An Investigation of Pure Alexia: Evidence Against 'Letter-by-Letter' Reading

by

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ABSTRACT

The relationship between initial lexical activation and the compensatory reading strategy observed in pure alexia was investigated. Lexical decision and naming were examined in three patients with pure alexia (DM, IH, and JL) using orthographic and lexical variables selected from two models of normal reading (Interactive-Activation and Cohort). The variables included word frequency, neighborhood/cohort size, neighborhood frequency, number of positions yielding cohorts, and unique point (i.e. point of resolution). Patients were affected by the same variables as the normal readers and their patterns of performance, although slower, were also similar. All subjects demonstrated a facilitatory effect of high word frequency and large neighborhood size. Results also indicated that the compensatory strategy is not 'letter by letter' or left to right. Patients with pure alexia appear to achieve normal lexical activation and then engage in a compensatory reading strategy which is guided by this initial activation.

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Acknowledgment

I would like to thank my supervisor, Daniel Bub, for his patience, support, and encouragement during the past two years. My attempt to combine clinical work and cognitive-neuropsychological research has not been easy for either of us. Without his continual reassurance, unfailing willingness to offer assistance, and unique ability to mollify my recurring doubts, the completion of this project would not have been nearly as successful.

Dedication

This thesis is dedicated to my previous mentor, the late Dr. Nelson Butters. It is truly an honor to have been part of his laboratory and to have witnessed his devotion to teaching and developing so many neuropsychologists and researchers. If I had not been given the opportunity to work in the midst of such an exciting environment, I am sure that I would not have discovered or pursued a career in neuropsychology. I feel very fortunate to have known Dr. Butters and will never forget his kindness and the positive impact he had on my life.

Literature Review and Introduction of the Current Study

History and Description of 'Pure Alexia'

In 1892, Jules Dejerine presented an analysis of a patient with a reading disorder he called 'pure word blindness'. The patient had suffered a left-sided stroke and was subsequently unable to read, although he had no difficulty writing, speaking, or understanding spoken language. Dejerine also noted that his patient showed no signs of optic aphasia or visual agnosia, as he was able to easily recognize and name objects placed before him. This syndrome is known today as pure alexia or letter-by-letter reading. Dejerine interpreted this patient's difficulties as resulting from a lesion which caused a disconnection between visual information available to the right hemisphere and the word recognition center in the left hemisphere. This disconnection meant that the patient could not transfer perceived letter codes into linguistic units. Variations of this account of pure alexia are still commonly accepted today.

Since Dejerine's time, there have been many case reports of pure alexia and the clinical picture of this syndrome has evolved. A close inspection of Dejerine's case and his interpretation was completed by Bub, Arguin, and Lecours (1993). These authors point out weaknesses in his assessment of the case as well as in the neuroanatomical explanation of the disorder. This scrutiny of Dejerine's interpretation of pure alexia does not serve to undermine the importance of his contribution, but allows one to reflect on the complexity of this particular syndrome and the minimal progress that has been made in the past century.

Currently, the syndrome is often referred to as 'letter-by-letter reading'. This title reflects the fact that these patients show a pattern of reading which is greatly affected by word length. A typical patient will need approximately 3-4 seconds to read a three letter word and reading times increase linearly with the addition of each letter. While it has been over a century since this disorder was first recognized, a generally accepted interpretation of pure alexia has yet to be developed. There are many theories which have attempted to explain this unique pattern of deficits. Two general classes of explanations have been offered: the first proposes that pure alexia is the result of a peripheral deficit and the second supports the notion of a central disturbance. Peripheral deficits are defined as damage to an area outside of the core reading system; these are typically disruptions in visual processing. In contrast, a central deficit involves damage to part of the core reading system.

One group of hypotheses suggests that there may be damage to a peripheral system which is responsible for mapping visual information onto word forms. Several investigators (Farah & Wallace, 1991; Friedman & Alexander, 1984; Reuter-Lorenz & Brunn, 1990) have suggested that pure alexia is the result of a constraint on the patients' ability to process single-letter identities or multiple visual forms. However, these explanations are complicated by the fact that all of the supporting evidence has been based on the mere co-occurrence of perceptual deficits and the typical characteristics of pure alexia (Bub & Arguin, 1995). These associations are not sufficient evidence that the peripheral disturbance is directly responsible for the letter-by-letter reading in these patients. Shallice (1988) also argued that there is no evidence to support the notion that letter-by-letter reading is a result of general perceptual impairment.

A second set of explanations is based on the notion that pure alexia is a more central disturbance. Warrington and Shallice (1980) postulated the existence of a visual word form system located in the left posterior cortex. This system is thought to be responsible for organizing the perceptual information of letter strings into more complex orthographic units, allowing for quick and accurate recognition of written words. According to Warrington and Shallice, it is the visual word form system that has been destroyed in patients with pure alexia. The pattern of letter-by-letter reading is therefore a compensatory strategy developed to overcome this deficit. They suggested that a process called 'reverse spelling' is the strategy used by these patients. Since the word form system is destroyed, it is necessary to access a spelling system which requires individual letter codes. By decoding a word one letter at a time, the spelling system is able to string the letters together to form a complete word unit.

Patterson and Kay (1982) also supported the existence of the word form system, but similar to Dejerine, suggested a disconnection of the automatic pathway to this area rather than an abolishment of the center itself. They based their interpretation on the clinical observation that patients had a difficult time identifying individual letters, but once all the letters were identified word recognition was rapid. That is, once the letters are decoded in a sequential format, the word form system is accessible via an alternative route and the whole word is recognized.

Evidence for Preserved Lexical Access

There is increasing evidence which suggests that the interpretations of both Warrington and Shallice (1980) and Patterson and Kay (1982) are incorrect. Several studies have produced evidence indicating that patients with pure alexia are still able to rapidly access orthographic word forms, suggesting that the word form system and the connections to it are intact. In normal readers, a word superiority effect (WSE) refers to the fact that letter perception is more accurate and rapid when the letters are presented in the context of a rapidly presented word as compared to a random string of letters. Patients with pure alexia have also been reported to show a word superiority effect (WSE) (Bub, Black, & Howell, 1989). However, the performance of the patients was still abnormal in that the perception of single letters and letters in multiple arrays required presentation times much longer than normal readers regardless of the type of display. Although the results seem to suggest that letter strings are able to reach higher level units (i.e. word forms) through the normal pathway, an interpretation is difficult because even when presented within words, single letter identification is still impaired relative to the time for normal perception.

Similarly, several researchers have reported that patients with pure alexia appear to implicitly comprehend briefly presented words even though they are unable to explicitly identify the target. Some letter-by-letter readers perform well above chance and are able to make rapid decisions on tests of lexical decision and/or semantic categorization (Bub & Arguin, 1995; Coslett & Saffran, 1989a; Coslett, Saffran, Greenbaum, & Schwartz, 1993; Shallice & Saffran, 1986).

In addition, Bowers, Arguin, and Bub (1996) found a robust and highly specific word priming effect in a patient with pure alexia (IH), despite the typical pattern of slow word identification. The patient showed faster identification latencies when a word presented in upper case letters was primed with the same word presented in lower case letters for only 100 ms. However, when orthographic neighbors, defined as a word differing from the target by only one letter (i.e. 'face' as a prime for FACT), were presented as primes there was no priming effect regardless of the letter position which varied. These results suggest that whole words were processed rapidly and in parallel indicating that the route which contacts specific higher level representations was intact. The authors argued that the patient's deficit in explicit word recognition is not the result of a disturbance in the orthographic system. They suggested that IH's reading impairments are a result of a partial disconnection between orthography and phonology. Clearly, the combination of these results and previous examples of other implicit reading abilities do not support the idea of a complete abolishment or disconnection from the word form system. However, they do support a theory of pure alexia based on a central rather than a peripheral disturbance.

It is also important to note that not all attempts to find evidence for implicit reading in patients with pure alexia has been successful. Some patients do not show an ability to identify or categorize words prior to explicit recognition (Behrmann, Moscovitch, Black, & Mozer, 1990; Patterson & Kay, 1982; Warrington & Shallice, 1980). Coslett et al. (1993) argued that these discrepant findings can be explained by the existence of two different, and structurally distinct, reading 'strategies'. Patients can either attempt to identify a word explicitly based on the compensatory strategy of letter-by-letter reading or they can process the whole word in parallel. According to this explanation, because patients with pure alexia have limitations in the reading system the whole word approach does not allow for explicit recognition, but does access lexical and semantic representations without awareness of this information by the patient. Coslett et al. suggested that patients may rely on the letter-by-letter approach because it allows them the security and practicality of explicit recognition. While these patients appear unable to recognize words via the whole word approach, according to the above noted results they are still capable of processing words in parallel at some level. However, since the patients can no longer immediately identify words, the default (or compensatory) process for word recognition becomes a letter-by-letter approach. Intuitively, this line of reasoning seems valuable as it is word recognition which is crucial in everyday situations. Recognizing that something is or is not a word has little practical benefit.

Coslett et al. (1993) suggested that because patients rely on the letter-by-letter approach for reading, they may be hesitant to switch to the alternative whole word approach. However, the authors reported that when coaxed to utilize a whole-word versus a letter-by-letter strategy, patients' performance on lexical decision and semantic categorization tasks improved. These researchers concluded that the implicit reading capabilities of patients with pure alexia represent automatic word processing, while letter-by-letter strategies are an attempt to process information using limited resources. In a normal system these two systems are connected allowing them to share information. In the patients, these two systems are thought to be disconnected. Coslett et al. hypothesized that the letter-by-letter process is carried out by an impaired left hemisphere while the right hemisphere is responsible for implicit processing. The authors argue that these two processes have been separated in pure alexia as a result of the associated lesion.

According to Coslett et al.'s (1993) explanation, an intact individual would presumably be able to utilize both systems, but would typically work within the whole word approach as it would be more efficient. The letter-by-letter approach would need to be implemented when a normal reader encounters a new or unusual pattern of letters or when presented with an entirely new orthographic system. However, even when presented with novel strings of letters (i.e. nonwords), normals are able to read much faster than the patients. Based on the notion of two separate strategies there are several possible explanations for this result. One simple explanation is that although the patients rely on a letter-by-letter approach, even the resources for this process are limited. A second possibility, based on Coslett et al.'s assumptions, is that even though normals rely on a letter-by-letter approach at times, the whole word information is made available to the letter-by-letter system and therefore helps to speed up the process. This exchange of information is thought to be disrupted in pure alexia due to lesion location.

While the theory put forth by Coslett et al. (1993) may be plausible, one argument against this explanation was discussed by Bub and Arguin (1995). Their patient, DM, was able to make accurate and rapid lexical decisions, but did not show the same pattern with regard to semantic classification. If a 'two separate systems' hypothesis is correct, a patient with pure alexia would not demonstrate this type of dissociation. In other words, if DM is utilizing an implicit reading strategy in order to make lexical decisions, then this implicit strategy should also lead to correct semantic categorizations. Since his performance on the lexical decision task indicated that he is able to use a whole word strategy to accurately and quickly respond it is difficult then to explain why one type of implicit response is possible while another type is not.

Bub and Arguin (1995) suggested that because semantic classification places a constraint on the number of possible targets (typically subjects are asked to decide if the target is a member of a specific category), it is possible that patients may be utilizing partial letter information to match one of the members of a pre-determined set. Following Coslett et al's explanation, the use of partial letter information would be a compensatory reading strategy. Bub and Arguin suggested that word forms are automatically activated in letter-by-letter readers, but that the activation is weaker than would be necessary for explicit identification. It may be that a certain level of activation will allow a patient to make both lexical decisions and semantic categorizations. Less activation may only allow for lexical decisions, therefore limiting semantic categorizations to a letter-by-letter strategy. Even less activation might discourage any attempt at a whole word decision, leaving the patient to rely on a compensatory strategy to make all types of decisions. Since, the initial strength of the signal likely varies from patient to patient, the reported individual differences in lexical and semantic decision making would be expected.

There are many hypotheses regarding the nature of pure alexia, but a well-supported explanation remains elusive. Price and Humphreys (1992) suggested that one important reason for the difficulty in this area is the heterogeneity of the patients. These authors argue that pure alexia, as it is currently defined, cannot be explained by a single functional deficit. They propose that several underlying functional deficits may be responsible for the group of patients which demonstrate a letter-by-letter reading strategy. Alternatively, it is also possible that two patients may have the same functional deficit, but adopt different compensatory strategies. Price and Humphreys concluded that the labels currently used to categorize reading disorders are not valuable in illustrating concurrent functional deficits.

While this argument could offer cognitive neuropsychologists some relief from the difficulty involved in explaining the underlying functional deficit in pure alexia, I believe that there is a 'core' deficit which is responsible for the development of the compensatory reading strategy observed in patients with pure alexia. The variable performance among these patients, within the domain of reading as well as various other domains, can be explained as resulting from the same core deficit, which is then further complicated by additional and various constraints on the compensatory strategy. It is true that various other difficulties often accompany pure alexia, but this is not inconsistent with the notion of a core reading deficit. For the purposes of the current investigation, it will be assumed that patients with pure alexia are similar with regard to the nature of their reading difficulties. Individual differences are certainly expected as the damage to each patient was unique. It is important to keep in mind that, as noted by Vallar (1990), complete homogeneity cannot be accomplished in any group of patients, nor in a normal sample.

The Current Study

The current study is based on two key assumptions which are supported by the literature reviewed above. First, I will assume that the core deficit in pure alexia is due to damage to higher level representations in the reading system (i.e. a central rather than peripheral deficit). The second assumption is that normal activation of lexical representations occurs in patients with pure alexia. Until recently, researchers investigating pure alexia have primarily focused on determining if normal activation does or does not occur. I believe that there is now ample evidence to support the assumption that normal activation of word representations occurs in these patients. This project will attempt to answer some important questions (discussed below) which follow from, yet extend beyond, previous research.

To begin, it is important to recap what is known about reading in patients with pure alexia. In a broad sense, we know that these patients rely on a compensatory strategy for explicit word identification even though 'normal' activation can and apparently does occur. The compensatory reading strategy used by these patients is very slow, but usually accurate. In addition, when it is observed, this strategy appears to represent a left to right, letter-by-letter identification process.

An initial difficulty is that a concise definition of what normal activation entails is not altogether clear. Typically, when lexical activation occurs in a normal reader he/she is able to explicitly identify a word based on the visual word representation which is contacted. Although it appears that patients with pure alexia are able to correctly and rapidly contact lexical representations, it is clear that these patients are unable to rapidly identify whole words. Thus 'normal' activation is defined as the initial contact with the lexicon, but does not include what happens after this activation. Although at this stage there are no answers as to why the patients cannot use the initial activation, there are two distinct possibilities. First, it may be that although initial activation is normal, due to an impaired system, the impulse never reaches a level of activation equivalent to that achieved by normal readers. As a result there may be enough activation to 'know' some things about the target (e.g. that the target is a word), but not enough to identify it. An alternative explanation is that the initial activation does reach the same level of lexical activation as in normal readers, but as a result of limitations in the reading system (i.e. disruption of the activation of phonology and semantics) this is no longer enough activation for a word to reach awareness. That is, an increased level of activation may be required in order for information to reach other components of the system. While the reason for a compensatory strategy is also interesting, for the purposes of the current study, the important assumption here is that activation of a ‘normal’ sort does occur. The question then becomes: 'What happens after the initial activation?'.

