 7.0% respectively.

6.2. Lexical Direct Route for Writing to Dictation?

The question addressed in this section is whether there is evidence in these patients for a lexical but non-semantic contribution (lexical direct route) to writing to dictation. To do this, two classes of stimuli were used for which semantics may make little or no contribution in the test conditions used. The first is nonwords with which the subject has become familiar but to which no particular meaning has been given. The second is function words, which may evoke little or no semantic mediation when presented in isolation (Saffran et al, 1980; Patterson, 1982; Jones, 1985; Plaut & Shallice, 1993).

6.2.1. Writing to Dictation of Familiar and Unfamiliar Nonwords: AN.

In Section 4.3.1, a study was made of AN's ability to learn to read thirty nonwords selected from Glushko’s 1979 corpus. These items, which are being referred to as familiar nonwords, were divided into two sub-sets of fifteen. In one sub-set the words were printed on the cards below the pictures of novel objects, and were treated as names for those objects. In the other sub-set (the non-semantic condition) the cards were blank except for the nonword being learned. AN's reading of the nonwords improved significantly in both conditions. The non-semantic condition was also run with AM who showed a significant improvement in reading these apparently meaningless items. In the following experiments, except where indicated, the "familiar nonwords" used to test these patients' writing were those from the non-semantic condition.

Both of these patients are severely impaired at writing nonwords to dictation. Whether they could learn to write nonwords to dictation, as they had learned to read them, was unknown. It was initially supposed that training in writing the familiar nonwords would be necessary for them to be written to dictation better than unfamiliar nonwords. The experiment reported here shows this not to be necessary. It shows that the reading training alone can establish such an advantage, and with AN, can do so after a long delay. With AN this experiment was performed after a gap of more than one month in testing sessions.

As well as the fifteen familiar non-semantic nonwords, the experiment used thirteen matched nonwords formed from them by rearranging their components to form novel but pronounceable nonwords of the same length and made of the same letters (the other two familiar nonwords could not be rearranged so as to produce pronounceable nonwords that were not pseudohomophones of real words).

This experiment was run as the first test of the session. To settle AN into the task, four simple concrete words were dictated one at a time and she wrote them without error. She was then asked to perform the same task with the fifteen familiar nonwords. AN wrote 15/15 of the nonwords without difficulty, to her own mild surprise and to the astonishment of the experimenter, because she cannot write novel nonwords of this length at all. This was confirmed by then asking her to write the thirteen matched novel nonwords to dictation. None were written correctly. Her writing of the familiar nonwords is reproduced in Fig. 6.1 and her attempt at the matched novel nonwords is shown in Fig. 6.2. The large advantage for familiar nonwords is clear evidence for a major lexical component in her writing to dictation.

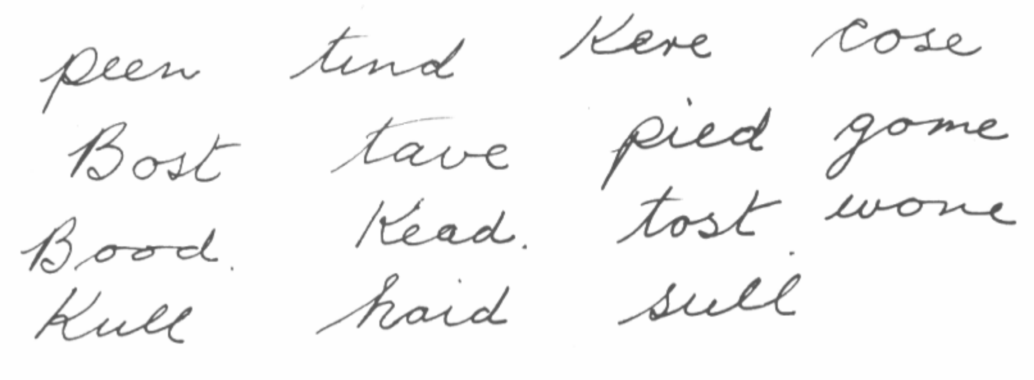

FIG. 6.1. AN's Fluent Writing to Dictation of Familiar Nonwords at the First Attempt. All are Spelled Correctly.

Four points become relevant in the context of this result. 1. AN was asked whether she had tried writing the familiar nonwords at any time prior to this test. She said that she had not, and indeed writes very little at all. 2. She had not seen the nonwords for at least a month before writing them. 3. Although her reading of these nonwords has improved it is still not perfect, being at approximately 60%. 4. Her writing to dictation of function words is much lower than 100%.

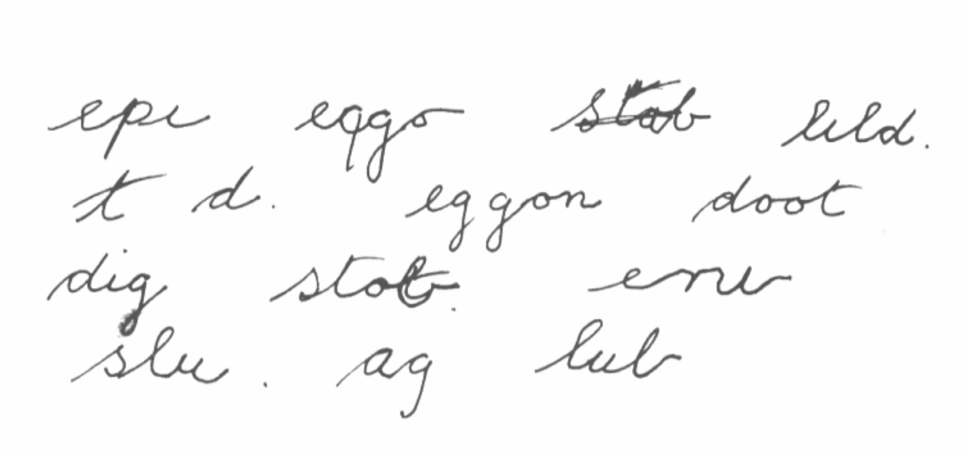

FIG. 6.2. AN's First Attempt at Writing to Dictation Thirteen Novel Nonwords made from those Shown in FIG. 6.1. The Nonwords used were: *epen; ecos; stob; vate; dilp; egom; doob; dake; stot; ewon; lulk; ahid* and *luls* in that Order. AN's Attempts at Writing these are Shown in Left to Right Order.

6.2.2. Writing to Dictation of Familiar and Unfamiliar Nonwords: AM.

The procedure and materials for this test were similar to those used with AN but with two minor differences. Firstly, AM was asked to write the fifteen nonwords to dictation before they became familiar i.e. prior to the commencement of the reading training, in order to obtain a baseline measure of performance. Secondly, this testing session took place three days after the completion of the reading training reported in section 4.3.4.

Prior to reading training, AM wrote 6/15 acceptable transcriptions[20] of the nonwords on which he was about to receive training. After reading training, he wrote 15/15 correctly at the first attempt, the difference being significant (McNemar $\chi^2 = 7.1$, 1 d.f., $p<.01$). This is in contrast to his attempts to write the matched novel nonwords to dictation for which he produced only 1/13 appropriate spellings. His writing of the familiar nonwords and his attempt at the matched novel nonwords is shown in Fig. 6.3. As with AN, the large advantage for familiar nonwords is clear evidence for a major lexical component in his writing to dictation. This is further supported by the fact that before reading training, four nonwords received spellings which, although appropriate, were different to those that he would see during taining. After training these nonwords all received the spellings which the patient had seen on the card during training.

Fluent lexical writing without practice is a surprising phenomenon within the context of theories assuming that access to a graphemic output lexicon depends upon previously learned associations between input addresses and their corresponding output addresses. This result will therefore be considered in more detail in the general discussion.

6.2.3. The *A Priori* Probabilities of the Spellings used for the Familiar Nonwords.

To determine whether the pronunciations used for the familiar nonwords are by themselves sufficient to specify their spellings, they were read to ten co-workers for writing to dictation. None of them had been shown the written forms of the nonwords. The nonwords were dictated as for AN and AM except that the subjects were told to write two versions of each nonword if they could, the first being the "most likely". None of the nonwords received the same spellings from every subject. The probabilities of obtaining the target spellings are given in Table 6.8.