Unlike the explanation offered by Coslett et al. (1993), I do not assume that the process of explicit word recognition is completely separate from the initial activation which occurs in these patients. Therefore, I also do not accept the description of the reading process as being ‘left to right’ or letter-by-letter, in the sense that contextual activation has no bearing on the decoding of letters. A primary goal of this study is to find evidence which supports the hypothesis that the initial activation of word representations has an effect on the compensatory reading process. If there is evidence to suggest that initial activation affects the compensatory reading strategy, a follow-up question will be: 'Are there constraints on how much or in what ways this strategy can be affected?'. The second focus of this study will be to determine if the compensatory strategy is actually a letter-by-letter process, in the strict sense of being explicit identification of letters as in a left to right fashion. If there is evidence that it is not, then I will try to offer some insight into what the patients are doing instead.

In order to investigate these two related questions, I will examine if and how patients with pure alexia are affected by variables which have been shown to affect reading in neurologically intact individuals. Most of the variables which will be investigated in this study have not been previously studied in patients with pure alexia. If one can begin to define the variables which affect reading and lexical decisions in these patients, then we can begin to reach a better understanding of where the system is damaged. My approach to this problem was to examine contemporary models of normal reading in order to find a set of variables which typically affect normal reading. These variables then served as empirical tools for investigating the performance of the patients. I chose to focus on two distinct, but not mutually exclusive, models of word recognition: 1) The Interactive-Activation Model (IA) and 2) The Cohort Model. These models are generally different in their approaches to the reading process, but do share some basic assumptions (the details of each model will be described below). They were selected because there is recent work supporting each of them and because both offer fairly straightforward assumptions regarding lexical decisions and naming.

It is important to point out that this investigation is not an attempt to show that the performance of the patients or the normal readers can be explained more effectively by one model or the other. The models and the variables which are relevant to each will simply serve as tools which allow a systematic approach to examining the performance of the patients. It may be that the results of the patients (and the normal readers) are related to one or both of the models. However, for the purposes of this study the critical comparisons are the effects of specific variables on normal word recognition versus word recognition in pure alexia.

I will be examining the results of both a lexical decision and a naming task. Given that some patients with pure alexia have been shown to make 'rapid and accurate' lexical decisions, there is some indication that this task may offer a better view of what affects the initial activation in these patients. In this sense, the results on the lexical decision task will likely offer important information regarding support for or against the assumption of 'normal' activation. If the lexical decisions of the patients are affected by the same variables which affect normal readers, it would be reasonable to conclude that activation in the patients is 'normal'.

The more difficult problem will be trying to determine if the initial activation affects explicit recognition (i.e. naming). It is necessary to bear in mind that the reading deficit in these patients is extensive. Because of their reliance on a compensatory strategy, it is unlikely that any effect which typically occurs in normals will clearly present itself in the naming responses of the patients. Since naming is rapid and automatic in normal readers, the effect of specific variables are apparent. In the patients, the extremely slow reading strategy may make it difficult to detect orthographic and lexical effects. Therefore, in addition to statistical analyses, the patterns of patient results will offer valuable information.

Based on findings from previous research, the following results are expected. Overall, the patients are expected to demonstrate effects which indicate they are sensitive to at least some of the important variables which affect normal reading. As mentioned above, these effects will likely be stronger for lexical decisions than for naming. Based on the assumption that normal activation occurs in the patients, the patterns of performance demonstrated by the patients on lexical decision tasks will be similar to those of the normal readers. While the variables' effects on the patients' naming performance is expected to be less apparent, it is hypothesized that results will indicate that the initial activation of a word does affect naming.

Following is an introduction of the two models and a description of the variables which will be investigated in the current study.

Two Models of Word Recognition

I. An Interactive-Activation Model of Reading. One influential model of reading was first put forth by McClelland and Rumelhart (1981) and later extended by Grainger (1990, 1992). This theory is the Interactive-Activation (IA) Model. McClelland and Rumelhart (1981) described four basic assumptions which are inherent to this model. First, perceptual processing is assumed to take place in a system which is composed of several levels of processing; a visual feature level, a letter level, and a word level, as well as some unspecified higher levels of processing. The second assumption is that the processing of visual information occurs in a parallel fashion. Parallel in this context refers to processing letters at the same time (i.e. spatially parallel) as well as processing at several levels simultaneously. Thirdly, this model assumes that perception is an interactive process. In other words, top-down processing and bottom-up processing occur simultaneously and interact in a way that allows both types of information to play a role in perception. Lastly, the model utilizes simple excitatory and inhibitory activations to provide a framework for the interactions between different sources of knowledge.

The Interactive-Activation model as described by McClelland and Rumelhart (1981) is presented in Figure 1. Of primary importance in this model is the interactivity among different levels of processing. Communication between levels is assumed to spread from one level to neighboring levels, but there are no connections between levels that are not adjacent. The messages sent between levels of processing can either be excitatory, thus increasing the activation of certain items, or inhibitory which serve to decrease the activation of the items which receive the message. In addition to between level communication, there are also intra-level inhibitory loops. This lateral inhibition leads to a decrease in the activation of incompatible responses within a given level.

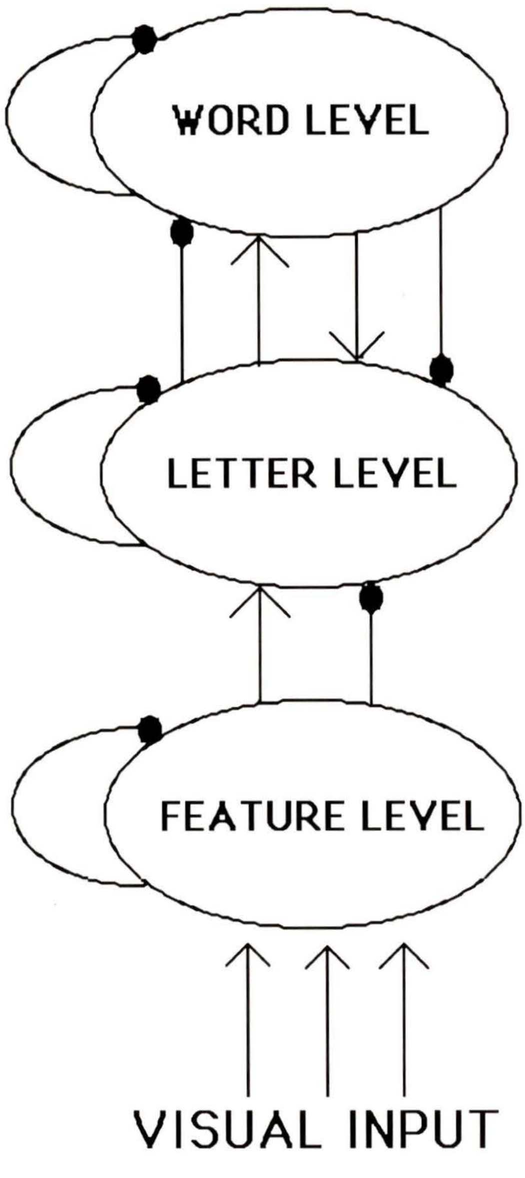


Figure 1. A simplified version of the Interactive-Activation Model.
Note: Arrows indicate activation and dots represent inhibition.

In the description of the model, McClelland and Rumelhart (1981) acknowledge the fact that many levels are involved in reading. However, since it would be nearly impossible to test and analyze the role and interactivity among all possible levels, the initial simulations of the model focused on the interaction between the word and letter levels only. Higher level processes such as phonology and semantics were not considered.

Since much of the research pertaining to patients with pure alexia has focused on reading at the single word level, an understanding of the predictions of the model at this level will be the primary focus here. At both the word and letter level each relevant (i.e., each word and each letter) unit can be represented by a node. Letter level nodes are not simply a representation of the letter, but rather the letter and its position within the target word. Each letter and word node has several neighbors between which there are two-way connections. Connections among neighbors in adjacent levels can either be inhibitory or excitatory. For example, a connection between the letter ‘d’ in the first location and the word ‘dog’ would be excitatory because they are compatible. However a letter not in 'dog' would have an inhibitory connection with the word. Two words, such as 'dog' and 'sea' would also inhibit each other since all intra-level activations are inhibitory.

Each node in the system is presumed to have an initial resting level of activation and these levels are thought to vary depending primarily on the frequency of occurrence in the English language. That is, frequently occurring letters (relative to position) and words will have resting levels of activation which are higher than those of words and letters which occur less frequently. As a result of higher resting activation levels, high frequency words will reach a threshold level for recognition more quickly than low frequency words.

Considering only the letter and word levels, the identification of a four letter word would proceed in the following manner. First, all letters would be perceived simultaneously. Letters which have higher resting activation levels would reach threshold faster than those with lower levels. Within the letter level, neighboring nodes would mutually inhibit each other. This will result in a decrease in the level of activation of all letters, but the letters in the target word will continue to receive facilitatory feedback from the word level. Based on the perception of the whole word pattern, several nodes at the word level will be activated simultaneously. Activated letters will either further excite or inhibit activated word nodes and activated words will do the same to letter nodes. For example, if a particular letter is more frequent than the others it will likely reach threshold first and then communicate with the word level first. As a result, each node that contains the letter in the proper location in the word will be further activated. Again, more frequent nodes will reach threshold more easily. As the remaining letter information is relayed to the word level and vice versa, activation of certain nodes will continue to increase as a result of excitatory activation. Other words which were initially activated will return to resting level if no further activation occurs. In addition, all activated words will be engaged in mutual inhibition, thus decreasing activation levels so in the end only the target will be activated enough to reach threshold. Simulations of this model have adequately accounted for the word-superiority effect found in normal subjects. In addition, the Interactive-Activation model shows an advantage of pseudowords versus unrelated letter strings or single letters which has also been supported in studies of normal readers.

Beyond frequency and number of shared letters, there are other factors that can affect the activation level of a node. The density of a word's neighborhood, as well as the frequency of the neighbors are also important in this model. Within the framework of the model, neighbors can be beneficial or harmful. The benefit of neighbors is the result of feedback to letters which are part of the target word. The activation of these letters by the neighbors then leads to more activation of the target. The harmful effects of neighbors are based on the frequency of the target word and the neighborhood. That is, a high frequency neighbor will interfere with the recognition of a low frequency neighbor because it will reach a higher level of activation, thus strongly inhibiting the target word. McClelland and Rumelhart (1981) suggested that the more neighbors a low frequency word has, the more likely it is that it will be confused with another word. The reason is not that there are more neighbors, but that the neighbors of a low frequency word tend to be higher frequency words. For this reason neighborhood size does not have the same inhibitory effect on high frequency words. In fact, the authors showed a slight facilitatory effect of larger as compared to smaller neighborhoods for high frequency targets.

Grainger (1990) and Grainger and Segui (1990) investigated the role of neighborhood frequency more thoroughly. Findings regarding orthographic neighborhood frequency revealed that, as suggested by McClelland and Rumelhart (1981), this variable has a strong effect on word recognition. The results indicated that many representations are contacted during visual recognition and that identification of the target word may be difficult when the competing representations are visually similar and of a higher frequency. This effect was shown to generalize over different word lengths, various frequencies, and different experimental tasks.

Grainger (1990) also explored the relationship between word frequency and orthographic neighborhood frequency. Previous work has shown that word frequency effects are substantially smaller in word naming than in lexical decision. Grainger (1990) argued that studies in the past have made the mistake of confounding word frequency and neighborhood frequency. Lexical decisions of low frequency words will be inhibited by the presence of higher frequency neighbors. Since naming does not require explicit identification of a word, the role of higher frequency neighbors is based on whether the higher frequency word and the target are pronounced similarly. If the higher frequency word is pronounced similarly, then it will lead to facilitation of the low frequency target. Because of the possibility that a higher frequency neighbor can be either facilitatory or inhibitory under conditions requiring naming, the overall effects will be smaller. Therefore, if neighborhood frequency is controlled and word frequency is manipulated, the word frequency effect in a lexical decision task should decrease while it would remain the same for naming, thus leading to comparable effects of the role of word frequency.

Grainger (1990) and Ferrand and Grainger (1992) completed several experiments in order to distinguish neighborhood frequency effects from word frequency effects. Overall, the results indicated that neighborhood frequency has different effects on naming versus lexical decision. Lexical decision latencies were slowed when a target had at least one orthographically similar higher frequency neighbor, whereas naming of words was facilitated. As proposed, when neighborhood frequency was controlled, the effects of stimulus word frequency on lexical decisions and naming were similar.

While each of these findings offers support for an Interactive-Activation model, one finding in particular provided strong support for this model. Although lexical decisions were slowed by the existence of a higher frequency word in the orthographic neighborhood, when a target word had several higher frequency neighbors the effect was not cumulative. In other words, when a low frequency word had five higher frequency orthographic neighbors the decision latency was not longer than in the case where only one higher frequency neighbor existed. In fact, the authors reported that words with several higher frequency neighbors were consistent with faster lexical decision responses as compared to words with only one higher frequency neighbor. Grainger (1992) suggested that this result can be explained by the presence of mutual inhibition within the word level. That is, all of the high frequency neighbors that are activated by the low frequency target serve to reduce the activation of each other by competing with and thus inhibiting one another.

While the IA model of word recognition has generally been well-supported, it is not without limitations. A shortcoming of McClelland and Rumelhart's (1981) original model of word recognition is the missing role of phonology and semantics. The authors stated that the 'pronounceability of a letter string is not an important feature of the perceptual facilitation we have accounted for' (p. 404). In other words, interactions between orthography and phonology were not viewed as necessary components of the reading process. The issue of connections with semantics was also not discussed.

Although not the focus of the current study, it seems important to briefly discuss the arguments for and against inclusion of a phonological component in current models of reading. From an evolutionary standpoint, it seems naive to assume that reading takes place in isolation from phonological processes. Reading requires intact visual perception as well as an intact language system. Given that both visual perception and language processing were important to human functioning long before a system designed to read written information was needed, it is unlikely that the reading system can be separated from either of these 'older' systems. Currently, there is an ongoing debate in the field of visual word recognition regarding the role of phonology in the processing of single words. One view supports the notion that since people learn to speak before they learn to read, words are stored as phonological representations. This view purports that to reach a specific lexical representation, the phonological system must be utilized. The visual form of a word is assumed to be transformed to a phonological code and then reaches the phonological representation of the specific word in the lexicon. The contrasting view argues that phonology is not required in the processing of written words; that only orthographic information plays a role. Alternative views lie somewhere in-between these two extremes, typically assuming that phonology is one part of word recognition, but that there are many other components as well.

Researchers have suggested that phonological information is contacted immediately and automatically when visually presented letter strings are processed (Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). Perfetti et al. (1988) concluded that during lexical access a high degree of phonetic activation always occurs, regardless of the requirements of the task. Grainger (1990) suggested that the role of phonology in reading should be considered and after further investigation included phonological processes in an extension of the IA model of reading (Grainger, O'Regan, Jacobs, & Segui, 1992). Grainger assumes that phonology, much like letter and word levels in the McClelland and Rumelhart (1981) version of the IA model, has connections with orthography as well as word level units. Orthography contacts both phonetic units and word/lexical level units immediately. Phonology then plays a role in determining the final identification of the word. As previously described, this model has both excitatory and inhibitory connections and as partial orthographic units or phonetic units reach threshold they will either inhibit or excite nodes at the word level. While it is clear that the inclusion of phonology will naturally lead to more specific predictions of how normal individuals will perform on both lexical decision and naming tasks, the details of the model in this regard have not yet been discussed.