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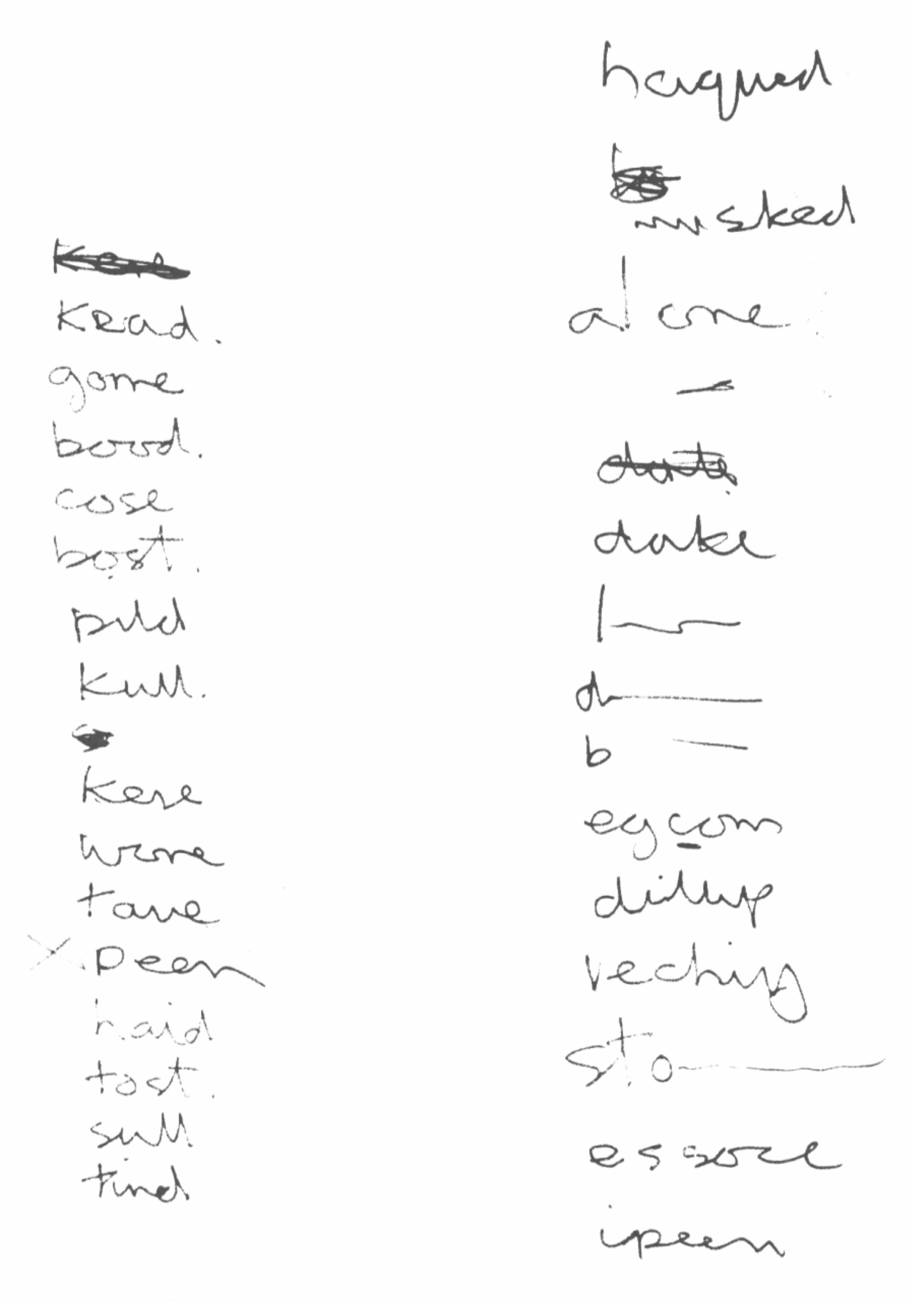
[20] Two received the spelling used by Glushko (*bost* and *sull*). Four received spellings different from those used by Glushko but appropriate nevertheless (Glushko's spellings are shown first: *kead - keed*; *kull - cull*; *peen - pean*; *tind - tinned*). This level of performance (40.0%) is surprisingly high and is considerably higher than his performance (10%) on similar nonwords from the background tests. The reasons for this are not clear.



Familiar Nonwords Novel Matched Nonwords

FIG. 6.3. AM's Fluent Writing to Dictation of Familiar Nonwords at the First Attempt. All are Spelled Correctly. Also shown is AM's First Attempt at Writing to Dictation Thirteen Novel Nonwords made from the Familiar Nonwords: *ahid; luls; ewon; dake; lulk; doob; stot; egom; dilp; vate; stob; ecos* and *epen*, in that Order from Top to Bottom.

TABLE 6.8
The Proportions of Ten Subjects who Wrote to Dictation the Spelling used with AN and AM as the Most Likely or Next Most Likely.

Target Nonword	Probability of Target Spelling	
	Most Likely	Next Most Likely
kead	.0	.1
bood	.6	.3
cose	.6	.2
bost	.4	.6
pild	.2	.5
kull	.1	.7
kere	.0	.1
wone	.2	.5
tave	.9	.1
peen	.5	.4
haid	.6	.2
tost	.7	.3
sull	.8	.2
tind	.3	.6
gome	.8	.2

The cumulative probability of obtaining the target spelling for all fifteen nonwords given their pronunciation alone is very low, even if both first and second choices are allowed. The patients' visual experience of these specific items must have played a crucial role in their written production of them to dictation. This is therefore further strong evidence for a major lexical component in their writing of these familiar nonwords.

6.2.4. The Semantic Associations Evoked when Writing to Dictation: AN.

This test was designed to see what semantic information, if any, is evoked by concrete nouns, function words, and familiar nonwords during writing to dictation. It used five concrete nouns (*lemonade, gift, ambulance, hand, cigar*): five function words (*since, while, often, quite, them*); five familiar nonwords that had been used to name novel objects (*heaf, wush, pook, pove, mear*); and five familiar nonwords to which no particular meaning had been given (*bood, tind, pild, peen, gome*). The version of this test just described was used with AN and an altered version used with AM.

AN was given the following instructions. "I am going to say some single items to you, one at a time. After I have spoken each one to you I want you to write it down but I also want you to tell me what it means. Anything that it brings to mind. It doesn’t matter what it is. Take as long as you like. I just want you to say anything that comes into your head, anything at all". The order of presentation was randomised.

AN wrote 5/5 concrete words correctly and provided clear evidence of available semantic information for all of them (e.g. *lemonade* - "Clear, a bottle, drinking and sweet "; *gift* - "Christmas. At holidays and giving"). She wrote 3/5 function words correctly but could not provide any semantic associations for any of them (*Often* - "That's a word but er, I don't know. Other things make it a word. It's not on it's own."; *Since*- "Oh God. Aye, well, it's a word but.......it's very hard. Since? It doesnae really have a meaning. Er, er, not a proper meaning. In fact you cannae really call it a word"). She wrote 5/5 of the nonwords that had been used to name novel objects, and gave clear evidence of having available the definitions that she had created herself for each nonword and it's associated nonsense picture (e.g. *heaf* - "Heaf. Oh it's a word, crushing, pressing and fruit or er everything. Chemicals? No, not that”; *mear* - "It's a brass er, er, er, toot, toot instrument"). She wrote 5/5 of the familiar nonwords to which no meaning had been given. She could not report any meaning that may have become associated with any of these nonwords (e.g. *pild* - "Na, na, na. Doesn't mean anything. I know the word" ; *gome*- "Gome, gome, er it doesn't mean anything. It's a word but it disnae mean....am I right or am I wrong"?

6.2.5. The Semantic Associations Evoked when Writing to Dictation: AM.

This test used ten concrete nouns, ten of the fifteen familiar nonwords and ten function words, all presented in random order. The procedure and instructions were identical to those used with AN.

AM wrote correctly 10/10 of the concrete nouns, 9/10 of the familiar nonwords and 6/10 of the function words. All of the concrete nouns evoked appropriate associations which were in all cases, reported before AM wrote a transcription. In contrast, the nine familiar nonwords, which apparently evoked no associations that AM could report, were all written fluently in cursive script before AM made any attempt to report any meanings the nonwords had for him. Typically, after writing each of the familiar nonwords, AM would say "There's nothing really. No. They're just er....junk.....but not like some things that aren't words. Nothing. I just write it". All of the six function words written correctly were treated in a similar way. They were written fluently before any attempt was made to report any meaning and only one word was reported to have done so (*before* - "Before. In front of ....not exactly. Definitely not after"). A typical response to the other five was "These are bad. Er, I couldn't say...not really a meaning word". Of the four function words that AM could not write successfully, two were given vague meanings (*them* - "Them. More than....er, maybe not just one"; *since* - "Difficult but ..... Why I can't work.....from then").

The performances of both patients support the view that concrete nouns and familiar nonwords given meanings evoke semantic activity that could support the writing of those words when they are presented in isolation, and that function words and familiar nonwords given no particular meanings do not.

6.2.6. Writing to Dictation of Function Words and Matched Nonwords.

One explanation for the difficulty of AN and AM in writing function words is that such words cannot be mediated by semantics when presented in isolation. The tests for semantic associations support this hypothesis. One inference from this is that function words normally depend upon a lexical direct route for processing and this route is only partially working in both of these patients. However, as no specific tests for a lexical contribution to writing function words have been made, the following experiment was designed to look for a lexical advantage in writing function words over matched novel nonwords. If no evidence for a lexical advantage was found it would suggest that all other lexical effects are due to semantic mediation and would weaken the view that a lexical direct route exists and is operating. If there is a lexical contribution, however, it would provide evidence for processes that are lexical but non-semantic.

The test compared AN's writing to dictation of function words and of novel nonwords. Twenty function words were selected such that there were equal numbers of two, three, four and five-letter words. The letters of each word were re-ordered to create novel but pronounceable nonwords (e.g. from the word *though* the nonword *hought* was created). The forty stimuli were randomly presented for writing to dictation without time constraint. AN correctly wrote 11/20 of the function words and 1/20 of nonwords, the difference being significant ($\chi^2 = 9.07$, 1 d.f., $p<.005$). This shows that there is a large lexical contribution to AN's writing of function words.

6.2.7. Discussion.

These studies provide evidence that the writing to dictation of function words and of familiar nonwords can be lexical but not mediated by meaning and that it can be fluent without practice. We can be confident that the writing is lexical because it depends upon knowledge of particular words and nonwords. Although the evidence suggests that it is the case, we cannot be sure that there is no semantic mediation because implicit access to some associated meaning is always possible. The test items were chosen to reduce the opportunity for any such mediation, however. The results of the semantic association test support the assumption that concrete nouns and familiar nonwords given concrete meanings, evoke semantic associations when presented one at a time, and that function words and familiar nonwords given no particular meanings do not.

Within the framework of models such as that of Patterson (1986) these results are evidence for a lexical direct route from phonology to the orthographic output lexicon (routes 2a and 2b in Fig. 5.1). This route could be either direct from the auditory input lexicon or via the phonological output lexicon.

6.3. Lexical Direct Route for Copying?

The question addressed in this section is whether there is evidence for a lexical but non-semantic contribution to copying from memory. Experiments of both immediate and delayed copying from memory are studied. The tests again use familiar nonwords and function words on the assumption that they evoke little or no semantic mediation. None of these tests were performed with AM.

6.3.1. Copying Familiar and Matched Nonwords.

During a testing session two days after that on which her writing to dictation of the familiar nonwords was tested, AN’s immediate and delayed copying of the same stimuli were tested and compared with her copying of matched nonwords. The matched nonwords were those used in the above test of writing to dictation (section 6.2.1), so they were not wholly novel to her. Each stimulus was printed on a separate card in lower case. AN was told that each stimulus would be displayed for two seconds and that she was not to read it but to write it as soon as the experimenter said “OK” after it was removed from view. The immediate copying condition was run first, and the order of presentation was randomised within conditions. AN correctly copied 15/15 of the familiar nonwords and 7/13 of the matched nonwords, the difference being significant ($\chi^2 = 8.34$, 1 d.f., $p<.005$). When a five second delay was introduced between removal of the word and the experimenter saying “OK” the scores were 15/15, and 5/13 respectively.

These results show that there is a major lexical contribution to the copying from memory of familiar nonwords that have been given no particular meaning. However, the familiar nonwords are ones that AN had learned to read and whose pronunciations she had therefore previously heard and spoken frequently. In terms of the model in Fig. 5.1, her improved reading of these stimuli was interpreted as evidence for a lexical direct route from print to sound that operates via activation of visual input and phonological output representations. Consequently, although this test demonstrates a lexical contribution to copying, it cannot be claimed that the lexical influence is restricted to the orthographic domain i.e. output from the visual input lexicon and the phonological output lexicon may be combining to generate written output. However, it is unlikely that this phonic lexical knowledge plays a crucial role in AN's copying of these items because she cannot read them aloud as well as she can copy them. Nevertheless, it is necessary to eliminate as far as possible, the phonological output lexicon as the source of lexical effects on copying from memory. To do this, the effects of training on copying alone, unaccompanied by any phonic input or output, were investigated. This investigation was also designed to provide more information on exactly what it is that the patient learns about a letter-string when it becomes familiar.

6.3.2. Learning to Copy Nonwords Without Hearing their Pronunciations.

Twelve six-letter nonwords were constructed by randomly combining twenty-four of Coltheart's three-letter nonwords. From these twelve, six were randomly selected on which AN would receive training in copying but not in reading. To study more precisely what had been learned, AN's copying of these words after training was compared with her copying of two sets of novel nonwords. The first was the set of six not used for training from the original set of twelve. The second was made by re-combining the first and second three-letter groups of the nonwords on which she was trained to form new nonwords such that the three-letter syllables maintained their position relative to the string as a whole e.g. the familiar nonwords *munsed* and *bonize* became the novel nonwords *munize* and *bonsed*. If the writing of independent but position specific parts is being learned then performance on this second set of novel nonwords should be equivalent to that on the familiar nonwords.

To ensure that AN's subsequent writing of these stimuli was not supported by output phonological processes, the six nonwords selected for copying training were hand-written on cards and presented to AN for reading. She failed to read any aloud correctly. The cards were then repeatedly presented to AN until she could copy them all correctly immediately from memory. This took between 15 and 20 trials. The test phase involved the random presentation of all eighteen nonwords, one at a time, printed in lower case on cards, for five seconds each followed by immediate copying from memory. AN correctly copied 6/6 of the familiar nonwords but only 1/6 of each of the two sets of novel nonwords. The familiar nonwords were copied significantly better than the novel nonwords ($\chi^2 = 7.9$, 1 d.f., $p<.005$). Finally, all eighteen nonwords were randomly presented for reading and AN read 0/18 correctly.

These results provide further evidence that the copying of familiar nonwords given no particular meaning can be lexical. They also shows that acquisition of the lexical knowledge is gradual, and that hearing and speaking the words is not necessary to the acquisition of this graphemic lexical knowledge. Finally, the results show that it is the spelling of the word as a whole that is being learned, and not the spelling of its independent but position specific parts.

6.3.3. Copying Function Words and Matched Nonwords.

To test for a lexical contribution to her copying from memory of function words, it was compared with her copying of unfamiliar nonwords of equal length. This test used the same twenty function words and matched novel nonwords from section 6.2.6 (e.g. from the word *though* the nonword *hought* was created). These stimuli were displayed one at a time in random order for five seconds each, and AN was instructed to copy them immediately upon their removal. AN's copying of the function words at 18/20 correct was significantly better than her copying of the nonwords at 11/20 correct ($\chi^2 = 4.5$, 1 d.f., $p<.05$). This test was repeated during a later session but with a ten second delay being introduced between the removal of the stimulus from view and the commencement of copying. AN then copied 19/20 of the function words correctly but only 5/20 of the matched nonwords. The lexical advantage in copying from memory therefore increases with delay. This can be clearly seen in the difference between the top and bottom plots of Fig. 6.4. What the plots also show is that there is a length effect and that the lexical advantage for function words exists at all the letter-string lengths tested.

6.3.4. Copying, Reading and Writing Function Words to Dictation.

Finally, AN's copying from memory of function words was compared with her reading and writing to dictation of them. AN has no difficulty in recognising and repeating function words that are spoken to her. Thus if the lexical advantage in copying function words from memory were due to mediation from either or both of the phonological lexicons then reading and writing to dictation should be as good as copying. Furthermore, other than for

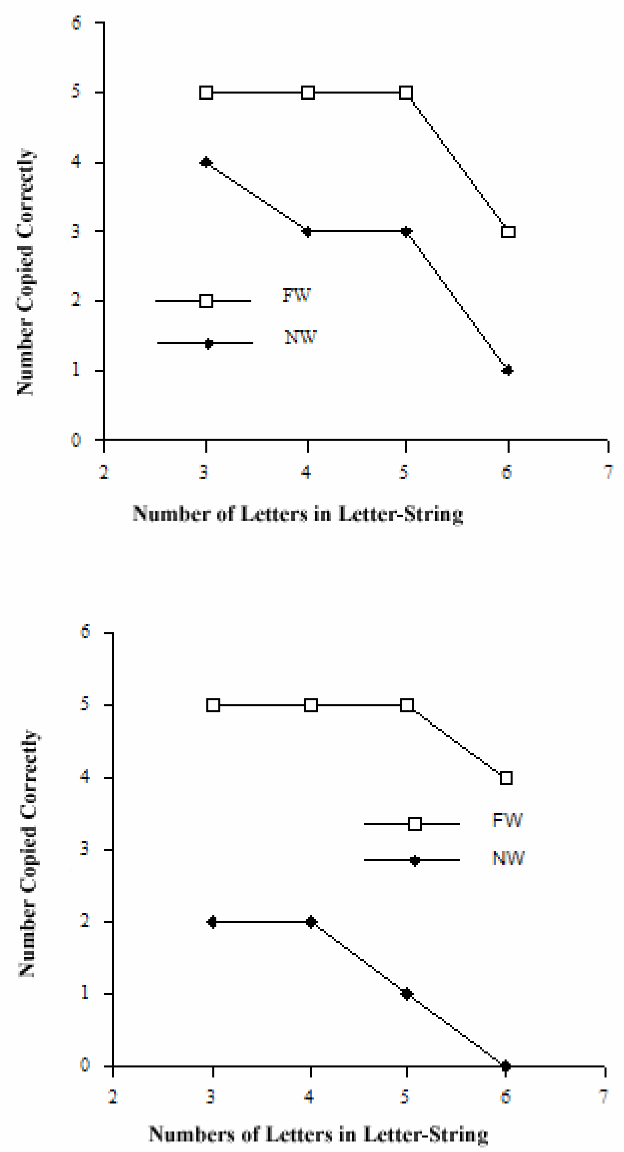


FIG. 6.4. The Plots Show AN's Performances at Copying Four Different Lengths of Function Words and Nonwords made from them. The Top Plot is for Copying Immediately after the Stimuli were removed from Display. The Bottom Plot is for Copying Delayed for Ten Seconds After Stimulus Removal.

her STM impairment, there is no evidence for deficits in auditory comprehension in this patient. She certainly understands spoken speech much better than printed text. Thus if the lexical component of function word copying is due to semantic mediation then writing to dictation should be at least as good as copying.

Thirty function words were used, and each was used in three tasks; 1) The word was printed in lower case on a white card and displayed for five seconds for immediate copying from memory. 2) The word was displayed on the same card for a maximum of five seconds for reading aloud. 3) The word was read aloud to the subject for immediate writing to dictation. The order of the stimuli and the task to be performed were randomised across trials. AN's copying, 26/30, was significantly better than her reading aloud, 9/30, (Mc Nemar χ^2 = 11.5, 1 d.f., p<.005), and than her writing to dictation, 6/30, (McNemar χ^2 = 15.0, 1 d.f., p<.005). These results are evidence that her function word copying is not mediated by any combination of meaning and the speech output lexicon, because if it were then it were then reading and writing to dictation should be at least as good as copying. Instead they are much worse.

6.3.5. Discussion.

These results are evidence that copying function words and familiar nonwords from memory can be lexical but not mediated by meaning. We can be confident that the writing is lexical because familiar items are copied much more accurately than unfamiliar combinations of the same letters. Furthermore, what is learned is the spelling of the familiar nonword as a whole. The lexical effects do not generalise to novel stimuli that maintain the same parts in the same position relative to the string as a whole, but in different combinations. Grounds for assuming that semantic mediation does not play a crucial role for these stimuli have been presented above. The poor writing to dictation of the function words together with the evidence for normal auditory comprehension is further evidence that semantic mediation can contribute little to the copying of these words. Within the framework of models such as that of Patterson and (1986) these results are therefore evidence for a lexical direct route from the orthographic input lexicon to the orthographic output lexicon (route 5 in Fig. 5.1).

6.4. General Discussion of Routes to Written Output.

This discussion will deal with AN's and AM's writing performances and the implications for the main issue of the nature of the functional organisation of routes from phonology to writing and print to writing.

6.4.1. Lexical but Non-Semantic Processes in Writing to Dictation and Copying from Memory.

AN can write to dictation and copy, function words and familiar nonwords given no particular meaning, much better than she can write novel nonwords of comparable complexity. AM shows the same advantage for familiar nonwords over matched nonwords in writing to dictation. Furthermore, both patients write the familiar nonwords correctly using spellings that are of low *a priori* probability. The results clearly show that writing to dictation and copying from memory both depend upon lexical processes.