Since the IA model is well-supported in the normal literature and has been adapted by Grainger to include more specific predictions regarding word recognition as well as a phonological component, it is a model of reading that should be applied to cases of reading impairments. Given that many accounts of pure alexia assume letter-by-letter instead of simultaneous processing, it may seem counterintuitive to attempt to apply a model which assumes simultaneous visual perception of letter strings. However, the notion that patients with pure alexia read in a left to right fashion is by no means globally accepted by researchers in this field. Several investigators have argued otherwise and alternative hypotheses have been offered based on evidence to the contrary (Shallice & Saffran, 1986; Price & Humphreys, 1992; Bub & Arguin, 1995). Since evidence exists which indicates that patients with pure alexia are capable of whole word processing, a simultaneous processing model can be considered as a possible explanation for the reading patterns observed in these patients.

II. A Cohort Model of Word Recognition. Recently a variant of the Interactive-Activation model, the Cohort model of word recognition was developed by N.F. Johnson and Pugh (1994). This model follows from the work of Marslen-Wilson and colleagues on auditory processing in normal subjects (Marslen-Wilson, 1987). The assumptions of the Cohort model have been strongly supported by studies of auditory perception. At the level of perceptual processing, the Cohort model assumes a bottom-up approach. This means that the system initially relies on the form of the input, rather than context. In auditory processing, the first phoneme of an utterance activates all possible words that start with the perceived sound. This group is termed the *word-initial cohort.* When the second phoneme is heard, a subset of the initial cohort will drop out from the possibilities for final selection. This process continues until there is only one candidate remaining with properties that match the perceptual input. Since auditory input is always presented and processed in a serial format, it is analogous to the assumed serial, letter-by-letter processing of written words demonstrated by patients with pure alexia.

Johnson and Pugh's (1994) recent development of a Cohort model of visual word recognition stems from this earlier work based on auditory processing. The primary goal in developing the word recognition model was to explain previous findings indicating that during the process of reading words, letter information has no immediate availability to the reader even though it is obviously used. In other words, normal readers automatically recognize entire words, but the individual letters are typically not explicitly recovered or acknowledged by the reader. The Cohort model assumes that individual letter information is important in the reading process even though readers are usually unaware of letter level information. Two further goals of the model were to account for the effects of both cohort size (i.e. number of orthographically similar words that share all but one letter) and frequency of occurrence (i.e. word frequency effects).

Johnson and Pugh's model, unlike the Cohort theory of auditory processing, does not assume a left to right, serial processing approach. There is no specification as to the order in which the letters are processed, but it is clear that they are perceived individually and one at a time. The theory purports that each letter in any given letter sequence is processed in terms of its immediate orthographic context. When a reader processes one letter, the two adjacent letters and/or spaces are also part of the percept, but are not explicitly identifiable. These three letter sequences are termed *wickelgraphs.* As a result of processing wickelgraphs, the reader has knowledge of orthographic patterns, not just single letters. As in auditory processing, lexical access is assumed to begin as soon as the first wickelgraph is encoded. The set of activated possible words that are consistent not only with the perceived first letter, but the first wickelgraph will be activated. From here the process is the same as the auditory cohort model described above.

Within the framework of the Cohort model of reading (Johnson & Pugh, 1994) it appears that readers can also implement an inferential strategy. That is, the initial cohort does not have to be completely resolved in order to identify a word. The authors state that readers can 'make a decision on the basis of characteristics of the initial cohort, they could wait until the cohort is fully resolved, or they could make it on the basis of characteristics at any time between these points' (p.257). It is assumed that adjacent letters in a word (i.e. wickelgraphs) are utilized in order to make a decision about the identity of a word. Other forms of contextual information, such as the frequency of wickelgraphs and the size of the activated cohort, are also important in identifying the target. This inferential strategy is described in a way which implies that readers are basing their responses on information which they are aware of, thus indicating an 'off-line' form of processing. The reader is assumed to have the ability to decide if he/she will or will not respond before complete cohort resolution based on the type of task, as well as the extent of orthographic information which has been activated.

Given that the Cohort model supports the notion of letter-by-letter processing which is assumed to typify patients with pure alexia, it seems that this model may be a reasonable explanation for the reading strategy observed in these patients. According to this model, normal processing of a word would be as follows. A reader would automatically identify the first letter/wickelgraph of a word and an initial-word cohort would be activated. The second letter/wickelgraph would limit the number of possible target words. The use of contextual information (i.e. letter combinations) constrains the possible choices even further, narrowing the options to, at most, a few targets. The reader's response is then based on orthographic and letter level information which leads to the identity of a specific word or words. When a lexical decision is required, the representation does not have to be mapped to specific points in other parts of the reading system (e.g. phonology or semantics). It is only necessary for the lexical representation to contact some part of phonological and semantic space in order for the reader to decide that the target is a word. Therefore, if one assumes that 'mapping out' of the lexicon is the primary difficulty for patients with pure alexia, a Cohort approach could lead to accurate lexical decisions.

In the case of a non-word, performance would depend on the characteristics of the target. If a non-word were orthographically similar to a word, it is more likely that it would be perceived as a word on a lexical decision task. That is, a Cohort model approach would turn up an initial cohort because any wickelgraph would lead to at least some options. As with a word, the process would continue until there were no options (i.e. all words had been eliminated from the possibilities). Then, according to Johnson and Pugh, if the non-word was pronounceable, a phonological cohort would be contacted and the same resolution process would occur. On the other hand, if the string of letters was orthographically distinct (i.e., a random string of consonants), then the initial cohort would either be small or no matches would be found, thus quickly yielding no possibilities. This explanation correctly predicts findings that readers take longer to identify and make decisions regarding words or non-words that are orthographically similar to words versus random strings of consonants. Random strings can be eliminated early because usually a minimum amount of information will indicate that the letters do not form a word. Words and 'word-like' non-words will require the activation of more orthographic level information in order to reduce the initial cohort.

The Cohort model would depict the process of lexical decisions in the following way. When a reader processes a word such as 'hard' - the first bigram (or first wickelgraph), 'ha', will activate several words and the first trigram (or second wickelgraph), 'har', will still activate a few. If the reader then decides to make a decision based on the available information, he/she would likely produce a ‘yes’ response because there are several possible words that would fit. However, the non-word 'harn' would result in the same elimination process as in 'hard' and unless the entire cohort is resolved will also result in a ‘yes’ response. While readers have been shown to indicate a ‘yes’ bias towards non-words which are similar to words and a ‘no’ bias to words which are low frequency and have few bigrams, the error rate for lexical decisions is typically very low. The fact that this type of error is infrequent suggests that if an inferential strategy of some kind is utilized in normal reading it is likely implemented very conservatively.

Interestingly, the pattern of performance observed in patient DM (Bub & Arguin, 1995) typifies the pattern of performance which would be expected if one were using a Cohort model and a rather liberal inferential strategy. That is, DM performs above chance when asked to make lexical decisions, but produces a substantial number of false positive errors when presented with non-words that are similar to high frequency words and false negative errors to low frequency words. Given the rapidity of his decisions (typically two to four times faster than naming), it is doubtful that he was able to explicitly process even one or two letters. If DM is using an off-line inferential strategy similar to that implied by the Cohort model, his decisions are likely due to very limited information. Arguin and Bub (1994) provided evidence that DM has difficulty identifying individual letters due to an inability to automatically identify familiar characters. This conclusion suggests that when making lexical decisions, DM may be using a Cohort model approach, but that letter and wickelgraph information may not be identified properly (i.e. mapped to the proper representation), thus leading to confusions among orthographic neighbors.

While the Cohort model of reading is another attractive candidate for explaining the compensatory reading strategy in pure alexia, some aspects of Johnson and Pugh’s (1994) model are not clear. One area of uncertainty is what the authors termed ‘initial semantic activation’. The description of this part of the model suggests an initial 'pulse' through the system which activates semantic information about the target word. This pulse is described as sublexical and while it is not capable of producing explicit recognition, it does have an effect on the processing of words. This was apparently included in the model to account for findings which indicate that identification of words can be more rapid than would be possible within a strict bottom-up model such as a Cohort model. Unfortunately, the authors do not expand upon this issue. The difficulty with their description of semantic activation is that it seems to be incongruent with the remainder of the model. In order to contact semantics immediately it seems the entire word must be represented, thus suggesting that simultaneous orthographic processing does occur. In addition, while the model is primarily bottom-up in nature, the addition of semantic activation seems to suggest top-down processes as well. It may be that Johnson and Pugh (1994) have answers regarding both of these concerns. However, for now, the role of semantics remains unclear.

A second concern regarding the Cohort model of reading is the role of phonology. Johnson and Pugh (1994) suggested that phonology is contacted only when a non-word which appears orthographically correct or an unrecognized low frequency word are the targets. However, the use of phonology as merely a check for non-words and low frequency words is not consistent with findings regarding automatic activation of phonological codes. As discussed above, there is evidence that phonological information is contacted immediately and automatically when visually presented letter strings are processed (Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). Although the current study does not extend into an investigation of phonological variables, this issue will be a focus of future studies.

Although there are some limitations to the Cohort model of word recognition, the letter-by-letter assumption makes it a model which can potentially be used to explore and clarify the reading deficit in pure alexia.

Description of the Relevant Variables

As discussed earlier, there are several questions which stem from previous investigations of pure alexia. The orthographic and lexical variables which will serve as tools in the investigation of these questions were taken directly from the two models described above.

Word Frequency. First, the role of word frequency will be examined. Normal readers demonstrate faster lexical decisions when presented with a high frequency versus low frequency word, and typically are somewhat more rapid in naming high frequency words (although this effect is usually not as strong). It is important to ascertain the role of this variable in each of the patients in the current study. Assuming that the patients use the same explicit strategy for both lexical decision and naming, the variables are expected to effect both tasks similarly. An absence of a word frequency effect (on one or both tasks) would support claims (Coslett et al., 1993, Rapp and Caramazza, 1991) that patients with pure alexia read in a letter-by-letter fashion with orthographic and lexical information having absolutely no influence on this strategy. Given previous evidence indicating intact lexical decisions and word specific priming, it is unlikely that this is the case.

On the other hand, the presence of a word frequency effect (for one or both tasks) would suggest one of two possibilities. It could be that the patients are reading letter-by-letter, and that the frequency effect is related to an off-line 'guessing' strategy based on previous knowledge. In other words, the patients may not be using higher level information based on activation of the word itself, but instead making a guess based on information that is consistent with a familiar word. Alternatively, word frequency effects could be interpreted as evidence that the patients are able to use higher level information that is contacted during the initial activation of the word. The presence of a word frequency effect in the patients would be an encouraging first indication of higher level effects on reading, but because there are other interpretations it would need to be supplemented with further investigations of other orthographic and lexical level variables.

Neighborhood/Cohort Size. A variable which would shed further light on the role of orthographic and lexical information in the compensatory strategy is neighborhood size. If the patients are simply constructing words in a letter-by-letter fashion and guessing what the word is as they accumulate individual letter information, then a larger orthographic neighborhood should lead to slower response latencies on both tasks. Regardless of whether a word is high or low frequency, more neighbors would mean more choices, thus slowing down the selection process. However, if the patients are initially contacting the lexicon based on either a whole word (i.e. IA model) or partial letter information (i.e. Cohort model) and this contact is assumed to produce normal connections with other members of the lexicon, the effects of neighborhood size will depend on the type of task and the frequency of the target word. This will be examined while holding word frequency constant since previous findings indicate that the effect of neighborhood size depends on the frequency of the target.

Regarding cohort size, Johnson and Pugh (1994) reported that a large cohort facilitates naming in normal readers, especially when the target is a low frequency word. On lexical decision tasks, a large cohort was also typically facilitatory, regardless of the frequency of the target. This result was interpreted as indicating that the size of the cohort is used as a critical piece of information in making a lexical decision. A large cohort allows the reader to feel fairly sure that the string of letters is a word and will therefore likely lead to a 'yes' response, allowing the subject to make a decision before complete resolution of the cohort. In contrast, a small cohort does not offer reassurance, therefore requiring complete cohort resolution and leading to longer decision latencies.

The Interactive-Activation model (based on work by Grainger and colleagues) also predicts that, in general, a larger neighborhood will lead to faster lexical decisions. The rationale, however, is quite different. In this model, if more neighbors are activated then more mutual inhibition will occur. In addition, since orthographic neighbors share several letters with the target word, they will facilitate the target letters which will in turn facilitate the target word. The combination of these two activities will allow the target to attain the highest level of activation and consequently be identified. A small neighborhood, on the other hand, will create less activation of individual letters, and will also produce less mutual inhibition of the competitors.

If the normal subjects and patients with pure alexia show a facilitatory effect of large neighborhood size (i.e. faster reaction times), it will support claims by both models that the density of the neighborhood is important. In addition, this finding would rule out a strict off-line 'guessing' strategy because if the patients are using this approach large neighborhoods would be inhibitory, thus leading to slower response latencies. That is, if patients with pure alexia read from left to right and base a guess on partial letter information, then the more possibilities there are to choose from, the longer it should take to respond. However, given the different explanations offered by the two models, even if the findings indicate a facilitatory effect of large neighborhoods, the exact nature of this result would be unclear. It is expected that neighborhood density will facilitate both lexical decisions and naming responses in the normal readers and the patients.

Number of Positions Yielding Cohorts. To further investigate the role of neighborhood/cohort size two additional variables are important. The first was taken from a direct prediction of the Cohort model. Johnson and Pugh (1994) reported that under further investigation, the role of cohort size was secondary to the 'number of positions that yield cohorts'. That is, as the number of positions that have neighbors increases, the time needed to resolve the cohort will also increase. However, it was noted that error rates in a lexical decision task are determined by the number of cohorts (based on the argument above). In addition, when the number of positions which yield cohorts is controlled, then the size of the cohort will have the effects discussed above (i.e. - large leads to facilitation).

There is no direct discussion of this variable in IA model literature. This is likely because all letters in a word are assumed to be processed simultaneously. While the IA model would not predict that having fewer positions would facilitate responding, the opposite prediction might be supported. This model assumes that neighbors which share several letters with a target word are helpful because they reinforce the activation of shared letters which in turn leads to more activation for the target. When few positions yield neighbors, then it is likely that only some of the target letters are facilitated by the word's neighbors. This would suggest that when a word has fewer positions with neighbors less activation of the target from the letter level nodes will occur leading to slower responses. Therefore, the role of this variable will offer more specific information as to the type of processing which occurs in the patients. If they demonstrate faster reaction times in response to words with 'few positions', then the interpretation would be that Cohort type processing is occurring. No effect or longer response latencies for 'few positions', would be evidence against the Cohort model and could be interpreted as evidence supporting an IA model of reading.