To what extent are these large lexical effects mediated via meaning? Consider first the familiar nonwords. They differ from English words in that they have no conventional meanings that govern their occurrence, and thus their meanings for individual subjects. They may acquire associations which could confer some kind of meaning upon them, nevertheless. One possibility is that the nonwords could acquire meaning through an association with the testing situation. Both patients, but particularly AN, have encountered a few hundred nonwords over the course of these and previous investigations and have been trained on more than fifty. It seems reasonable to assume that these nonwords would all share the same associations with the general testing situation and any individual nonword would thus have no meaning to distinguish it from any other nonword encountered in the same situation. Thus, if AN's and AM's writing of familiar nonwords were mediated by general associations with the testing situation it would be highly inaccurate and show confusions between the various familiar nonwords. Instead, they can write these nonwords accurately, and errors of the kind predicted have never been observed. Another possibility is that all nonwords somehow evoke meanings for subjects, e.g. through similarities to meaningful words. The semantic association test shows no sign of this being the case so it would be necessary to assume that any such associations are implicit. Furthermore they would also have to be reliable and distinctive. Finally, any such implicitly evoked meanings would then have to select the nonword spellings for graphemic output, rather than the spellings of the familiar real words usually used to express any such meanings. Although none of these can be definitely ruled out they do not seem plausible.

Consider now the function words. Both patients read and write them much worse than they do concrete content words. This may be because when presented in isolation from any sentential context they are not well mediated by meaning. This is supported by the study of the semantic associations that they evoke. Both patients understand function words in normal speech well, and better than in text. They can repeat them, and use them in their own productive speech, though with some anomic difficulties. AN can copy them, with or without a delay, much better than she can either read them aloud or write them to dictation. If her copying of function words were mediated by any combination of meaning and a speech output lexicon then writing to dictation would be at least as good as copying. Instead it is much worse.

Finally, consider AN's writing of animal names. She copied them significantly more accurately and significantly faster than she wrote them to confrontation. If copying relied upon semantic mediation it is difficult to explain why her writing of animal names to confrontation is significantly worse than her copying of them. This is at least evidence for a large non-semantic contribution to her immediate copying of concrete nouns from memory. It is not by itself however, evidence for a *lexical* non-semantic contribution because it is unknown whether these animal names were copied via a sub-lexical route i.e. route 4 in Fig. 5.1. However, results reported later suggest that this is unlikely. AN was shown to be very poor at copying six-letter nonwords (2/12) unless she was trained to do so and even when the items for copying were displayed for five seconds rather that the one second used in the animal name experiment. If animal names were to be processed sub-lexically i.e. treated as nonwords, AN would be predicted to perform much worse than she did (23/30).

Hillis & Caramazza (1991) proposed that there are only sub-lexical processes and lexical processes that are semantic. The above results are evidence that these two processes contribute little or nothing when AN writes function words, familiar nonwords and animal names, and yet she can write them accurately. Similarly, AM can write to dictation accurately familiar nonwords to which semantic and sub-lexical processes can contribute little. Furthermore, the absence of any effect of regularity shows that these patients writing of familiar items does not usually depend upon a contribution from sub-lexical processes. It is therefore concluded that these results are evidence for lexical but non-semantic processes in both writing to dictation and in copying from memory.

6.4.2. Lexical Direct Routes to the Orthographic Output Lexicon from Phonology and from the Orthographic Input Lexicon?

Evidence for lexical but non-semantic processes are not *necessarily* evidence for lexical direct routes. This is because it is not immediately clear at which stage or stages of processing the lexical effects occur. Consider first the task of writing to dictation. It is possible that the lexical but non-semantic effects occur only after the auditory input has been translated into some form of graphemic code by sub-lexical processes. Thus sub-lexical translation could provide part of the spelling, and lexical processes within the graphemic domain could then supply the rest. To allow for such a possibility the model in Fig. 5.1 might be amended to allow access to the orthographic output lexicon from the graphemic output buffer. However, it is unlikely that such an explanation can account for the lexical effects observed above for at least two reasons. Firstly, the processes of sub-lexical translation from phonology to writing are very impaired and unreliable for both patients. Secondly, the spellings used for the familiar nonwords are of low *a priori* probability and would therefore conflict with many of the spellings produced by sub-lexical processes. If it was assumed that information within a graphemic lexicon or lexicons can be accessed by sub-lexical auditory processes, then this will require substantial reinterpretation of the functional role and computational requirements of such lexicons.

Consider now the lexical but non-semantic processes in copying from memory. Instead of explaining the results in terms of a lexical direct route from the input to the output lexicon we could consider the possibility of access to an orthographic output lexicon via sub-lexical access to the graphemic output buffer. This line of thought implies changes to theories such as that of (Patterson, 1986) that are radical and interesting, but which seem much less plausible than a lexical direct route from the input to the output lexicon. Another possibility might be to propose a direct output from the orthographic input lexicon to the graphemic output buffer, but this would tend to make the orthographic output lexicon seem unnecessary. This issue will be returned to in the final part of this discussion where the implications of fluent lexical writing without practice will be considered.

6.4.3. Lexical versus Sub-Lexical Levels.

Shallice (1988) proposes a multi-level word-form version of writing to dictation that is analogous to that proposed by Shallice & McCarthy (1985) for reading. This account distinguishes between multiple levels of a direct route from the phonological output word-form system to the graphemic output word-form system, but suggests that impairments to these different levels do not show a double dissociation. AN and AM provide evidence on this in that they can learn to write familiar nonwords as wholes, but cannot write novel nonwords formed by re-combining parts of words that they can write. The experiment in which AN learned to copy nonwords without hearing or speaking them also showed that learning to copy bi-syllabic nonwords did not improve her copying of novel nonwords composed of the syllables in new combinations, even when they maintained their position in the string as a whole. This very specific comparison is therefore evidence for better preservation of lexical levels than of sub-lexical levels in this patient. Together with phonic writers who show the reverse form of selective preservation this supports the view that the different levels can doubly dissociate.

Campbell (1983) proposed an analogy theory of writing nonwords to dictation that was a mirror image of the analogy theories of reading (e.g. Marcel, 1980). The above findings would provide difficulties for this proposal too. Accurate writing of familiar nonwords accompanied by failure to write novel combinations of the parts would not easily be explained.

6.4.4. AN and AM's Sub-Lexical Deficits.

AN and AM, along with at least five other phonological agraphics, are also phonological dyslexics. Both patients seem to have a general impairment in sub-lexical processing which includes a difficulty in dealing with novel combinations of familiar word parts. In AN, this is consistent with her moderate deficit in phonic assembly and in verbal digit span. Although phonic assembly has not been tested in AM he is known to have a reduced verbal digit span. Whether all these impairments arise from a common cause or a coincidental association is not known. It is known that not all patients show this pattern of association, but that does not settle the issue because the extent of individual variability in this aspect of cognitive organisation is not known.

6.4.5. Fluent Lexical Writing without Practice.

The fluent writing to dictation of nonwords (that have never been written before) by phonological dysgraphics is a finding surprising to both patients and experimenter! Though probably not counter-intuitive, it is counter-theoretical. It raises questions that invite new theoretical solutions. There is a simple methodological point here which is that this finding was made possible by the use of familiar nonwords. It is hard to see how it could have been made using either words or novel nonwords. In fact, the difficulties encountered in testing whether a single lexical item can be more than one letter-string (section 4.5), arose precisely because the stimuli were real words in the language. The consequent problems would not have arisen had familiar nonwords been used. The advantage gained by using this technique is that the nature and frequency of a patient's experience of a letter-string can be controlled. The 'pseudosemantic' condition particularly, might be a useful tool in investigating the organisation of the semantic system. Furthermore, the training component of the familiar nonword paradigm may have useful implications for rehabilitation. This technique may therefore merit wider use.

The next point to be made is that the familiar nonwords used in the tests of writing to dictation of items that had never been written before, were ones that the patients had been learning to read aloud over a period of a few weeks. They had therefore already heard and spoken them more than twenty times. We know that the visual aspects of the training are crucial because spellings with low *a priori* probability were used, but the results reported here do not tell us whether the phonological aspects are also crucial or not. Further studies, to be reported in the next section, show that they are not.

Interpretation of these results depends upon whether the graphemic input and output lexicons are thought to be identical or not. If they are identical then the result may be expected because learning to read specific items at a lexical level would also entail learning to write them at a lexical level. Although the idea of a common input and output lexicon may be seen as being strengthened by the above results it still faces substantial problems. These include accounting for results such as those of Hillis & Caramazza (1991) in which a patient showed a word class deficit that was specific to output. Furthermore, if a lexicon must be usable for both recognising visual input and for generating graphic output from a wide variety of visual and non-visual inputs then a greater burden is placed upon any process theory that attempts to show how this is possible.

The possibility that input and output lexicons are distinct must therefore still be taken seriously. If they are, then fluent lexical output without any practice in writing the specific words concerned suggests that the output lexicon can acquire knowledge without producing any overt output. This raises the question as to how it acquires knowledge of the spelling patterns to be produced in any case. In the model of Patterson (1986), and in many others also, the inputs that the orthographic output lexicon receives are all just addresses that select the appropriate spelling pattern. No route is shown that can tell the output lexicon what that spelling pattern should be. This suggests that either additional routes must be added to provide this training information, or the information received from the orthographic input lexicon must specify something about the internal structure of the items concerned, rather than being just an arbitrary address. Both of these possibilities lead to radical changes in the general framework proposed by such models.

The point was made above that the familiar nonword paradigm shows the visual aspects of training to be crucial because nonword spellings with low *a priori* probabilities were used and yet those specific spellings were written to dictation. What this result does not tell us is whether the phonological aspects are also crucial. In other words, it is not known whether the formation of a graphemic output lexicon representation depends upon both seeing and saying the nonword repeatedly or whether visual processing alone is adequate. The following experiments show that phonological processing is not necessary.

They demonstrate that after visual discrimination training using novel nonwords, both patients can write those specific nonwords to dictation at the first attempt, even though they have never heard or written them before. This result raises two major types of question. Firstly, are those to do with "routes" and communication beween lexicons e.g. By what route or routes does this visual experience train the orthographic output lexicon? Even more generally are questions about what extra-lexicon activity can be generated by the internal activity of any single lexicon. It also raises the question of how lexical graphemic output is accessed by a nonword that has never been heard before. Secondly, there are 'coding issues' about the nature of the communication between lexicons. This result suggests that if a fluent, lexical graphemic output code can be trained by a lexical visual input code, then the visual knowledge acquired must preserve information about the essential inner structure of the word-forms through all stages of transmission from input to output. It must also be accessible for matching with structured patterns of phonic activity.