Neighborhood Frequency. As indicated by the work of Grainger (1990) and Grainger and Segui (1990), another important variable is neighborhood frequency. Neighborhood frequency is defined as the word frequency of the orthographic neighbors of the target. According to these authors, the effect of neighborhood frequency depends on the task. In naming, more frequent neighbors typically lead to facilitation. The exception to this prediction would be when a higher frequency neighbor is a phonological enemy (i.e. is pronounced differently). When a lexical decision is required, higher frequency neighbors lead to slower reaction times. In general, low frequency targets are more sensitive to the effects of neighborhood frequency. Another key finding reported by Grainger and Segui (1990) and Grainger et al. (1992) is that increasing the number of higher frequency neighbors does not slow the responses of normal readers on a lexical decision task. This finding was interpreted as support for the IA model's assumption of mutual inhibition. In addition, lexical decision responses to words with several higher frequency neighbors (as opposed to one higher frequency neighbor) were reportedly faster.

If the patients with pure alexia show an effect of neighborhood frequency, the interpretation would be that the compensatory strategy is not purely letter-by-letter. Instead, a neighborhood frequency effect, especially on the naming task, would indicate that the reading strategy in patients with pure alexia is affected by higher level orthographic and lexical information. This would indicate that the strategy is not separate from implicit identification, nor can it be considered letter-by-letter.

'Unique Point'. An investigation of this final variable is an attempt to directly refute the notion that patients with pure alexia read words in a left to right fashion using an off-line type of 'guessing' strategy. The critical independent measure will be the location in the word at which the cohort can be resolved. This point will be referred to as the 'unique point'. For example, the unique point in the word 'able' is the second position. If one reads from left to right, the 'b' is the point where there are no other neighbors and the target word can be identified. The cohort for the word 'hard', however, cannot be resolved until the fourth position is processed because there are still neighbors after the third position (harp, hark). This particular variable is not expected to have an effect on the lexical decision or naming rates of normal readers as there is no reason to assume a left to right process in single word reading. If the patients are reading one letter at a time and from left to right, they should respond faster to words that can be resolved at the second position versus the third position, and faster to the third as opposed to the fourth. An absence of this pattern will support the claim that these patients are not reading from left to right.

What is Expected?

There are several possibilities as to what one might expect to find. First, if patients are in fact reading left to right and using a bottom up process based on individual letter information, then orthographic and lexical variables should have little or no effect on reaction times or error rates. In addition, the patterns of performance of the patients should look different than those of the normal readers.

A second possibility is that initial activation is normal in these patients as is the link between this activation and explicit reading. However, it may be that there is a disruption in the lexicon, leading to weaker or diffuse connections between lexical representations. If this is the case, the patients may be affected by some of the same orthographic variables as are normal individuals, but will not respond to others because of the nature of their deficit. For example, a variable such as word frequency may still affect the patients' reading because it is part of the lexical representation of the word, but unrelated to the rest of the lexicon. On the other hand, lexical variables that represent intact connections within the lexicon (e.g. neighborhood density or neighborhood frequency) will either not affect patients with pure alexia or will not produce the same pattern of results as reported in normal reading. This set of results would suggest that the difficulties seen in pure alexia are due to a disruption, but not a total destruction, of the lexicon.

A third possibility is that the patients will demonstrate the same pattern of performance as seen in the normal subjects. That is, the patients' performance would be affected by the same variables as seen in normal reading, with the effects on performance producing the same patterns of responding. If this is the case, there would be no reason to assume that the mapping from visual information to the lexicon is disrupted. In addition, this set of results would suggest that higher level information does interact with the compensatory strategy and that implicit word identification has not been separated from the explicit strategy employed by these patients. Under these circumstances, the deficit in pure alexia would likely be explained by damage to a part of the system which is beyond the level of lexical access.

This third possibility is the scenario that I am expecting. Previous results offer strong evidence supporting intact lexical access and representations of individual words (Bowers et al., 1996). This suggests that normal activation occurs, indicating an intact system up to the point of lexical access. Evidence which can be interpreted in favor of intact orthographic/lexical organization is not so straightforward. One piece of evidence which seems to support intact connections within the lexicon is the lexical decision performance of patient DM (Bub & Arguin, 1995). As described above this patient made errors which indicated neighborhood effects. He responded ‘yes’ to non-words with large neighborhoods and ‘no’ to low frequency words with small neighborhoods. This effect would not be expected unless the appropriate neighborhood of the target word was also activated. Based on these and other previous findings, the current study will attempt to show that the reading strategy of patients with pure alexia is affected by the same variables which affect normal readers.

One attractive explanation of pure alexia which is consistent with the notion of damage beyond lexical access was suggested by Bub and Arguin (1995) and Bowers et al. (1996). The authors hypothesize that the initial processing of the whole word is normal, but there is weaker than normal output from this system and therefore activation is insufficient to explicitly identify the word. The observed letter-by-letter approach is thought to be a 'clean-up strategy' which is used to fill in missing or weakly activated parts of the initial lexical access. The apparent letter-by-letter approach is necessary to fill in the letter positions which were not activated sufficiently. Thus, the notion of a left to right, letter-by-letter approach would be incorrect. Unfortunately, the data of the current study are not able to verify this explanation. Methodology for potential future studies with this particular goal will be described in the discussion of the current study.

Summary

The primary goal of the current study is to show that the deficit in patients with pure alexia is not at the level of mapping from the percept to an orthographic representation. In other words, the initial activation of a target word occurs normally. Furthermore, I will attempt to show that this initial mapping (i.e. activation) to the lexicon is not disconnected from the explicit reading strategy of the patients. Instead, it is hypothesized that pure alexia is a disruption in mapping out of the orthographic space into other regions which are crucial in word recognition (i.e. phonology and semantics). Thus, it is suggested that the compensatory strategy is designed to repair this damaged mapping operation.

The tools of this investigation will be orthographic and lexical variables which have been shown to affect normal reading. These variables were derived from two contemporary models of normal word recognition: the Cohort model and the Interactive-Activation model. Comparisons of normal readers and the patients with pure alexia will serve to illuminate how each patient's reading strategy is influenced by variables which have important roles in intact reading. The results of these comparisons will indicate if and (more generally) how orthographic and lexical information affects the compensatory strategy which characterizes pure alexia. In addition, the results may shed some light on the nature of the patient's underlying reading process (i.e. letter-by-letter or simultaneous).

Case Reports and Method

Participants

Three patients with pure alexia (DM, IH, and JL) were tested and ten neurologically intact individuals served as control subjects.

Patient 1. DM, a right-handed male, was 24 years old at the time of testing. He was an undergraduate engineering student when he suffered from a left parieto-occipital hemorrhage secondary to an occipital arterio-venous malformation in February of 1990. One month later the hemorrhage was evacuated and the malformation was removed. Post-surgical CT scans indicated left occipital damage, the lesion which is classically associated with pure alexia. The corpus callosum was spared. No language deficits other than the processing of visual words were observed in this patient. The experiments reported here were conducted approximately one year post-surgery.

Previous investigations of DM's performance (Bub & Arguin, 1995) found the typical slowed reaction times and clinical presentation of pure alexia when he was asked to name a target item. However, he was able to make rapid lexical decisions (although still slower than normal readers) with accuracy consistently above chance. The authors interpreted these findings as evidence that DM can access lexical information in a normal fashion under certain conditions (e.g. when judging familiarity of words), but must rely on a less efficient strategy (i.e. letter-by-letter reading) when explicit identification is required.

Patient 2. IH, a right-handed male, was fifty-five years old at the time of testing. He had suffered a subarachnoid hemorrhage 10 years earlier. No CT scan was available to the investigators, but the neurological case report indicated that IH had suffered a left temporal-occipital hematoma. Following the hemorrhage, his primary complaints included a complete right-homonymous hemianopia, moderate anomia (i.e. word finding difficulty), surface agraphia (problems with spelling), and reading difficulties.

Unlike DM, IH demonstrated slowed lexical decisions, as well as slowed reading suggesting the use of a similar strategy for both types of tasks. However, Bowers, Arguin, and Bub (1996; this study is described above) reported that IH demonstrated fast and specific orthographic priming, indicating that he is able to gain relatively normal access to orthographic representations.

Patient 3. JL, a right-handed male, was approximately 70 years old at the time of testing. In 1986, he suffered from a stroke, which resulted in a dense right homonymous hemianopia as well as pure alexia. Test results used in the current study were collected in 1989 and 1990. No CT scan was available, but based on his reported difficulties, his lesion was likely in the left occipital-temporal region. He demonstrated no other language deficits. He showed intact spelling, normal object recognition, and presented as very articulate and well-educated.

Neurologically intact participants. Ten normal readers (five males and five females) were tested. All were right-handed and under twenty-five years of age. Each participant was an undergraduate attending McGill University in Montreal. All subjects spoke English as a first language.

Data Collection

Stimuli and Materials. The stimuli were 1271 words and 678 nonwords. All items were four-letters long and were displayed in uppercase, printed in a large, bold font. The words were selected from the Pocket Lexicon which contains 19839 entries from the Merriam-Webster Pocket Dictionary of 1964. Their frequencies ranged from 0 to 10595 per million words (Francis & Kucera, 1982). The nonwords were made by changing one letter of a four-letter word such that the item remained pronounceable and that it was roughly matched to the base-word on single-letter and bigram frequencies (Mayzner & Tresselt, 1965). For the set of words, the average frequencies of the constituent letters and bigrams were 181 and 772, respectively. The stimuli were presented on the screen of a Macintosh computer controlled by PsychLab software (Bub & Gum, 1988).

Procedure. All subjects were presented with each stimulus on two separate occasions; once to name the words and nonwords and another time to decide if the item was a word or nonword (i.e. lexical decision). Words and nonwords were distributed randomly across 20 blocks of 89-98 trials, each comprising 32-34 nonwords. Normal subjects completed the experiments in approximately 5, 30-minute testing sessions conducted over a period of a couple of weeks. Each of the three patients completed the testing in approximately 8 sessions over a duration of a few weeks to several months, depending on the availability of the individuals.

Each trial began with a 1500 ms fixation point presented. Its offset was followed by a 500 ms delay and then by a target word or nonword. For the normal readers the fixation point and targets were presented in the center of the screen. For the patients the fixation point and target presentation were moved to the left half of the computer screen because all three patients had right visual field deficits. The target remained on the screen until the subject responded. For the naming task, participants were instructed to report the target by reading it aloud. The lexical decision task required the participant to answer 'Yes' if the target was a word or 'No' if the target was a nonword. On both tasks, participants were instructed to respond as quickly and accurately as possible. Reaction times were recorded via a voice key which triggered the offset of the stimulus. Verbatim responses were then recorded by the experimenter.

Rationale of data collection procedure. This large set of four letter items was chosen for testing in order to embody a representative set of points within the lexicon. Gathering this extensive data set from each participant allowed the experimenter the opportunity to carry out experiments after data collection was complete. This procedure allowed a potentially unlimited number of related experiments in order to answer important questions, without the difficulty of contacting patients repeatedly. When working with individual cases, patients may not be available for further testing. Questions often remain unanswered because the patient relocates or simply decides he/she is no longer interested in participating.

A second strength to this method is that when conducting individual experiments, the largest number of possible targets which meet the criteria under investigation can be included. Typically, when an individual experiment is designed a restricted number of targets are chosen for practical purposes. It is rare that all possible targets are used. In the current study, it was possible to search the database for all items that fit the description for each individual experiment.

A third strength of this approach is that all lists were formed randomly. Under typical experimental conditions there is a risk that presenting a specific type of list to the subjects will lead to biased responding. Indeed, this type of difficulty was reported in experiments by Johnson and Pugh (1992). The authors found a strong facilitatory effect for large cohorts when normal readers were presented with a list of words with large cohorts separately from a list of items with small cohorts. However, when subjects were tested later using mixed lists of items that had both large and small cohorts, the earlier result decreased markedly.

Development of the Database

A large portion of the current study was devoted to the development of an extensive and accurate database for the set of four-letter words. A survey of the current and past literature was completed in order to choose the orthographic and lexical variables most relevant to the current study. Variables which were obtained from the two models under investigation were the primary focus. Following is a list of the independent variables which were chosen to be included in the database:

(a) Word frequency

(b) Bigram frequency

(c) Single letter frequency

(d) Letter confusability

(e) Total number of neighbors

(f) Total number of higher frequency neighbors

(g) Total number of lower frequency neighbors

(h) Number of neighbors (total, higher, and lower) at each letter position

(i) Unique point

(j) Number of positions with neighbors

The values of the first four variables have been reported many times in previous studies. Information necessary for the final six variables, however, have not been reported previously. In order to determine *e, f,* and *g*, the number of neighbors in each position (h) was computed. For each word, the number of neighbors at position 1 was calculated first. As described earlier, orthographic neighbors are words made of the same number of letters as a particular target and which only differ from it by one letter (e.g. CART-DART; Coltheart, Davelaar, Jonasson, & Besner, 1977). For example, in its first position, the word CART would have the neighbors D, H, M, P, T, & W. Next, whether these neighbors were higher or lower frequency than the target was determined. In this example, the frequency of CART is 5 per million, DART and MART are lower frequency neighbors, and the other four are higher. This same procedure was completed for each letter position. In the second position CART would have one neighbor (CURT), and then two neighbors (CANT and CAST) in the third position. The total number of neighbors, total higher frequency neighbors, and total lower frequency neighbors were then calculated by summing the information for the individual letter positions.

The next variable, *unique point*, is the position, going from left to right, at which the word has no neighbors. For the word CART, the unique point is the fourth position because it is not until this point that the word can be identified. The word SICK is unique at the third position. There are no four letter words other than sick which begin with 'SIC'; thus once the letter C is reached there are no other possibilities.

The final variable, the number of positions with neighbors, was computed by organizing all target words according to the number of neighbors in each position. The number of positions with zero neighbors was recorded. In keeping with Johnson and Pugh (1994), words with zero positions yielding neighbors were not included. The remaining words were placed either in a set containing one or two positions with neighbors (i.e. 'few positions' yielding neighbors), or the set with three or four positions (i.e. 'many positions' yielding neighbors) with neighbors.

Experimental Investigations

After the database was complete, the questions outlined in the introduction led to the development of several experimental investigations. For the purposes of the current study the investigations focused on the reaction times and error responses to words only. Lexical decision and naming reaction times were examined separately.

Fox Pro. In order to complete the experiments, a relational database software package was utilized. Previous studies have frequently contaminated findings by confounding variables when choosing experimental stimuli. Also, some of the variables of interest tend to strongly covary. As discussed earlier, two such variables are the lexical frequency of a target and the total number of orthographic neighbors. FoxPro (1993) was selected as the tool for avoiding this pitfall. This software package is described as a relational database management system.

Utilizing FoxPro, the sets of experimental stimuli were created so that they differed markedly on the variable(s) under investigation, but were closely matched on all other important variables. For example, in order to study the joint effects of orthographic neighborhood size and word frequency, four different sets of items were chosen - (1) high frequency words with large neighborhoods, (2) high frequency words with small neighborhoods (3) low frequency words with large neighborhoods, and (4) low frequency words with small neighborhoods. All other variables were held constant in order to insure only the effects of cohort size and frequency were responsible for any differences in performance.

While this type of experimental design would be rather cumbersome without a relational database, using Fox Pro made this task quite manageable. In order to chose the items for the experiment described above, one would need to determine (usually based on previous literature) the definition of the critical variables. For the example above, the ranges for high frequency and low frequency would need to be established as well as the number of neighbors which constitute a small versus large neighborhood. The appropriate ranges were then entered into the program and Fox Pro searched the entire database to find all of the items which met the defined ranges. All other variables were then matched by deleting outliers in each category until all four sets were matched on all but the critical variables.

Analyses

After the experimental stimuli were appropriately chosen and matched on all relevant variables, the data of the individual patients and the averages of the normal subjects were examined. To begin, all items that were recorded as voice key errors were eliminated as were items that were extremely fast (<300 ms) or extremely slow (> 5000 ms for the patients and >1000 ms for the normal subjects). The extreme responses were thrown out because they were assumed to indicate voice key errors that were not recorded by the experimenter.

Next, for each experiment, mean reaction times and standard deviations were calculated for each patient and the average of the normal subjects on both the lexical decision and naming task. All items that were two standard deviations above or below the mean were eliminated. Given the large number of targets that generally comprised a particular set, even after eliminating the outlying data points a large set of reaction times remained for the purposes of analysis.

In addition to reaction time data, the error rates of the patients were also examined. The sum of errors produced by each patient for each experimental condition was calculated and then converted to an error percentage. Although previous studies have investigated error rates in normal subjects, those studies typically utilized experimental conditions which yielded errors (i.e. limited exposure duration, backward masking). Due to the limitations of the patients, the current study placed no constraints on the viewing time or time allowed for a response. As a result, normal subjects produced very few errors.

SPSS 7.0 was used to compare differences in reaction times and error rates for the conditions under investigation. Analysis of variance and T-tests were completed where appropriate. It is important to note that the data of the patients generated large standard deviations, thus leading to more difficulty in attaining significant findings. Therefore, patterns of performance are also important in the current study in order to obtain a better understanding of the variables which affect the patients with pure alexia.

Experimental Investigations

The experiments reported here were designed to determine if the explicit reading strategy observed in patients with pure alexia is affected by the initial mapping (i.e. activation) to the lexicon. The first investigations (Experiment 1 & 2) were an attempt to discredit the claim that pure alexia can be explained by a deficit at the level of mapping from the perceptual level to an orthographic representation. In other words, the goal was to show that initial activation of a target word occurs normally in the patients in this study. The latter experiments (3-6) will specifically investigate the organization (i.e. associations between) lexical representations and the effects of initial activation on the compensatory strategy. In addition, the issue of whether the explicit strategy observed in these patients is actually letter-by-letter and/or left to right reading will also be examined.

Each experiment was designed to examine the effects of a particular variable(s) uncontaminated by other variables. For all experiments, the patterns of naming and lexical decision results of each of the patients was compared to the results of neurologically intact readers. The subjects and procedure for choosing experimental stimuli were the same for all experiments. (See the above description in the METHOD section.)

Experiment 1

It is well-documented that normal readers are strongly affected by word frequency on various word identification tasks. Higher frequency words lead to faster, more accurate responses. Typically, this facilitatory effect of higher frequency words is stronger on lexical decision tasks than naming tasks. Naming is thought to be less affected by word frequency because explicit identification is not required. Therefore, naming latencies are based on the pronunciation of the word with little or no reliance on lexical information. Based on these previous findings, there were two purposes for the initial experiment.

First, Experiment 1 served to check the validity of the data from intact control subjects. If the normal readers were performing as expected the results would suggest that the data are likely valid. If a word frequency effect was not evident in the normal results, the question as to why this effect is absent would need to be pursued. Two possible explanations would be that the normal readers were somehow different than other groups of normals or that the data collection process was somehow flawed.

In addition, this experiment investigated the effects of word frequency in each of the patients on both tasks. If frequency does not affect the patients' accuracy or speed of responding there would be no reason to conclude that the explicit reading is affected by any higher level information. The absence of a word frequency effect would be consistent with claims by other researchers (Patterson & Kay, 1982) that the reading strategy in pure alexia is as it appears, a strict letter-by-letter approach.

Alternatively, if the patients demonstrate a word frequency effect, there are two potential interpretations. The first is that word frequency effects occur within the framework of an explicit, off-line strategy. This explanation would also be consistent with claims that the patients read letter-by-letter. This approach would likely involve a 'guessing' strategy based on partial letter information used to determine the identity of a word. If the patients are 'guessing', they are likely choosing more frequent words which are compatible with the limited information they have processed. This would lead to faster and more correct responses for high frequency targets and less accurate and slower responses for the low frequency items.

The second alternative is that word frequency effects indicate the use of higher level information in the explicit identification of words. That is, the activation of lexical representations may be underlying the word frequency effect. Both the IA and Cohort models assume that high frequency words are identified faster because they have higher resting levels of activation. Word frequency effects based on whole word activation would support the notion that the initial activation of a word affects the compensatory strategy of patients with pure alexia.

While an effect of word frequency alone will not prove that orthographic and lexical information affects explicit identification in the patients, it would justify the investigation of other variables. On the other hand, if the patients do not demonstrate a word frequency effect the claim that the patients are reading letter-by-letter would be supported and there would be little benefit in forging ahead.

Stimuli. For the purposes of this experiment, high frequency was defined as above 100 (mean = 427) and low frequency was below 60 (mean = 4.4). The initial set of high and low frequency words were matched for bigram frequency, single letter frequency, letter confusability, and total number of neighbors. The matched sets of high and low frequency items contained 200 words each.

Results. As expected, normal readers responded faster to high frequency target items on both the lexical decision and naming tasks. Also, as previously reported, the effect in lexical decision (56 ms decrease in reaction time for high frequency items, $p<.001$) was stronger than in naming (11 ms decrease, $p<.01$). All three patients also demonstrated significant frequency effects on both tasks. In addition, DM made significantly more errors ($p<.001$) on the lexical decision task when the target words were low frequency versus high frequency. Table 1 summarizes the facilitation of high frequency words with regard to reaction times and error rates.

Discussion. The results of this initial experiment indicate that the patients show the same pattern of frequency effects as normal readers. As discussed above, there are two possible explanations for this finding: an explicit, off-line strategy based on guessing or an automatic effect of higher level information on the compensatory strategy. The second interpretation is consistent with earlier research indicating 'normal' activation in patients with pure alexia (Bowers et al. 1996, Bub & Arguin, 1995) and is the explanation favored here. This experiment is encouraging in that it does not offer strong support for the claim

Table 1.

Mean Lexical Decision Latencies (in ms), Mean Lexical Decision Error Rate, and Mean Naming Latencies for Experiment 1.

	Lexical Decision			Naming
	Word Freq	**RT**	**Error %**	**RT**
DM	High Freq	667 (84)	5.5 (0.2)	1662 (544)
	Low Freq	732 (98)	62.5 (3.4)	2163 (620)
IH	High Freq	1102 (461)	1.5 (0.9)	1921 (591)
	Low Freq	1463 (728)	4.0 (1.4)	2139 (600)
JL	High Freq	1764 (668)	2.0 (1.0)	2114 (537)
	Low Freq	2451 (645)	6.0 (1.7)	2314 (451)
Normals	High Freq	561 (42)	NA	485 (30)
	Low Freq	617 (53)	NA	496 (40)

Note. Standard deviations are in parentheses. Error rates are reported as percentage incorrect.

that the reading strategy employed by the patients is strictly letter-by-letter. The following experiments will further investigate the role of orthographic and lexical variables in the compensatory strategy.

The findings of Experiment 1 are consistent with both models of word recognition. According to the IA model, frequency effects are the result of higher resting levels of activation. Higher frequency words reach threshold more quickly than low frequency words because they start at a resting level closer to threshold. The IA model, therefore, assumes that frequency effects are based on direct access to whole word forms. The Cohort model also predicts frequency effects based on a similar notion of a baseline level of activation. The initial cohort is formed when the first wickelgraph is encoded. Higher frequency words that contain the wickelgraph will be activated more quickly and will reach a higher level because they start at a higher level of activation. This prediction is also based on the idea that frequency effects are the result of access to word forms. However, in contrast to the IA model, the words are contacted based on partial letter information rather than whole word processing. Despite this difference, the results of Experiment 1 are consistent with the predictions of both models.

Experiment 2

According to Johnson and Pugh (1994), the Cohort model makes a general prediction that the processing time for words should increase with increasing neighborhood size. However, specific predictions are dependent on the amount of cohort resolution that is required for a particular task. When more cohort resolution is needed the effects of neighborhood size are typically inhibitory. The authors described how neighborhood size can also be facilitatory in both naming and lexical decision tasks.

Based on the assumption that naming does not require cohort resolution, Johnson and Pugh (1994) stated that a member of a large cohort will be identified faster than an item belonging to a small cohort. This effect will be stronger for low frequency as compared to high frequency words. Naming latencies, according to the Cohort model, are primarily based on the time needed to establish the initial word cohort. The cohort for a low frequency word with many neighbors will be activated more rapidly than a low frequency word with few neighbors because the item's letter patterns are more likely to be familiar. A high frequency word will be less affected by cohort size because the patterns of its letters are already familiar.

Lexical decisions typically involve complete cohort resolution. However, according to the Cohort model, the reader can choose to make a decision based on context and higher level information (typically semantic) at any time during the process. Johnson and Pugh (1994) reasoned that when a word is a member of a large neighborhood, it activates a larger initial cohort leading the reader to feel quite certain that an item is a word. Under this circumstance, cohort resolution becomes less necessary and a large cohort leads to faster reaction times. The authors also found that when the size of the initial cohort was varied normal readers were biased to respond 'yes' to items with large neighborhoods and 'no' if the target was part of a smaller neighborhood. In general, the Cohort model assumes that the effect of cohort size on response latencies and error rates depends on the extent to which the cohort must be resolved. However, since the results were not completely predictable, it was concluded that 'how and when cohort information is used is determined by the task and under the cognitive control of the subject.' (p.300). In other words, the reader can choose to base a lexical decision on neighborhood information or can 'play it safe' and wait until complete cohort resolution has occurred.

In the original IA model (McClelland & Rumelhart, 1981) the effects of neighborhood size were discussed only briefly and related to single letter identification rather than whole word identification. The authors reported a facilitatory effect of large neighborhoods on single letters in pseudowords. They suggested that the large neighborhoods led to more facilitatory feedback to the individual letters. Grainger (1990,

1992) acknowledged the existence of neighborhood size effects on words, but argued that the number of neighbors is not the important measure, but instead the frequency of the neighbors is crucial. This work has shown that neighborhood size effects are typically strongest in low frequency words where items also tend to have several higher frequency neighbors. The correlation between neighborhood size and number of higher frequency neighbors does not exist for high frequency words, therefore explaining the minimal effect of neighborhood size for high frequency items.

Andrews (1989, 1992) also found that a large neighborhood facilitates lexical access. In a recent study (1992), she controlled for bigram frequency in order to control for potential confounds due to orthographic 'wordlikeness'. That is, words with large neighborhoods tend to share bigrams with many other words and are more likely to have a high bigram frequency. When bigram frequency was controlled (i.e. high vs. low) a large neighborhood still had a facilitatory effect on response latencies. Andrews interpreted this finding as evidence that lexical similarity (i.e. whole word representations) rather than orthographic redundancy was responsible for the facilitation.

Experiment 2 will examine the effect of neighborhood size on the patients' performance. Neighborhood size affects normal readers and appears to do so based on relationships between lexical representations. If the patients' results indicate a disruptive effect of large neighborhood size, the off-line 'guessing' strategy described as a possible explanation of the frequency effects would appear to be correct. That is, a large neighborhood would make it more difficult for the patients to make an accurate 'guess' based on partial letter information. If this explicit, guessing strategy was responsible for the patient's reading patterns, then a high frequency word with no neighbors would be the best case scenario and a low frequency word with a large neighborhood would be the worst. Support for this strategy would be consistent with the claim that higher level information (i.e. lexical variables) does not affect the patients' reading strategy.

Alternatively, if the patients' responses are facilitated by large neighborhoods (as in normal reading), there would be reason to believe that the connections within the lexicon are intact and that information regarding a word's neighborhood has a beneficial effect on their explicit responses. This finding would also rule out the 'guessing' strategy described above. Although a facilitatory effect of large neighborhood size would be strong evidence for higher level effects in the patients, it is also important to remember that neighborhood size is related to bigram frequency and may covary with other orthographic variables as well.

Stimuli

First, one set of items with large neighborhoods and one with small neighborhoods were chosen utilizing FoxPro. The mean number of neighbors for the large neighborhood set was 12.0, while the mean for the small neighborhood set was 1.3. Second, given the results of Experiment 1, each of the sets was separated into a set of low frequency (less than 60) and a set of high frequency (more than 100) items. The four groups of words were matched as closely as possible on other variables, including bigram frequency, single letter frequency, as well as single letter confusability. However, there was a significant difference between the large and small neighborhoods on bigram frequency. This is not surprising given the fact that words with more neighbors typically contain bigrams which are more common. Based on Andrews findings discussed above, this difference in bigram frequency is not considered to be a confound, but rather an irrelevant artifact, in the current experiment. Table 2 lists the specific characteristics of each group of stimuli.

Results

The results of the normal readers revealed a significant main effect of neighborhood size on both lexical decision reaction times ($F(1,373) = 9.39$, $MSe=2600.20$, $p<.01$) and naming latencies ($F(1,380) = 13.56$, $MSe=1247.88$, $p<.001$). Faster responses were concurrent with large neighborhoods on both tasks. There was no interaction of

Table 2.

Mean Descriptive Statistics of the Experimental Stimuli for Experiment 2.

Variable	**Experimental Category**			
	HF Lg Nei	**HF Sm Nei.**	**LF Lg Nei**	**LF Sm Nei**
Word Frequency	493 (313)	578 (345)	16 (16)	11 (13)
Total # of Neighbors	10.9 (2.7)	1.8 (1.0)	12.2 (2.4)	1.3 (0.8)
# of Higher Freq Neighbors	0.7 (0.7)	0.2 (0.5)	6.9 (3.3)	0.7 (0.7)
# of Lower Freq Neighbors	10.2 (2.8)	1.6 (1.0)	5.3 (3.3)	0.6 (0.7)
Bigram Frequency	249 (83)	198 (171)	169 (68)	94 (118)
Combined Single Letter Frequency	843 (462)	911 (445)	721 (458)	758 (424)
Letter Confusability	1.9 (0.3)	1.9 (0.2)	1.9 (0.3)	1.9 (0.2)

Note. The values reported for single letter frequency, bigram frequency, and letter confusability represent a sum for the entire word. HF = High Frequency, LF = Low Frequency, Nei = neighborhood, Freq = frequency size neighborhood size and word frequency, indicating that large neighborhood size had an equally facilitatory effect on both high and low frequency words.