6.5. The Roles of Visual and Phonological Experience in Creating Lexical Orthographic Representations.

In the familiar nonword paradigm the patients both heard and saw the nonwords that they later wrote to dictation, during training. By giving the subjects controlled experience of a new set of nonwords it was possible to separate the effects of these two different processes.

6.5.1. Lexical Writing to Dictation of Nonwords Never Before Heard or Written.

The question addressed here is whether visual experience alone of a previously novel letter-string can support lexical writing to dictation. Both patients took part in the following experiment but were tested separately.

Method.

The method chosen for this experiment was one that required the patient to become visually familiar with each specific nonword but which at the same time required no phonological processing. To achieve this the patient was given a visual discrimination/matching task using five newly constructed, and therefore novel nonwords. The patient was told only that their word recognition abilities were being studied. Neither they nor the experimenter at any time during training spoke or wrote the nonwords being used. To further distinguish lexical from sub-lexical writing, nonwords with ambiguous spellings were used i.e. nonwords that could legitimately be spelled in more then one way. The five nonwords used for the discrimination/matching task were; *veaj*, *lubb*, *keke*, *poph* and *weck*. These nonwords, which will be referred to as 'familiar nonwords' from now on, were each printed in one hundred and twenty point size, in different fonts on one A4 sheet of paper, and also printed individually on separate white cards. The sheet was placed in front of the patient who was asked to read each nonword. They were then shown each card (in the order that the nonwords appear above) and asked to point to the matching nonword on the sheet. After two consecutive runs through all five cards without error (AM only required two runs through the cards, AN required four), four one-letter variations of each nonword (one at each letter position e.g. *weaj*, *voaj*, *veoj*, *veak*) were added to the pack making twenty-five cards in total. The patient was again shown each card in turn and this time asked to say whether the nonword on the card appeared on the sheet or not. After all the cards had been shown once they were shuffled and the task was repeated until no errors were made to any of the twenty-five nonwords in a single trial (AM required three trials and AN five). For the final stage the A4 sheet was removed from view and the patient was shown each of the nonwords on the cards and asked to say whether what they were being shown was the target nonword or not. This was repeated until two consecutive error free trials occurred (both AN and AM only required two trials). After about a five minute break the patient was told that the experimenter would read some words aloud for them to write down. The five familiar nonwords were read in random order for writing to dictation. Immediately afterwards, five novel nonwords made from the familiar nonwords by re-combining their letters, were dictated for writing in the following order; *avej*, *ulbb*, *ekek*, *phop* and *kwec*. At the writing to dictation stage no explicit reference was made to the training procedure. The patient was simply asked to write down the words spoken to them. Finally, the patient was asked to try again to read the familiar nonwords on the sheet.

Results.

The familiar nonwords were all written fluently, without hesitation and in cursive script, by both patients at the first attempt. AM expressed surprise at his own ability to do this and after writing the last of the familiar nonwords correctly, said "Now how did I do that"? However, both patients had difficulty in writing the novel nonwords. AM produced no appropriate spellings and AN produced only 1/5. In contrast to the familiar nonwords, their attempts to write these were hesitant, effortful and combined with overt vocalisation of components of the dictated nonword. Fig. 6.5 shows both patients writing of both types of nonword. Neither patient read aloud correctly any of the familiar nonwords either before or after training.

Discussion.

The successful writing to dictation of visually familiar nonwords never before written or heard is a surprising result because both of these patients have difficulty writing novel nonwords to dictation. Evidence for this is provided by the patients' failure to write the novel versions of the familiar nonwords successfully. It is therefore unlikely that the successful writing of the familiar nonwords was produced sub-lexically. This is evidence that the familiar nonwords were written lexically. Further support for this claim comes from the fact that the familiar nonwords were all ambiguous with regard to how they could be spelled and yet both patients produced the specific spelling that they had seen during visual discrimination training. In other words, even if these patients had intact sub-lexical processing skills, they would be unlikely to render all the specific spellings correctly in one attempt. Direct evidence for this claim is provided below.

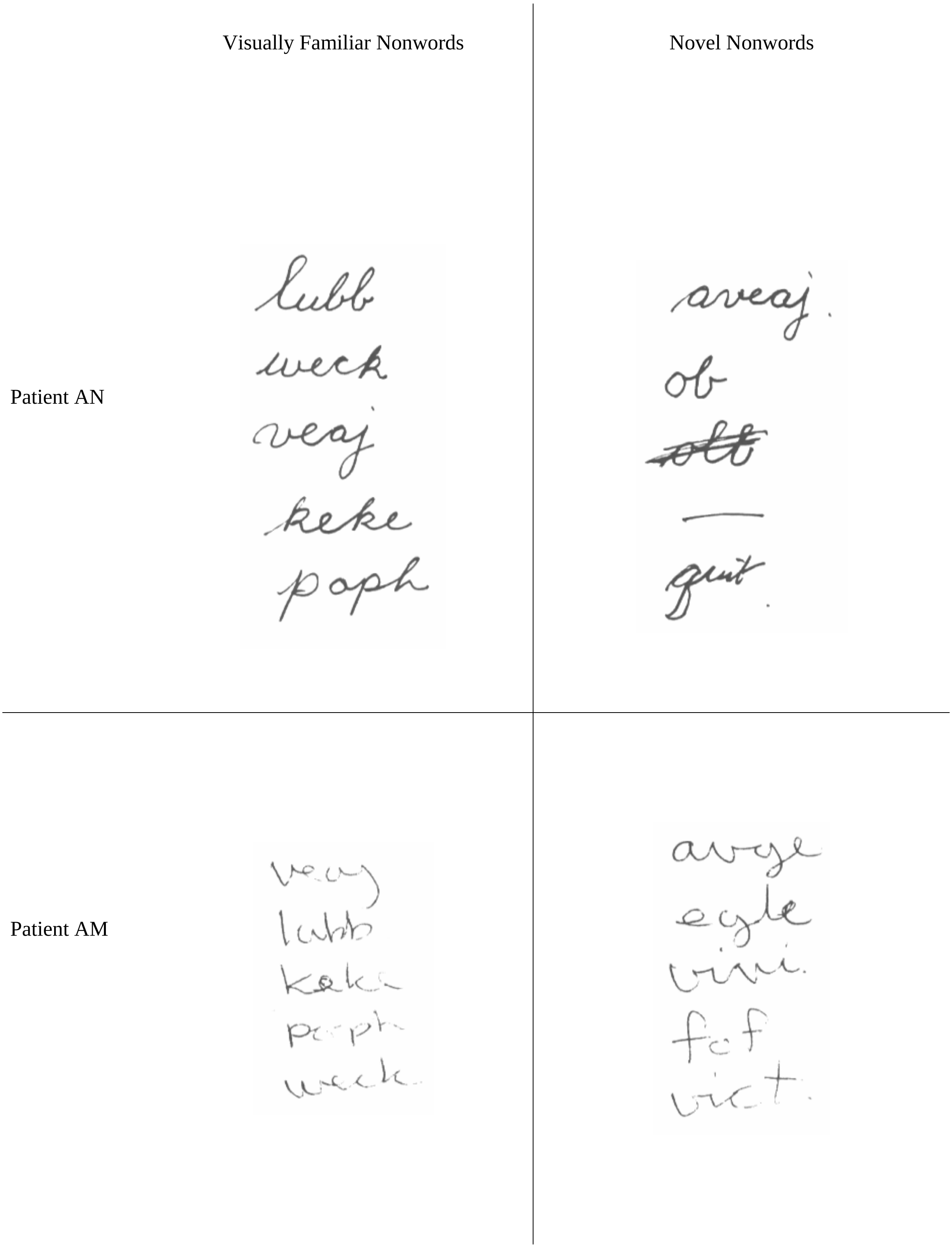


FIG. 6.5. AN's and AM's Writing to Dictation of Nonwords with which they were only Visually Familiar (*veaj*, *lubb*, *keke*, *poph* and *weck*) and Novel Nonwords made from them (*avej*, *ulbb*, *ekek*, *phop*, and *kwec*, Presented in that order).

6.5.2. The *A Priori* Probabilities of the Spellings used for the Familiar Nonwords.

To check whether the sounds of the visually familiar non-words are adequate to specify the spellings used during visual discrimination training and reproduced by the patients, forty-two normal subjects were read the nonwords and asked to write them. Table 6.9 shows that any individual familiar nonword spelling is highly improbable given pronunciation alone. The cumulative probability of producing all five spellings correctly is therefore very low. The patients must therefore have been using their visual experience of these non-words. Thus visual familiarity alone is adequate to establish lexical writing to dictation of non-words. We can be sure that the writing is lexical because: 1. the patients can write only the specific non-words with which they are familiar; 2. sub-lexical processes cannot specify the particular spellings used and 3. these patients are lexical writers because their sub-lexical processing is severely impaired anyway. It is important to clarify the claim being made here.

TABLE 6.9.
The Variety of Spellings and Their Probabilities of being Produced by Forty-Two Normal Subjects in Response to Five Dictated Nonwords; *veaj*, *poph*, *keke*, *weck* and *lubb*.

Version								
1	2	3	4	5	6	7	8	9
veege	veej	viege	veeg	viege	veage	veag	vege	vedge
.23	.16	.16	.14	.09	.09	.05	.05	.02
poff	pof	poffe	pough					
.70	.26	.02	.02					
keek	keak	keck	keik	kiek	keeke	keke		
.77	.09	.05	.02	.02	.02	.02		
wek	weck	whek	wheck					
.53	.37	.05	.05					
lub	lubb							
.74	.26							

That the graphic output of these patients is lexical does not seem to be in doubt. What needs to be made clear, is in what sense the output is lexical. It is not clear that these lexical output representations are established and retrieved via lexical routes and these 'routes' issues will be discussed later. What *is* clear is that the output is lexical in the sense that each letter-string has to have been released from memory as a whole item. The written output forms cannot have been released as strings of independently specified parts because the parts are ill-specified by auditory input. In other words, implicitly available in these output representations, is information about the whole item that is unlikely to be specified in a bit-by-bit translation. The claim therefore, is that visual experience can establish lexical graphemic output forms in memory.