The performance of the patients also indicated neighborhood size effects. Figure 2 depicts the pattern of response latencies of the normal readers and each patient. An analysis of JL's performance indicated a main effect of neighborhood size ($F(1,371)=10.86$, $MSe=522,295.35$, $p<.01$) on lexical decision latencies, while the neighborhood effect for naming did not reach significance ($p=.089$). Responses to items with large neighborhoods were faster for both tasks. IH's results revealed main effects of neighborhood size on response latencies ($F(1,348)= 8.65$, $MSe=367,827.78$, $p<.01$) and error rates ($F(1,397)= 4.01$, $MSe=.05$, $p<.05$) for the lexical decision task. His performance on the naming task indicated an interaction between frequency and neighborhood size ($F(1,350)=5.57$, $MSe=410,299.41$, $p<.05$), with large neighborhoods yielding a stronger facilitatory effect on low frequency items, than on high frequency words.

An analysis of DM's performance showed a main effect of neighborhood size on lexical decision error rates ($F(1,397)=3.86$, $MSe=.21$, $p<.05$). He made 34 percent errors for words that had small neighborhoods and 22 percent for words with large neighborhoods. DM did not show interactive or main effects on response latencies for either task.

Discussion.

The results of this experiment are consistent with the notion that normal activation is taking place in these patients. Normal readers have been shown in previous experiments and in the current study to be affected by the neighborhood size of a word. Words with larger neighborhoods lead to faster reaction times on both lexical decisions and naming tasks than words with smaller neighborhoods. Normal readers in this experiment produced very few errors regardless of neighborhood size. Two of the three patients also demonstrated effects of neighborhood size similar to that of the control subjects. Although

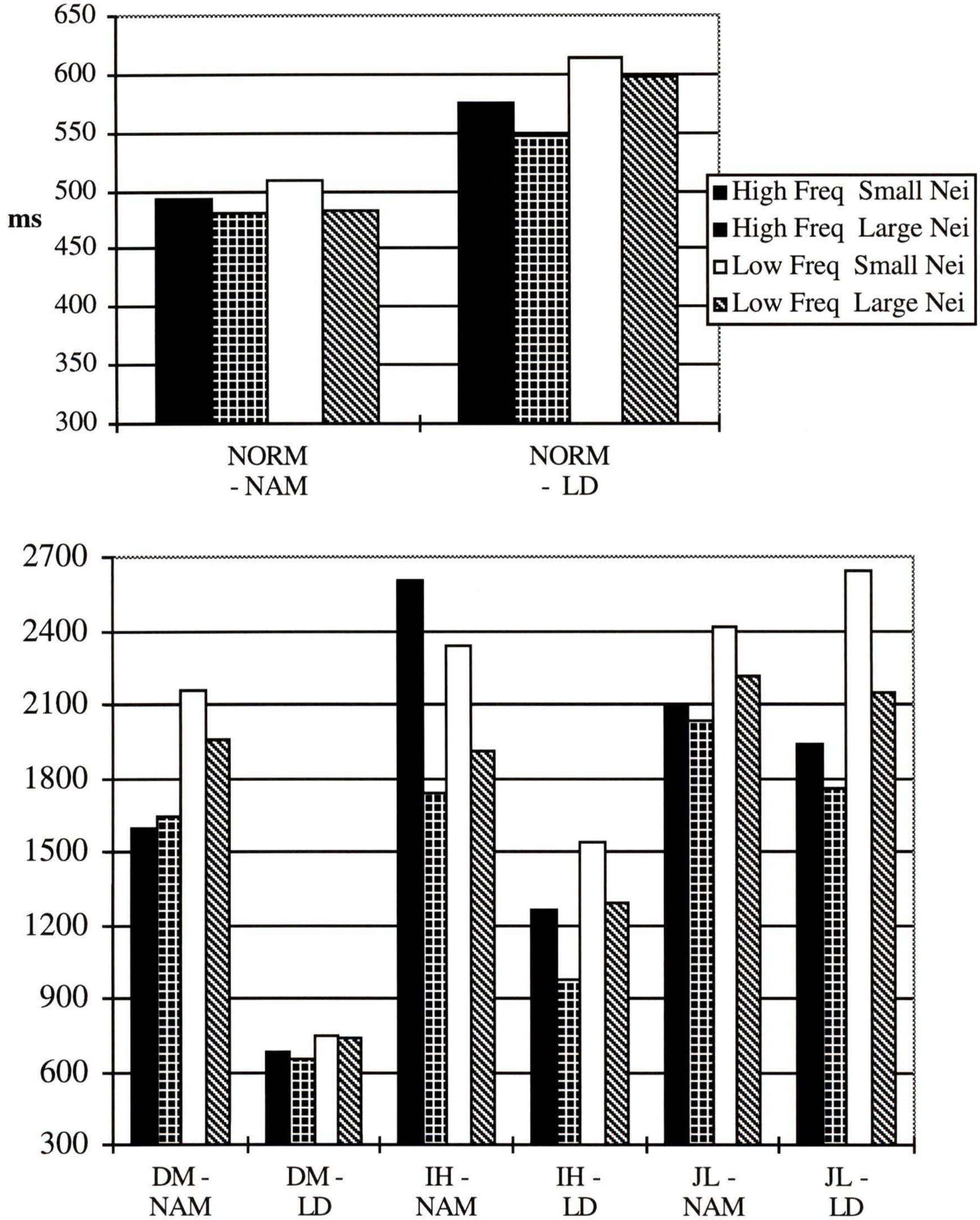


Figure 2. Lexical Decision and Naming Latencies of the Normal Readers and Patients for Experiment 2. Word Frequency and Neighborhood Size were investigated.

Note: NORM=Normal readers; NAM=Naming; LD=Lexical Decisions; Nei=Neighbors; Freq=Word Frequency

DM's response latencies did not indicate a beneficial effect of large neighborhoods, he made fewer errors on the lexical decision task when items had large neighborhoods.

It would be difficult to argue that effects of neighborhood size, particularly in normal readers, are not related to direct lexical access. Although some researchers (e.g., Grainger, 1990) have suggested that these effects may be related to orthographic confounds such as bigram frequency, the work by Andrews (1992) indicated that neighborhood size effects are based on lexical similarity. Since it appears that 'normal' activation occurs in the patients, the effects of neighborhood size are likely due to the same processes that are thought to be responsible for these effects in normal readers. Therefore, the patients' performance suggests that the lexical representations contacted during initial activation are intact with respect to the organization of the lexicon. Neighbors are contacted and the size and features of the neighborhood is relevant to further processing in the patients.

In addition, the results of this experiment suggest that the initial activation may have a stronger effect on the lexical decisions of the patients than it does on explicit naming. Each of the patients demonstrated improved performance for items with large neighborhoods when asked to make lexical decisions, but the effects on naming were less consistent.

While these findings provide further support for the hypothesis that normal activation occurs and that this activation takes place within an intact lexicon, they do not enlighten us as to what occurs during the compensatory strategy in patients with pure alexia. Lexical decisions may be more sensitive to orthographic and lexical variables because a response can be based on lexical activation alone. Contact with other components of the reading system may not be required (i.e. semantics and phonology are not necessary). While naming may be affected by the same variables to the same degree, these effects may be obscured by the patients' difficulty mapping out of the lexicon onto other components, such as phonology. Thus, the role of the initial activation in explicit recognition could be important, but not apparent because of another deficit.

With regard to the models of word recognition, both support a facilitatory effect of large neighborhood size. However, the Cohort model assumes that the effect of cohort size would be weak or non-existent for high frequency items. The normal readers in the current study did not show this predicted interaction, suggesting that the reason for the neighborhood size effects are not as the Cohort model has described. In this experiment, larger neighborhoods were facilitatory, even for very high frequency words. This finding is also inconsistent with Grainger's (1990, 1992) results which suggest a minimal effect of neighborhood size for high frequency words. Grainger reasoned that an interaction would be expected because neighborhood size is not the crucial variable, but rather neighborhood frequency is important. That is, higher frequency neighbors are responsible for the facilitation and since high frequency words have few, if any, higher frequency neighbors, this effect will not occur. Interestingly, the results of Experiment 2 do not conform to the predictions of either model.

Experiment 3

Although the results of Experiment 2 were inconsistent with predictions of the Cohort model, the precise reason for this difference is difficult to ascertain without further investigation. Converging evidence against the Cohort model would be necessary in order to completely disregard the model's utility. With regard to the current study, supporting or rejecting the two models was not a primary focus. Therefore, rather than focusing on explaining these discrepant results, the investigations were continued based on the variables which were originally chosen from both of the models.

Given the basic assumptions of the Cohort model, Johnson and Pugh (1994) also investigated the 'number of letter positions yielding cohorts'. They expected that as the number of positions with neighbors increased, the length of time needed to resolve the cohort would also increase. Since this effect would only impact tasks which require complete cohort resolution, lexical decisions were expected to be affected whereas naming was not. The authors reported that normal readers performed faster on a lexical decision task when words had fewer positions which yielded cohorts. Experiment 3 investigated whether words with fewer positions yielding cohorts leads to faster lexical decisions for the patients.

Results of this experiment will offer further support for or against the claim that patients with pure alexia process words one letter at a time. If the patients show an effect of the number of positions with neighbors consistent with the results reported by Johnson and Pugh (1994), one could conclude that they are processing words based on a letter-by-letter approach. While this result would support letter-by-letter reading, it would not necessarily indicate a left to right strategy. On the other hand, if this variable does not effect the patients' performance, the findings would suggest a whole word approach thus supporting the claim that higher level processes affect the explicit strategy.

Stimuli. Frequency, bigram frequency, single letter frequency, letter confusability, and total number of neighbors were held constant. Two sets of words were selected, one with few positions yielding cohorts (1 or 2) and one with many positions yielding cohort (3 or 4). Each set consisted of 262 words.

Results. The number of positions with neighbors was significant for the normal subjects on the lexical decision task, but in the opposite direction of the Cohort model's prediction. That is, normal readers responded faster ($p<.05$) to the set of neighbors with several positions yielding cohorts. As expected, there was no effect for naming. IH produced faster reaction times for words with 'many positions' on the naming task ($p<.05$). There were no other significant effects of this variable for any of the three patients on either task.

Discussion. The results of this experiment are not consistent with the findings of Johnson and Pugh (1994) or the assumptions of the Cohort model. These results cannot be attributed to the fact that the words in the current study were only four letters long, thus leading to a small difference between 'few positions' vs. 'many positions'. Johnson and

Pugh used four and five letter words and the average number of positions with cohorts in their study were 2.4 (few) and 3.1 (many) for the four-letter items. One difficulty which was not discussed by the authors of the previous study was minimum control of other variables in the experiment. The average frequency was similar for both groups, but included a wide range of values. In addition, bigram frequency and other orthographic variables were not controlled. It is possible that the effect of number of positions yielding cohorts reported by Johnson and Pugh (1994) may have been due to a confounding factor.

The results of the current study are inconsistent with the claim of a letter-by-letter reading strategy. If the patients had processed the letters one at a time, the expected result would be a strong facilitatory effect of fewer positions with neighbors. These findings, in addition to the results of the first two experiments, suggest that the patients' explicit strategies are affected by the activation of the whole word.

Experiment 4

This experiment focused on predictions made by Grainger (1990, 1992) based on the IA model. As noted above, Grainger (1990) and Grainger et al. (1992) have supported the notion that the number of higher frequency neighbors, rather than neighborhood size, is a key variable for determining inhibitory and facilitatory effects. This variable has also been shown to interact with word frequency. Grainger (1990) found that, on lexical decision tasks, low frequency targets with one or more higher frequency neighbors are more difficult to identify (as measured by error rates) than low frequency words with no higher frequency neighbors. Medium (or high) frequency words are affected in the same manner, but to a much smaller extent. The relationship between frequency and neighborhood frequency is the opposite when a task requires naming. More frequent neighbors provide facilitatory effects for naming and this effect is stronger for low frequency words. The effects of word frequency are considered to be a baseline effect and neighborhood frequency seems to be an additive effect.

Grainger et al. (1992) also found that increasing the number of higher frequency neighbors did not, as might be expected, produce further inhibition for low frequency words on a lexical decision task. In fact, a reduction in the inhibitory effect was reported. This result was interpreted as evidence for the concept of mutual inhibition as defined by the IA model. When there is a larger number of higher frequency neighbors they inhibit each other, therefore not allowing any of the neighbors to reach a high level of activation. If only one higher frequency neighbor exists, there is nothing except the low frequency target to inhibit it. The higher frequency neighbor is able to reach a higher activation level leading to stronger inhibition of the target word.

Part I.

Method. The first part of Experiment 4 investigated the effect of zero, one, and more than one higher frequency neighbors in a set of high frequency and a set of low frequency words. All six groups were matched for single letter frequency and letter confusability. As noted earlier, bigram frequency is related to total number of neighbors and in this case was higher in the set of words with several higher frequency neighbors as compared to the sets with one or zero higher frequency neighbors. Consistent with Experiments 1 and 2, the high frequency set consisted of words with frequencies of greater than 100 and the low frequency words were less than 60.

Results. Figure 3 summarizes the results of the normal readers and the patients on Experiment 4, Part I. For the high frequency set there was no effect of the number of higher frequency neighbors for the normal subjects or the patients on either task. This result is consistent with the findings of previous studies (Grainger, 1990; Grainger et al., 1992).

In the low frequency set, normal readers demonstrated a main effect of neighborhood frequency ($F(2,321)=7.80$, $MSe=1482.54$, $p<.001$) on the naming task. Words with several higher frequency neighbors were read faster than words with one

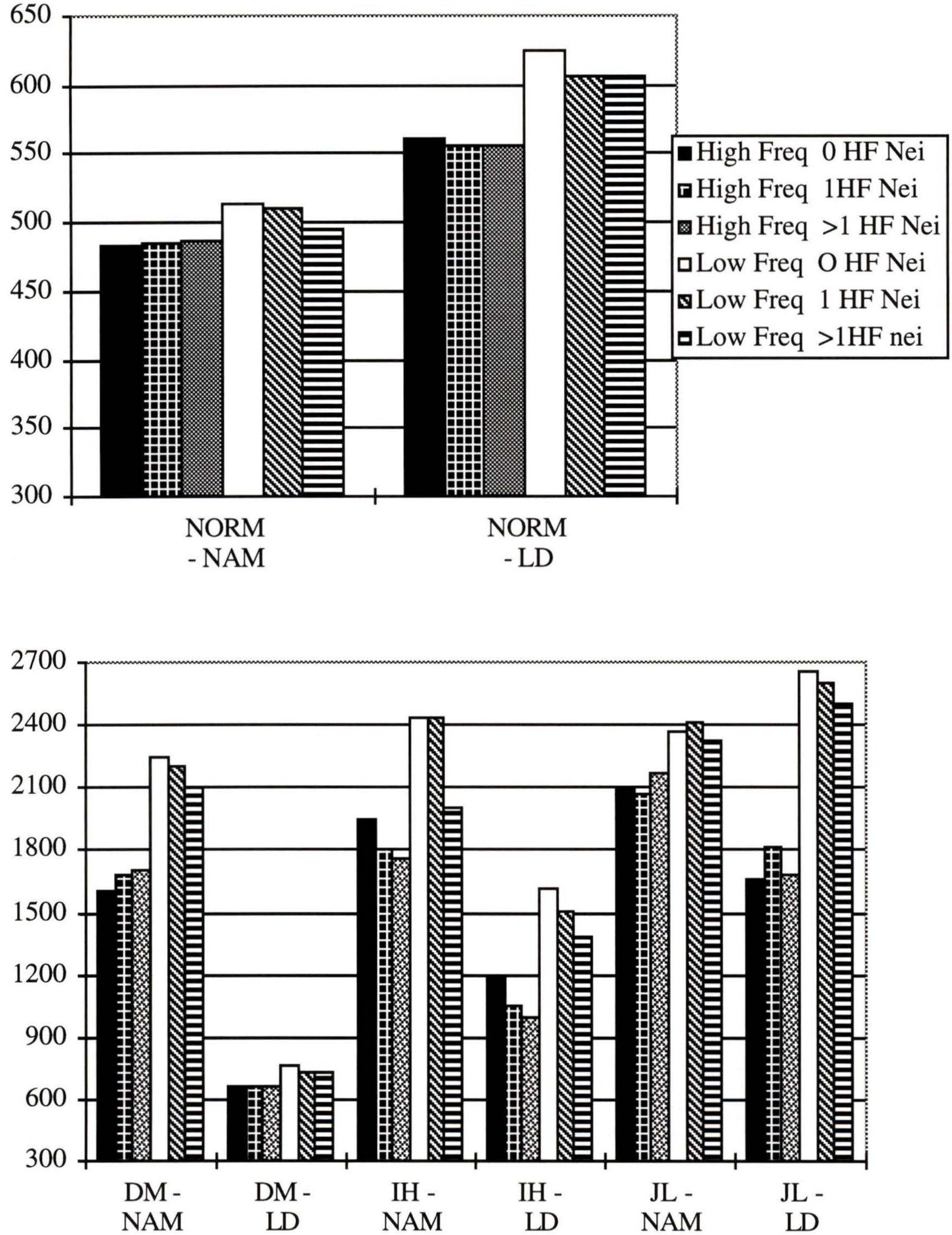


Figure 3. Lexical Decision and Naming Latencies of the Normal Readers and Patients for Experiment 4, Part I. Word Frequency and Number of Higher Frequency Neighbors were investigated

Note: NORM=Normal readers; NAM=Naming; LD=Lexical decisions; Freq=Word Frequency; HF=High Frequency; Nei=Neighbors; >1 HF Nei= several higher frequency neighbors.

(p<.05) or zero (p<.05) higher frequency neighbors. IH's results were the same as those of the normal subjects. He showed a main effect of neighborhood frequency ($F(2,289)=14.62$, $MSe=433,347.02$, $p<.001$) on the naming task. His responses were faster when words had several higher frequency neighbors versus one ($p<.01$) or zero ($p<.01$) higher frequency neighbors. In addition, both IH and the normal group showed a nearly significant main effect of neighborhood frequency on the lexical decision task (IH, $p=.077$, normal readers, $p=.079$). JL and DM did not demonstrate significant neighborhood frequency effects on either task, although the means of their response latencies were in the same direction as the normal readers.

Discussion. These results are only partially consistent with those reported by Grainger and colleagues. Response latencies on the naming task were, as predicted by the IA model, facilitated by higher frequency neighbors. Several neighbors led to faster reaction times. However, the reported inhibitory effect of one or more higher frequency neighbors on lexical decisions (Grainger, 1990; Grainger et al., 1992) was not observed. This may be due to the fact that the data of the patients are highly variable.

IH was the only patient that also demonstrated a pattern of performance that was consistent with normal reading, showing a neighborhood frequency effect on the naming task. His results suggest that when a low frequency word is the target the activation of the higher frequency neighbors is strong enough to facilitate naming. This result indicates that IH's compensatory reading strategy is affected by variables which represent higher level, whole-word processes.

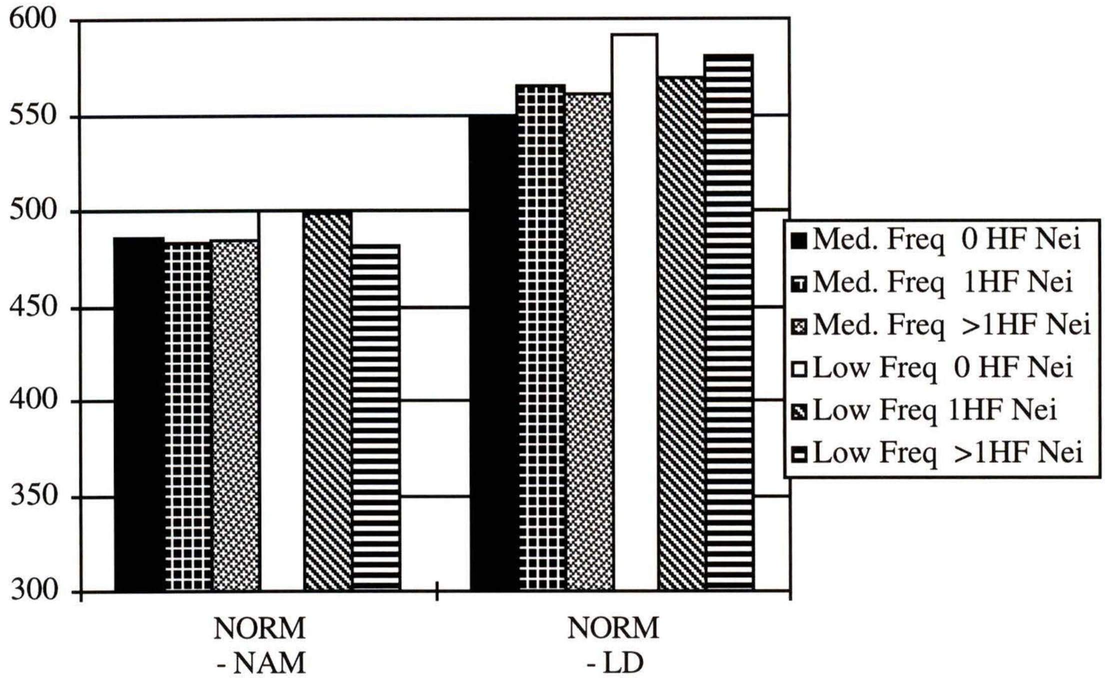
The lack of results for JL and DM in this condition may reflect, as suggested earlier, that each patient requires a different level of initial activation for information to become available to the patient's explicit strategy. Given that normal readers appear to be less affected by neighborhood frequency as compared to both word frequency and neighborhood size, relatively speaking, neighborhood frequency may not be important enough to affect the patient's explicit strategy. While IH seems to be more sensitive to neighborhood frequency, it may be that JL and DM are also sensitive to this variable, but require more activation than IH in order for it to play a role in lexical decisions or naming.

Part II.

One difficulty with Part I is that neighborhood size was not held constant across conditions. Grainger et al. (1992), however, did hold this variable constant. In an attempt to replicate the previous findings, a second experiment investigated the effect of neighborhood frequency while holding neighborhood size constant.

Stimuli. Similar to the study by Grainger (1990), low frequency (less than 20) and medium frequency (between 50 and 100) words were used. The previous study also used stimulus sets which contained words with large neighborhoods (9 - 12 neighbors on average). Unfortunately, it was difficult to find a large number of items that fit the criteria for large neighborhood size in all the conditions. For example, only 14 words were found which fit into the condition requiring low frequency, zero higher frequency words, and more than four total neighbors. However, it should be noted that Grainger's (1990) experiments contained only 12 target items per condition. While these small groups of targets are sufficient for investigating normal performance, the difficulty for the current study is that the standard deviations are large, as are the number of items that must be eliminated (i.e. outliers), for the patient data. It becomes more difficult to gain a clear picture of how the patients are affected by certain variables when small sets of items are used.

Results. The results of this experiment did not replicate Grainger's (1990) findings. Analysis of the normal readers revealed that there were no effects of neighborhood frequency on either task. The patient data indicated only a few significant results. Figure 4 depicts the response latencies of the normal readers and the three patients. An analysis of DM's lexical decision response latencies revealed an interaction of word frequency X neighborhood frequency ($F(2,225)=4.16$, $MSe=34{,}636.46$, $p<.05$).



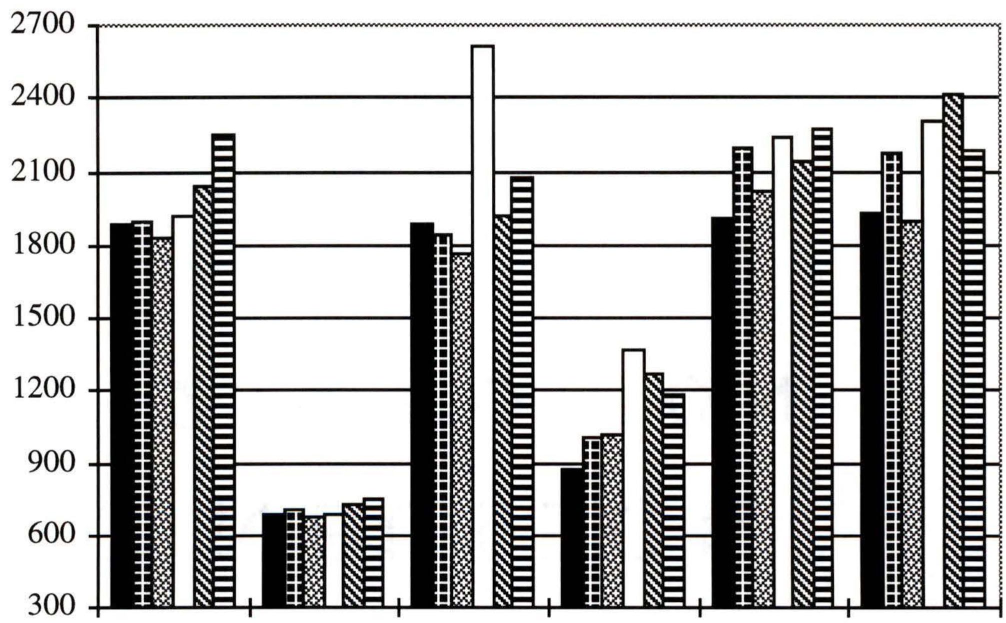


Figure 4. Lexical Decision and Naming Latencies of the Normal Readers and Patients for Experiment 4, Part II. Word Frequency and Neighborhood Frequency were investigated.

Note: NORM=Normal readers; NAM=Naming; LD=Lexical decisions; Med. Freq=Medium word frequency; HF=Higher frequency; >1 HF Nei=several higher frequency neighbors

He demonstrated faster response latencies when an item had several higher frequency neighbors (versus one higher frequency neighbor, $p<.05$) and was a medium frequency word, but did not show the same benefit of several higher frequency neighbors when the word was a low frequency target. IH's response latencies on the naming task also indicated an interaction of word frequency X neighborhood frequency ($F(2, 221)=3.29$, $MSe=1,173,837.80$, $p<.05$). IH demonstrated faster response latencies when a low frequency word had one or several higher frequency neighbors as compared to zero higher frequency neighbors (both comparisons, $p<.05$), but there were no significant effects of neighborhood frequency for the medium frequency words. Analysis of JL's performance showed no effects of neighborhood frequency.

In addition, DM's error rates indicated a main effect for neighborhood frequency ($F(2,241)=3.38$, $MSe=0.21$, $p<.05$) on the lexical decision task. The mean error rate was higher when a word had one higher frequency neighbor (M=46%) as compared to zero ($p<.05$, M=25%) or several ($p<.05$, M=28%) higher frequency neighbors.

Discussion. Taken together, the results of Parts I and II suggest that the effect of neighborhood frequency is not as potent as Grainger and colleagues have previously reported. It is unclear why this variable appears to have been important in Grainger's work, but was not a strong indicator of performance in the present study. It is unlikely that the differences between Grainger's findings and the current results are due to a qualitative difference between groups of subjects. A more probable explanation is that the methodology, likely the choice of stimuli, is somehow discrepant. Experiment 5 was designed in an attempt to further understand these results.

Again, for the purposes of the current investigation, it is the patterns of performance demonstrated by the patients that are of interest. Although the patients did not show the effects of neighborhood frequency that would be expected by Grainger and colleagues, their pattern of performance was generally consistent with the normal readers in this study. These results offer more support for the assumption that the patients with pure alexia are accessing information in a qualitatively normal fashion.

The fact that IH's naming performance was affected by the frequency of neighborhoods is exciting evidence which supports the claim that the initial activation has contact with the compensatory process. If the reading strategy of the patients was completely separate from the lexical representation of the word, IH's results would be difficult to explain. Why would the compensatory approach be facilitated by the fact that the target word has several neighbors that are higher frequency? If this patient were strictly guessing based on an off-line strategy, his error rate would increase as the number of higher frequency neighbors increased. This is not the case. His error rate remains very low regardless of the number of higher frequency neighbors, but his response latencies decreased. This result strongly suggests that the lexical representation of the word, which includes information about neighborhood size, frequency, etc., affects the reading strategy of this patient. In addition, IH's performance indicates that the organization of the lexicon is intact.

Experiment 5

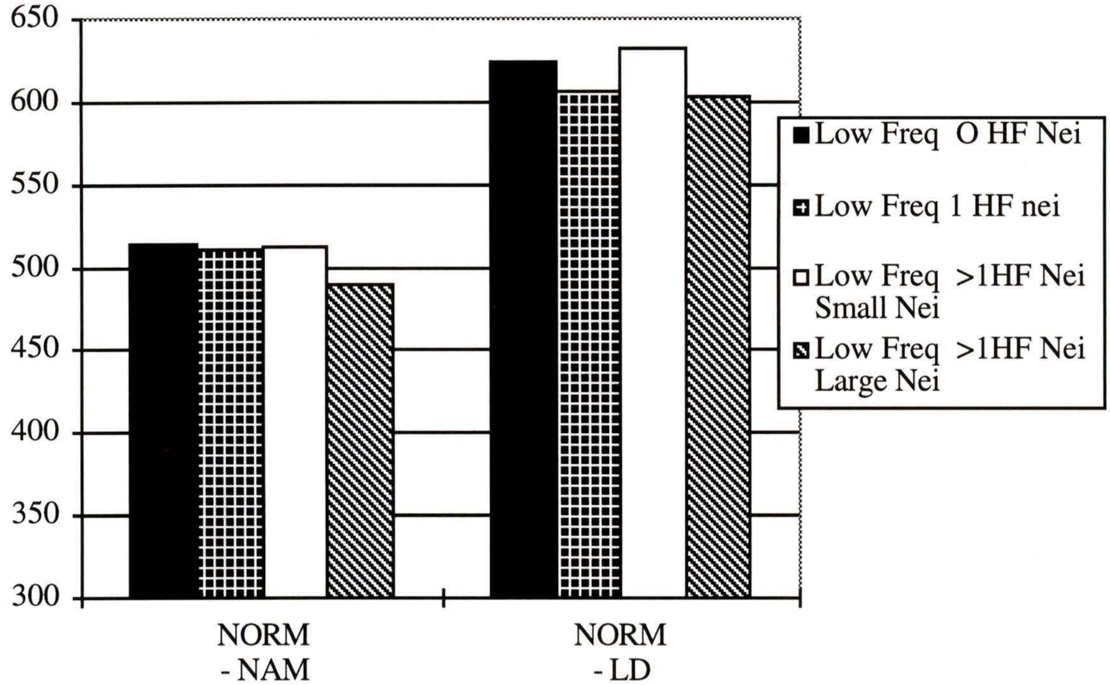
This experiment was designed to further investigate the results of Experiments 2, 3, and 4. It is yet unclear how the variables of neighborhood size and neighborhood frequency are related and which of the two is responsible for the neighborhood size effects reported in normal readers and present in the current study for the normal subjects and the pure alexic patients. While Grainger (1990, 1992) claims that neighborhood size is not the critical factor, this variable is held constant and is always quite large in his investigations of the effects of neighborhood frequency. In Experiment 4, Part I, when neighborhood size was not controlled, the effects reported by Grainger were not found. Neighborhood size was then held constant in Part II and a new set of items was examined. This time neighborhood frequency affected naming latencies in that several higher frequency neighbors led to faster responses, but this variable had no effect on lexical decisions.