There is however, a question which needs to be considered here. An alternative explanation for these results[21] *might* be that the patients, as a result of the visual experience of the five nonwords during training, formed strong episodic memories for them. The successful writing to dictation might then arise because given an adequate visual episodic memory trace, partial or inaccurate sub-lexical phonological transcoding might mediate the selection of each of the nonwords. If episodic memory processes are involved, they are unlikely to be independent of the language system however because the written output of these patients is in fluent cursive script and is not a literal transcription of a visual memory. The process therefore uses abstract letter identities. The role of episodic memory in the organisation and operation of the language system is not theoretically specified however and so this explanation itself raises many questions. Nevertheless, the reports which follow, are of experimental attempts to obtain evidence on this question.

The basic finding in section 6.5.1 was based on the learning of only five items. This is admittedly a small number but the size of any stimulus set is constrained by the difficulties that any particular task causes for these patients. It was therefore decided to try to replicate the original finding but to keep the stimulus set to five items.

6.5.3. Lexical Writing to Dictation of Nonwords Never Before Heard or Written: A Replication.

The procedure used for this test was identical to that in section 6.5.1. The nonwords used for the discrimination/matching task were again chosen to be ambiguous with regard to the way they might be spelled to dictation. The familiar nonwords were all written fluently by

[21] These findings were submitted to the journal 'Nature' and I am grateful to an anonymous reviewer for suggesting this as an alternative explanation.

both patients at the first attempt. However, both patients had difficulty in writing the novel nonwords. AN produced no appropriate spellings and AM produced only 1/5. Neither patient read aloud correctly any of the familiar nonwords either before or after training. Fig. 6.6 shows both patients writing of both types of nonword.

This result suggests that the phenomenon of lexical writing to dictation of nonwords never before heard or written is robust. If this involves episodic memory processes then it might be supposed that the effect would be short lived. Indeed, on both occasions that the phenomenon occurred, writing was tested only five minutes after visual discrimination training was completed. Writing was therefore tested after a longer delay.

6.5.4. Lexical Writing to Dictation of Visually Familiar Nonwords after a Five Month Delay.

Both patients' writing to dictation of the first set of familiar nonwords on which they were trained and the novel nonwords made from them, was tested five months after the original experiment. During the five months none of the nonwords had been used in any of the testing sessions nor, to the best of the experimenter's knowledge, had the patients seen them printed or attempted to write them.

At the beginning of a test session, both patients were told that some words would be read to them and they should attempt to write them down. The familiar nonwords were presented first to both patients. Both patients wrote 3/5 of the familiar nonwords correctly, and both produced one spelling that could be considered appropriate if a generous criterion was used, for the five novel nonwords. When asked how she had written them, AN said of the familiar nonwords "Aye, I've got those in my mind" and of the novel nonwords she said "God no, I've never seen the word though". The patients' written responses are shown in Fig. 6.7. The order of presentation for the familiar nonwords was, for AN, *lubb*, *poph, weck*, *keke* and *veaj* and for AM, *lubb, weck, poph, keke* and *veaj*. The order of presentation of the novel nonwords was, for AN, *kwec*, *phop, avej*, *ulbb* and *ekek* and for AM, *phop, avej*, *ulbb*, *ekek* and *kwec*. Although the differences between the writing of the

FIG. 6.6. A Replication of AN's and AM's Writing to Dictation of Nonwords with which they were only Visually Familiar (*phon, kobi, gute, ceft and wege*) and Novel Nonwords made from them (*honp, tefc, uget, ikbo and eweg* Presented in that Order).

two types of nonwords are not statistically significant, the fact that the spellings of the familiar nonwords are highly improbable still suggests that they are produced lexically and that the effects are long lasting. In the two experiments where the patients produced lexical written output after visual discrimination training, we know that the amount of visual

FIG. 6.7. AN's and AM's Writing to Dictation of Visually Familiar Nonwords and Novel Nonwords made from them, Five Months after Visual Discrimination Training. See Text for Order of Presentation.

experience was sufficient to produce lexical output but we do not know whether it was necessary. It might be supposed that if episodic memory traces are supporting the writing to dictation of the familiar nonwords, then little visual experience might be necessary i.e. writing may be possible after the first episode of training. If however, the visual experience creates memories within the language system we might expect that frequency of experience would be an important variable.

6.5.5. Lexical Writing to Dictation of Visually Familiar Nonwords after Different Amounts of Visual Experience.

Thirty, four-letter nonwords were constructed and randomly divided into six sets of five. Each of the six sets was printed in seventy-two point size on a separate A4 sheet and each nonword was printed in fourteen point size on a separate white card. The six sets of nonwords were randomly divided into two groups of three. Each of these two groups was used for discrimination training with one patient and as novel nonwords with the other patient. Each of the three sets was then used with a different amount of visual training. The discrimination /matching task was simplified for this experiment. A trial consisted of showing all of the five nonwords from one of the sets of cards and asking the patient to point to the corresponding nonword on the sheet (nonwords were shown one at a time).

TABLE 6.10
The Groups of Nonword used for Visual Discrimination Training and as Novel Nonwords for Writing to Dictation and the Number of Training Trials for each Set.

Number of Visual Discrimination Trials	AM Familiar AN Novel	AN Familiar AM Novel
1	phyk ewel tepe marn chac	kewm tept vedd quan gryg
4	ceph ezry koit pute deec	phet moxe vait effy womm
8	tord jais bewm hiph rarc	irms moif pror kend nirt

Table 6.10 shows the nonwords and the amount of visual training given to the two

patients with the sets within each group. The sets to used for visual discrimination training were randomly assigned to one of three conditions where the independent variable was the number of discrimination trials performed before the patient was asked to write the nonwords to dictation. The effect of one, four and eight discrimination trials was examined. As in the original experiment, there was a five minute delay between the completion of visual discrimination training sessions and the writing to dictation test. No reference was made to the training procedure before writing was tested. The visually familiar nonwords were dictated to both patients first.

Of the nonwords used for visual discrimination training, AN wrote the specific spellings for 0/5 after one trial, 0/5 after four trials and 2/5 after eight trials. All others were attempted but none received an appropriate spelling. AN wrote no appropriate spellings for any of the novel nonwords. AM's writing of the specific spellings of visually familiar nonwords was 0/5 after one trial, 1/5 after four trials and 5/5 after eight trials. All others were attempted and in addition to the six specific spellings AM produced an acceptable spelling for one other familiar nonword from the four trial condition. He also produced an acceptable spelling for one of the novel nonwords in the four trial condition and one from the eight trial condition. The differences in performance between familiar and novel nonwords after eight trials are not significant for either patient. However, this is because of the small stimulus sets. Given the ambiguity of the spellings used, the writing of familiar nonwords still suggests that the spellings are lexical and that learning is gradual and slower for AN than for AM.

If the patients were forming episodic memories for the visual forms of familiar words, and selection of the appropriate spelling for writing to dictation was mediated by residual sub-lexical processing, it is likely that confusion errors would be made, particularly if the set from which the choices were made contained similar letter-strings. If however, this procedure was adequate for visually familiar nonwords and if the letter-strings from which the choices were made were not held in memory but were printed and in constant view, then the patients should also be able to use dictated novel nonwords to select their printed spellings. The final experiment was designed to test this hypothesis.

6.5.6. Spoken Familiar Nonword to Printed Familiar Nonword Matching.

The visual discrimination training from the original test (section 6.5.1) was repeated with the same five familiar nonwords and the same twenty orthographically similar distracters. These twenty five nonwords were printed in random order on an A4 sheet. The five familiar nonwords were also printed in random order on another sheet with twenty newly created, orthographically dissimilar distracters. The five novel nonwords from the same experiment were likewise printed on two sheets, one with twenty orthographically similar distracters and the other with twenty orthographically dissimilar distracters. After discrimination training the five familiar nonwords were spoken to the patient and they were asked to point to the printed form on the sheet counting the similar distracters. This was repeated with the sheet containing the dissimilar distracters. Next, the novel nonwords were spoken to the patient and they were asked to match those to an appropriate form, firstly from amongst the similar distracters and then from amongst the dissimilar distracters.

Both AN and AM chose 5/5 correctly for the visually familiar nonwords with both types of distracter and both scored only 1/5 for the novel nonwords with both type of distracter. When dictated the novel nonwords, AN responded twice with "Not there" to both types of distracter and AM three times with "Can't see it" to both types of distracter. Confusion errors of the type predicted by partial sub-lexical processes selecting from visual memory, did not occur.

6.6. General Discussion Concerning the Creation and Retrieval of Orthographic Knowledge.

This last series of investigations arose from the unexpected finding that both patients, who cannot write novel nonwords to dictation, can write nonwords to dictation that they have learned to read. What investigations in this section (section 6.5.) show is that visual experience alone is sufficient to support lexical writing to dictation of nonwords that have never been written before. Before the implications of these results for current theories are considered, the issue of which memory systems are involved will be considered.

6.5.7.1. Episodic or Short Term Visual Memory for a Small Set of Items?

During these investigations, both patients, but particularly AN, have been exposed to hundreds of nonwords, not just five, and many of these were orthographically similar. Furthermore, they have encountered nonwords on dozens of occasions and both patients have received training on over fifty items. The set of eligible items from which a graphic form must be selected is therefore not small and neither is the number of episodic memories which the patient may have formed. Also relevant is the fact that at no time before, during or after any of the writing to dictation tests, was any reference made to a training phase or any particular set on nonwords. The patients were simply asked to write down what was said to them.

Because writing to dictation was tested shortly after the patients were trained on a small sub-set of nonwords, it could be hypothesised that they use a specific short term memory trace for writing the specific items. However, this does not explain the patients success at writing the familiar nonwords to dictation after a five month delay. AN was similarly successful at writing the nonwords she had learned to read after over one month's delay. Furthermore, in the original experiment, although there were only five 'target' nonwords they were seen amongst twenty distracters which were themselves seen several times. The crucial difficulty for this explanation however, is that AN is only able to copy 2/12 six-letter nonwords from immediate memory (section 6.3.2) and only 5/20 three, four, five and six-letter nonwords after only a five second delay (section 6.3.3.) Furthermore, these were presented singly and so her short-term visual memory was not adequate for copying a stimulus set of one!

Another difficulty for the visual memory trace explanation (whether it be short-term or episodic memory) is posed by the fact that the writing of familiar nonwords was always compared with the writing of novel nonwords which were orthographically similar. Firstly, for every familiar nonword learned, there was a novel nonword that could be spelled using the same letters, and secondly, the novel nonwords sometimes had the same first letter as the familiar nonwords. If writing to dictation involved a process of referring to a visual memory it seems likely that either a familiar nonword would be produced in response to a novel nonword or the familiar nonword spelling could be retrieved and rearranged to produce an appropriate spelling. However, these patients are very poor at writing the novel nonword forms of the familiar nonwords and neither do they erroneously produce familiar nonword spellings for novel nonwords.[22] An example of this is shown in Fig. 6.5 where it can be seen that although the familiar nonword *keke* was written correctly by both patients, the novel nonword *kwec* was written as *quit* by AN and *vict* by AM.

Nothing in this discussion precludes the *possibility* that the patients are forming episodic or short-term visual memories for a small set of items which are accessed during writing to dictation, but the aspects of their performances outlined above present difficulties that are not easily explained. Even if it was accepted as an explanation, questions then arise about access to and transcription of the visual memories from a novel auditory input. Firstly, the non-trivial problem of selecting the correct episodic memory trace has to be solved. Once this is overcome, the problem of how to retrieve the correct item arises. An anonymous reviewer suggested that partial cues transmitted from the phonic domain might be adequate to support performance. The spoken to written nonword matching experiment provides evidence on this. It shows that spoken to written nonword matching is strongly affected by visual familiarity. The failure of both patients to select appropriate spellings for the novel nonwords shows that this mechanism by itself is not adequate. It might be argued that it would be adequate to select from just five nonwords but for the reasons given above, the patients have not experienced just five nonwords. In retrospect however, there was a methodological error in the design of this last experiment. The stimuli for the matching task were presented in blocks according to whether they were nonwords on which training had been given or novel forms made from them. Although this does not alter the conclusion that partial sub-lexical translation alone is not adequate to match a spoken form to an orthographic form, this particular result is not good evidence against the notion that the patients are assisted in selecting the visually familiar items because they have a specific visual memory for the small subset of five items. Further investigations will involve using a

[22] Although on one occasion a response to a novel nonword was close to a familiar nonword spelling when AN wrote *aveaj* in response to *avej*.

larger data set over a longer period of time and then random spoken presentation of the visually familiar nonwords and novel forms for matching to written forms.

Finally, it appears unlikely that the successful writing to dictation of visually familiar nonwords is mediated by some processes separate from the normal language system. One piece of evidence for this is that during the tests of writing familiar nonwords after different amounts of visual experience, AN produced four English words in error and AM two. The processes involved therefore at least have access to the normal language system. Furthermore, whatever processes are involved, they include the use of abstract letter identities because both patients transcribed typeface into cursive script. Whilst bearing in mind the dangers of making inferences based on associations, one final aspect of AN's performance is relevant here. It might be reasonable to suspect that lexical writing to dictation of visually familiar nonwords was performed by some process that had little to do with the normal language system, if there was no evidence that lexical orthographic output can be trained in AN. However, the investigation of writing animal names showed that lexical graphic output can be trained and that it is gradual. These two basic aspects of performance are at least corroborative with the findings of the experiments reported in this section. None of this evidence is conclusive, but at this point it looks unlikely that the patients are just transcribing one from a small set of items in visual memory.

The alternative explanation for these results is that the graphemic output is lexical both in the sense that the written forms embody word-specific knowledge (i.e. are specific ambiguous spellings) and that they become encoded in and retrieved from long-term memory. In models like that in Fig. 5.1 this means as a lexical representation in the graphic domain. How this is established and whether this is as both an input and an output representation is discussed below.

6.6.1. The Acquisition, Transmission and Retrieval of Lexical Knowledge.

These results raise basic issues concerning the acquisition, transmission and retrieval of lexical knowledge. One question that arises is by what route or routes the newly acquired word-form knowledge passes from input during training to output during test. The implications of the data are different depending upon whether the orthographic domain is conceived to have separate sub-systems for visual word recognition and spelling production or whether there is just one orthographic lexicon.

Coltheart and Funnel (1987) reported a patient, HG, who was surface dyslexic. HG was impaired at reading low frequency irregular words particularly if they were presented amongst nonwords. He would produce regularisations, for example, reading *quay* as "kway". Coltheart and Funnel concluded that HG's failure to recognise these words when they were mixed with nonwords was due to a mild impairment of access to a visual lexicon. HG was also surface dysgraphic and was impaired at writing low frequency irregular words to dictation for which he produced regular spellings e.g. spelling "*blew*" as bloo. This was interpreted as a mild impairment of retrieval from an orthographic lexicon. If the visual lexicon and orthographic lexicon are one and the same module, then it would be predicted that the words on which reading errors are made would be the same words on which writing errors are made. When this was investigated Coltheart and Funnel found a high correlation between the words that could not be read or written reliably and concluded that the data was best accounted for by a single orthographic lexicon. Other supporters of the single lexicon view include Allport (1983) and Allport and Funnel (1981).

In contrast to this view is that embodied in Fig. 5.1, of separate input and output lexicons. Campbell (1987) investigated the spelling errors of two students who consistently misspelled words, the English forms of which they reliably recognised as words in a lexical decision task. Of crucial importance was the fact that the students were at chance in rejecting their own misspellings as nonwords in the same lexical decision task. Campbell argued that separate input and output lexicons could most easily accommodate this data. She argued that the orthographic output lexicons of the students only contained the misspellings which they consistently generated. On the other hand their orthographic input lexicons contained both correct representations acquired through normal reading and incorrect representations of their own misspellings acquired through reading their own writing. Failure to reject their own misspellings arose because of these dual representations in their visual input lexicons. Amongst other adherents of the separate lexicon model are

Monsell (1987) and Caramazza and Hillis (1991). Shallice (1988) provides a review of the neuropsychological evidence relating to this issue for both the orthographic and phonological domains and concludes that it is unresolved but that the weight of evidence supports the single lexicon view. The experiments reported in this section, whilst not adjudicating between the two positions, is relevant. Both patients can write fluently to dictation nonwords which they have only ever seen but have never written. A major problem for the separate lexicon view is how lexical graphic output can be generated from a lexicon which has never been explicitly trained to produce such an output (this question will be dealt with shortly). No such problem exists for the single lexicon model however. On this view, lexical graphemic output is possible simply because the orthographic knowledge is created through visual discrimination training and made available for output. The single lexicon view therefore seems the most parsimonious explanation of this phenomenon.

The question of how newly acquired word-form knowledge passes from input during training to output during test has different implications for the two lexicon model. If the distinction between visual input and graphemic output lexicons is sound, as some theoreticians argue (see above), then two possibilities arise, both with problematical implications. One possibility is that the knowledge acquired through visual training is stored only in a visual input lexicon. If this is the case, then such knowledge can produce fluent motor output at test. How this output would be produced in response to a novel auditory input is unclear. Auditory processing would necessarily be sub-lexical and how output from sub-lexical phonological-to-orthographic conversion processes could access visual input lexicon representations cannot be explained without proposing radical modifications to the architecture of current models. An alternative proposal is that information about new words can be transmitted to the graphemic output lexicon during training. This means that new items can be added to the lexicon without any overt output taking place but the problem still remains of how a novel auditory input accesses the graphemic output lexicon for writing to dictation . An extension of this idea is to suppose that visual experience can create new knowledge not only in the graphemic output lexicon but in the auditory input and phonological output lexicons also! There is no evidence for this proposal in the data reported here, but further experiments will investigate its plausibility. The proposal that activity in one lexicon can train another is not without precedent however. Denes, Cipolotti and Semenza (1987) reported a phonological dyslexic, ML, who could read words she had never seen written. These words were part of the Friulan dialect which has no written tradition. Now, a word that has never been seen before has the same status in the orthographic domain as a nonword. It has no lexical representation and so can only be read sub-lexically, a procedure which is not available to phonological dyslexics. However, these 'nonwords' that ML could read were also words that she had heard spoken, and spoken herself, all her life and for which she had therefore formed phonological input and output representations. Denes, Cipolotti and Semenza (1987) suggested that this might be possible if, even though a word had never been seen before, frequent pronunciation made tacit knowledge of how the word might be written, available to the visual input lexicon. In other words, a potential graphemic form could be generated by repeated auditory exposure to a word. This means spontaneous training of a lexicon in one domain by a lexicon in another domain. The analogue of this explanation for writing to dictation of words never heard or written, is that repeated visual exposure to a word generates a potential phonological form. Thus the auditory input lexicon can recognise a visually familiar nonword when it is spoken for the first time. This explanation would still require that visual experience can generate an orthographic output form, although this does not seem so unlikely if one accepts cross domain transfer of knowledge. Of course this last problem is avoided altogether if one adopts the single lexicon approach.

On the basis of the data available, the various theoretical interpretations of the results discussed here cannot be adjudicated between. Further work should make it possible to determine which of the proposals is the most likely. There is one final issue to which the data are relevant and to which none of the arguments about separate lexicons or transmission routes are crucial. This issue is to do with lexical information codes.

6.6.2. The Nature of Lexical Codes.

This last series of experiments has reported two patients who are capable of producing lexical orthographic output of nonwords which they have seen but never written before. This result has important implications for our assumptions about how lexical knowledge is coded. Whether the code for this output is released from the orthographic input lexicon or from the orthographic output lexicon which has been trained by the visual input (or from a unitary orthographic lexicon), lexical orthographic output demonstrates that the knowledge acquired must preserve information about the essential inner structure of the letter-string through all stages of transmission from input to output.

Whether items within a lexicon are coded in a local or distributed fashion is an important and unresolved issue. A variety of local code types have been proposed including logogens (Morton, 1980), units (McClelland & Rummelhart, 1981) and nodes (Ellis, 1988; Morton, 1980; Stemberger, 1985). A code is local if a single undifferentiated signal is associated with each item. For example, in Stemberger's interactive activation model of speech production, when a node in a lexicon is activated it does not release any form of structured code but merely transmits "*activation*" to the appropriate node(s) at other levels of the system. In other words there is no information in either the node itself, or the outcoming 'signal', about the internal structure of the item (the spelling pattern in this case) for which that node is a representation. These nodes or local codes are merely category labels.

Consider now the consequences of restricting training on nonwords to visual input. If training was to produce just a new local code for each nonword in the visual input lexicon, then that item could not be written to dictation because neither the local code or its output contains information about this graphemic structure. The code in the visual input lexicon must therefore be a structured description either to support written output directly or to train a representation in the graphemic output lexicon. Such structured descriptions imply codes that are distributed in populations of neurones or cell assemblies (Singer, 1990).

7 Outstanding Issues and Summary.

Warrington and Shallice (1979) and Shallice (1988) proposed that deficits of access to stored information can be distinguished from deficits affecting the stored representations themselves by certain characteristics of a patient's performance. One of the characteristics they proposed was the degree of consistency in responding to the repeated presentation of the same stimulus. What they argued was that if a patient consistently makes errors to the same items, this is indicative of a storage deficit but if a patient shows inconsistency in the items to which they make errors, this is indicative of a disorder of access. The underlying assumptions are that in storage deficits the items are permanently lost but in access deficits they are present and available but can only be accessed intermittently. Shallice (1988) has gone on to suggest that the consistency criterion (along with several others) should apply as a general principle across cognitive theories and domains. However, Rapp and Caramazza (1993) argued that whether or not some pattern of impaired performance is indicative of a deficit of access or storage "relies crucially and necessarily upon assumptions regarding the *nature* of access and storage". As they point out, there is no reason to assume that access mechanisms may not be permanently damaged, thereby making that information for which they are responsible for retrieving *consistently* unavailable. Similarly they argue that there is no principled basis for assuming that stored representations cannot be temporarily affected by fluctuating local factors thereby producing *inconsistent* responding. It is difficult to adjudicate between these two positions and it is therefore difficult to interpret a particular aspect of AN's performance as being due to storage or access problems.

In section 4.1.2, AN's ability to sound-out all of the letters of the alphabet (except 'x') was tested twelve times. AN made seventy five responses that were clearly errors. The interesting aspect of these errors is that they were produced by all twenty-five of the stimulus letters. Every target letter both produced an error and was sounded-out correctly. Not only was there a high level of inconsistency in the items that produced errors but also in the responses that were produced. For the reasons given above it is not possible to claim that this performance indicates that AN has a deficit in accessing the appropriate phonemic representations. However, as each presentation of the alphabet was only separated by about three or four minutes, the alternative explanation that the phonemic representations are themselves temporarily 'damaged' or unavailable, means that these temporary fluctuations can be very short lived. Temporary unavailability of linguistic information (both lexical and sub-lexical) has been noted before, for example in deep dysgraphic patients (e.g. JC of Bub and Kertesz, 1982) who can recover the ability to spell abstract words and even the appropriate graphemes to produce spellings of nonwords. However, this temporary unavailability has been over a much longer time scale (approximately six months for JC) and this author knows of no other reported case where representations have been reported as 'lost' and 'available' again within such short time periods as those that occur in AN.

Both AN and AM have impairments in reading and writing nonwords. In that sense both could be described as phonological dyslexics and phonological dysgraphics. However, they both have impairments in reading and writing real English words as well and so are not clear cases of either syndrome if these two syndromes are conceived of as being deficits in sub-lexical processing only. A sub-lexical processing deficit accompanied by word class and part-of-speech effects in both reading and writing are characteristic of deep dyslexia (Coltheart, 1980) and deep dysgraphia (Newcombe and Marshall, 1980) and are patterns of deficits that both AN and AM exhibit. AN and AM are therefore functionally similar to patients described as deep dyslexics and deep dysgraphics. However, if, as Coltheart (1987) suggests, the semantic error is the central feature of deep dyslexia and deep dysgraphia, then neither of these syndrome labels is a good description of these patients either because neither patient systematically makes semantic errors in either in reading or writing. Both patients are therefore good examples of why Ellis (1987) argued that there is little to be gained by using syndrome labels and that patients are better described in terms of their patterns of impaired and preserved abilities.

Much of the development and refining of models of the functional architecture of the language system has been in response to data obtained from the performances of brain injured patients. Such neuropsychological studies can provide a privileged view of the organisation of cognitive processes. Models of the functional organisation of the processes and routes involved in reading and writing single words and nonwords are now well developed. Unresolved issues remain nevertheless and prominent amongst these are those concerning the number of routes that exist for reading, writing to dictation and copying words and nonwords. All theories accept that an indirect route via the semantic system exists for all of these tasks. What is not agreed is the number of non-semantic routes that exist. Dual route theories propose that there are two, one which deals with familiar words and one which deals with novel words and nonwords. These routes are considered to be capable of selective impairment. Multiple-levels theory proposes that there is one broad route with several levels, each of which deals with different sizes of units ranging from whole morphemes to single graphemes. This model does not allow for selective preservation of the morphemic level with concurrent impairment to 'lower' levels. Analogy theories propose that there is one route dedicated to processing familiar words which is parasitised for processing novel words and nonsense words. Other approaches argue that there is only a sub-lexical route which operates in conjunction with the semantic route. Computational approaches propose just one non-semantic route which is capable of processing all letter-strings. This thesis reports investigations into the reading and writing abilities of two patients whose brain injuries resulted from cerebro-vascular accidents. Their performances are interpreted in relation to the issue of whether there are non-semantic lexical routes for reading, writing to dictation and copying.

Both patients are moderately anomic and have severe impairments in reading and writing nonwords. Investigations of the locus of impairment in AN's nonword reading showed her to have normal orthographic analysis capabilities but impairments in converting single and multiple graphemes into phonemes and phonemic blending. Both patients were able to read familiar whole words but not novel combinations of their sub-word segments. This finding along with tests that showed her orthographic and phonological segmentation abilities to be normal, and that she was unable to read nonwords that were close orthographic neighbours of words that she could read well, provide no evidence for reading by analogy processes in AN. In an experiment that has been referred to as the familiar nonword paradigm, both AN and AM were able to learn to read nonwords to which no meanings were attached but could not read novel forms of the same nonwords. Both patients were unable to report any meanings for the familiar nonwords when they read them and there was no evidence that learning to read them improved their sub-lexical processing abilities. Their results are evidence for a direct lexical route from print to sound that is dedicated to processing whole items that are specific familiar combinations and that is functionally dissociable from a route or levels that deal with novel combinations. It was also shown with AN that if nonwords are given meanings then she learns to read them faster than if they are not given meanings.

Both patients have severe impairments in writing novel nonwords to dictation. As they can repeat spoken nonwords after they have failed to write them, this is not due to a short-term memory impairment. Despite the nonword writing impairments, both patients were able to write to dictation the meaningless nonwords that they had learned to read, at the first attempt, and AN did so one month after learning to read them. Neither patient however, could write novel nonwords made from the familiar nonwords and this combined with the fact that the familiar nonwords used spellings that were of *a priori* low probability, is evidence that they were not being processed sub-lexically. Tests of semantic association showed that the familiar nonwords evoked no semantic information that the patients could report and semantic information was therefore unlikely to be mediating their writing. Function words dictated to AN evoked little semantic information but she wrote them to dictation significantly better than nonwords made from them. These results are evidence for a direct lexical route for writing to dictation.

When a five second delay was introduced between display and being asked to write them, AN was significantly better at copying the meaningless nonwords than she was at copying the novel nonwords made from them. This demonstrates a lexical advantage for copying. She was also significantly better at delayed copying of six-letter nonwords that she had been trained to copy than she was at copying novel nonwords made from them. This was despite the fact that the novel nonwords were made by recombining the first and second halves of the nonwords on which she had been trained and these halves retained their positions from the parent nonwords. AN was significantly better at copying function words than nonwords made from them. She was also better at copying function words than she was at reading or writing them to dictation. These results are evidence that copying of function words and familiar nonwords from memory can be lexical and not mediated by meaning. This is evidence for a direct lexical route for copying.

AN and AM were both able to write to dictation nonwords whose spellings were of *a priori* low probability, that they had never heard or written before but with which they had been made visually familiar during a visual discrimination task. The ambiguity of the spellings and their inability to write to dictation novel nonwords made from them suggests that the output was lexical. The creation of lexical orthographic information which can be retrieved by novel auditory input is difficult to interpret within the framework of current models. The most parsimonious explanation involves supposing that there is only one lexicon in the orthographic domain. This is an incomplete explanation and problems remain. An alternative explanation is that written output that appears to be lexical is in fact mediated by an episodic memory trace for the training sessions. Whilst there appear to be difficulties for this explanation too, it has not been satisfactorily rejected. The issues raised by this finding remain unresolved.

Finally, the experiments on training these patients to read nonwords and copy nonwords demonstrate the simple fact that it is possible for them to learn. What they learn however, seems to be at the level of the whole word and there is no evidence that sub-lexical processing improves as a result. The implication of this is that for some patients re-training them to read is best done at the level of the word and not by trying to train their sub-lexical skills. The accelerated learning when nonwords are given pseudosemantics may have implications for re-training too. Support for this comes from a finding by de Partz, Seron and Linden (1992) who demonstrated that in their patient LP, orthographic lexical representations were re-established quicker when words were presented with a semantically related drawing than when they were repeatedly presented on their own.

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