A closer look at the results of Experiments 2, 3, and 4 indicated what appears to be a divergent finding in the results of Experiment 4, Part I. While there was a consistently strong effect of neighborhood size in experiments 2 and 3, there was little effect (only on the naming task for IH and normals) for several higher frequency neighbors versus only one higher frequency neighbor. Overall, the set of low frequency words with several higher frequency neighbors had larger neighborhoods than the items with only one higher frequency neighbor. The number of lower frequency words was always small for these items, so the size of the neighborhood was primarily a measure of the number of higher frequency neighbors. Based on the results of Experiments 2 and 3, the set of words with several higher frequency neighbors would be expected to be faster because the words have more neighbors than the other two sets. This experiment will further investigate the relationship between neighborhood frequency and neighborhood size and the effects each has on word recognition.

Part I

Stimuli. The group of low frequency words with more than one higher frequency neighbor (from Part I of Experiment 4) was separated into two groups, those with many neighbors and those with few neighbors. The small neighborhoods had an average of 3.6 neighbors and the large neighborhoods contained 7.6 neighbors.

Results. Figure 5 summarizes the results of Experiment 5, Part I. Normal readers were significantly faster on both lexical decision ($p<.01$) and naming ($p<.001$) when the set of words with more than one high frequency neighbor contained several neighbors as compared to a few neighbors. On the lexical decision task, the small neighborhood set was inhibitory compared to the set which contained only one higher frequency neighbor ($p<.01$). IH showed significant facilitation ($p<.01$) for items with



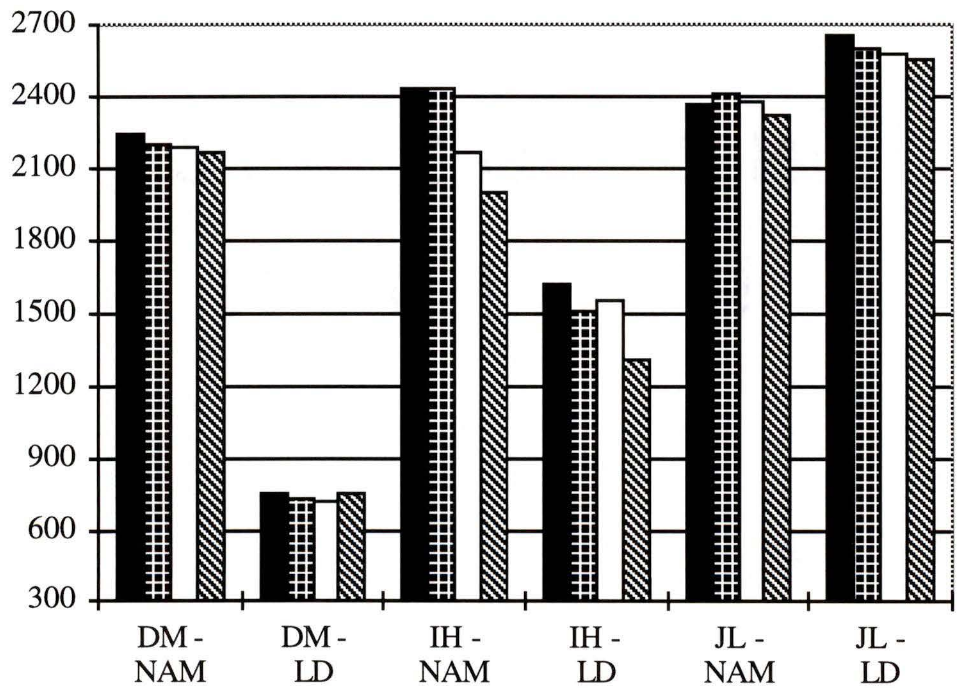


Figure 5. Lexical Decision and Naming Latencies of the Normal Readers and Patients for Experiment 5, Part I. Neighborhood Size and Neighborhood Frequency were investigated.

Note: NORM=Normal readers; NAM=Naming; LD=Lexical decisions; Freq=Word frequency; HF=higher frequency; >1 HF Nei=several higher frequency neighbors; Nei=Neighbors/Neighborhood.

large neighborhoods as compared to small neighborhoods on the lexical decision task. On the naming task, IH's response latencies were faster for words with small neighborhoods as compared to only one neighbor ($p<.05$). IH's reaction times were also faster, but not significantly so ($p=.062$), when the set contained target items with many neighbors as compared to words with small neighborhoods. In contrast, DM's performance indicated an inhibitory effect of larger neighborhoods on the lexical decision task. His response latencies to words with larger neighborhoods were slower than for words with small neighborhoods ($p<.01$).

Discussion. The results of the normal readers seem to indicate that the neighborhood frequency effects reported by Grainger (1990) were enhanced by the fact that the target items had large neighborhoods. Words with small neighborhoods appear less sensitive (and perhaps not at all) to the effects of neighborhood frequency. Although the IA model would predict that two or three higher frequency neighbors would mutually inhibit each other even if there were no other neighbors, this does not seem to be the case. Perhaps a large number of higher frequency neighbors are needed in order to produce the strength of mutual inhibition needed to facilitate the activation of the target. Another possible explanation is that the larger neighborhoods are facilitatory for two reasons. The first is proposed to be the effect of mutual inhibition described by Grainger. The second important role of large neighborhoods is to increase the activation of the target letters, which then increases the activation of the target word. It may be that the feedback to the letter level is the dominant factor here and that neighborhood frequency effects are secondary, but also important.

Based on this explanation, the limited findings in Experiment 4-Part II may have been the result of difficulty finding targets with large neighborhoods. In order to find sets with enough items, the large neighborhood criteria was relaxed to as small as 4 neighbors. It may be that the range of neighborhood size in the Grainger studies was more strict, with all targets having very large neighborhoods. The mix of 'smallish' neighborhoods and large neighborhoods in the current study may have canceled out any effects which might have been present with only large neighborhoods.

Another possibility, which has been suggested by Grainger (1992) is that the ratio of higher frequency to lower frequency neighbors is important. Grainger suggested that only a few higher frequency neighbors may be inhibitory and that it is only when several higher frequency neighbors exist that the facilitative effect is seen. This suggests that a word must have more higher frequency than lower frequency neighbors in order for the reported effect of neighborhood frequency to emerge. It seems that even if a word has a few higher frequency neighbors, a large number of lower frequency words may interfere with the effects which are typically produced in this situation. That is, while several higher frequency neighbors are typically inhibitory in a lexical decision task, the presence of a higher ratio of lower frequency items may lead to distributive effects of inhibition over the entire set of items, thus leading to less direct inhibition of the target item. The second part of this experiment investigated the ratio of higher to lower frequency neighbors.

Part II

Stimuli. The low frequency set containing more than one high frequency neighbor used in Experiment 4, Part I (and above) was again separated into two conditions - this time varying the ratio of higher to lower frequency neighbors. Words with at least 2 more higher frequency neighbors versus lower frequency neighbors (e.g. 6 higher frequency and 4 lower frequency) were chosen for the 'higher frequency' set and words with a minimum of 2 more lower frequency than higher frequency neighbors were selected for the 'lower frequency' set. The 'higher frequency' set contained words with a mean ratio of 8.6 higher to 4.2 lower frequency neighbors, while the 'lower frequency' items had an average of 4.1 higher and 7.8 lower frequency neighbors.

Results. The results indicated that the ratio of higher to lower frequency neighbors does not affect normal reading. All three patient's demonstrated similar patterns of performance. Analysis of JL's results revealed the only significant effect in this experiment, indicating faster reaction times when naming words that had neighborhoods containing a larger number of lower frequency neighbors ($p < .05$).

Discussion. Taken together, the results of Experiment 5 offer further support for the assumption that normal activation occurs in patients with pure alexia. Similar to normal readers, IH and DM showed facilitatory effects on the lexical decision task for items with several higher frequency neighbors and large neighborhoods. Although, JL showed effects of neighborhood size in earlier experiments, he was not affected in this condition. In fact, he demonstrated the only effect of high versus low frequency ratio, indicating a preference for more lower frequency items on the naming task. It may be that JL is utilizing a somewhat different strategy than the other two patients.

As discussed earlier, the results on lexical decision tasks may be indicative of what occurs during the initial activation of a word. The patients, at least at the level of initial activation, appear to be affected by the same variables as normals. The findings so far have also suggested that explicit recognition (i.e. naming) is also affected by some of the same variables, but to a lesser extent. It may be that only certain variables are able to gain enough activation to affect the compensatory reading strategy. Thus, based on the fact that neighborhood frequency has minimal effects on normal word identification, it is not surprising that this variable has little effect on the patient's performance.

This experiment also suggests that for normal readers neighborhood size is a stronger indicator of facilitation and inhibition in word recognition than is neighborhood frequency. The ratio of higher to lower frequency neighbors was not an important factor. It seems that a large neighborhood, regardless of the number of higher frequency neighbors, is required in order to attain the facilitatory effects in naming and lexical decision which have been reported by Grainger and colleagues as well as by Johnson and Pugh (1994). While the number of higher frequency neighbors may also have an effect on normal reading, this effect appears to be secondary to neighborhood size.

This result is consistent with the notion of inter-level facilitation as defined by the IA model. It seems that the neighborhood size is most important because it leads to increased activation of the target letters. More activation at the letter level will automatically lead to more facilitation of the target word. The patients are also affected by neighborhood size suggesting that they too are helped by more activation of individual letters. This result may indicate that an IA approach to word recognition can be used to model the reading deficit in pure alexia.

Experiment 6

Thus far it appears that orthographic and lexical variables which affect normal readers produce similar effects in the three patients with pure alexia, particularly on the lexical decision task. Although these findings offer strong evidence against a strict letter-by-letter reading strategy, there are still no answers as to what is actually happening during the reading process. Experiments 1 - 5 suggest that lexical access in these patients is still intact and that it is organized in a normal fashion. In addition, it appears that the patients' compensatory strategies are affected by some of the variables investigated above, suggesting that word identification is not completely separate from implicit activation. However, regardless of which variables are manipulated, these patients still read and make lexical decisions at an extremely slow rate. As discussed earlier, it is possible that the patient receives an initial pulse through the reading system and that the lexicon is contacted normally. However, this contact is too weak for the patient to explicitly identify the entire word. Based on what has been reported in this study so far, this seems to be a reasonable explanation. The letter-by-letter approach may be a compensatory strategy primarily for the purpose of 'cleaning up' and/or clarifying the content of the initial pulse. If this is the case then a strict left to right strategy would not necessarily be required. It is more likely that some positions, for a variety of reasons, need more attention during the compensatory process than do others.

One way of checking this hypothesis is to determine if the patients are faster to respond when the 'unique point' of the word is in an earlier rather than later position. That is, if patients begin the left to right process with no prior information (i.e. no contact from the initial activation) and proceed only from left to right, then words that can be explicitly identified in the second or third position should be faster than those that can not be identified until the fourth position is reached.

Method. There was a minimal number of words which have a unique point in the second position (only 32 of the 1271 four letter words) and although they were matched with the other sets with regard to word frequency, they had significantly fewer total neighbors. Given the findings of the earlier experiments indicating a strong effect of neighborhood size, words with unique points in the second position were not used in this experiment. The final sets contained 397 items each and were matched for frequency, bigram frequency, single letter frequency, and letter confusability. The average number of neighbors was 6 for the items with a unique third position and 7.5 for those with a unique fourth position.

Results. There was no effect of unique point for the normal readers on either task. The patients, however, consistently showed the opposite effect than would be expected if they were using a left to right reading strategy. DM named words fastest when the unique point was the fourth position ($p < .01$). IH also showed facilitation for a unique fourth as compared to third position on the lexical decision ($p < .05$) and naming task ($p < .01$). JL demonstrated the same pattern for lexical decisions, with the unique fourth position resulting in faster reaction times than a unique third position on both tasks ($p < .05$).

Discussion. Although this pattern was completely unexpected, it is strong evidence against the claim that the patients are utilizing a strict left to right reading strategy. One possible explanation for these interesting results is that, similar to normal readers, patients with pure alexia initially process words in an ends-in fashion. Given a four letter word, this would mean that the first and fourth letters are activated most strongly and that it is the middle two letters that need further analysis. When the fourth letter holds important information, such as ruling out several other neighbors, then responding is facilitated. It may be that only one of the two middle letters will then need further processing in order for the word to be identified. On the other hand, if the fourth letter is less critical than the second or third letters for ruling out competitors then there would likely be more need to identify both the second and third letters. If the patients with pure alexia are processing words in an ends-in manner, it seems logical that when several neighbors exist at the middle positions and few at the first and/or fourth positions, longer reaction times will occur. Alternatively, when the first and fourth positions have many neighbors and the second and third have few (or none), response latencies will be faster.

While this result strongly suggests that patients with pure alexia are not reading in a strictly letter-by-letter fashion, what they *are* doing is still not clear. Some possibilities will be discussed below.

General Discussion

First, the results of the current study will be summarized according to the main assumptions and expectations put forth in the introduction. There were two assumptions which were based on previous research findings. One basic assumption was that the initial activation in patients with pure alexia occurs in a 'normal' fashion. That is, when a patient is presented with a word, regardless of the task, there is an automatic mapping of the perceptual aspects of the stimuli to an orthographic/lexical representation. The patients showed strong effects of lexical variables, indicating that they are able to contact the lexicon in the same way as normal readers. Support for the second basic assumption is also evident in these findings. The second assumption was that the core reading deficit in pure alexia is the result of a central rather than a peripheral deficit. The conclusion that normal activation occurs in these patients also supports a central deficit. The fact that patients' performance was affected by orthographic and lexical variables indicates direct and accurate access to higher level representations. If perceptual uptake of letters or letter strings were impaired, this type of access would not be attained. While it is clear that some patients also demonstrate impaired perceptual processing, the extent and presentation of these additional peripheral deficits tend to vary among patients with pure alexia and are considered secondary to a central deficit.

Based on these two assumptions, the patients' performance was expected to show effects of orthographic and lexical variables which have been reported to affect normal reading. As hypothesized, the patients with pure alexia demonstrated effects which were very similar to the group of normal readers. The variables which appeared to have the most influence on both the patients and the normal individuals were word frequency and neighborhood size. The normal readers and all three of the patients demonstrated a facilitatory effect of high frequency words on both naming and lexical decision tasks. In addition, large neighborhoods were consistently helpful to both the patients and normals. The combination of these two findings is strong evidence against a letter-by-letter reading strategy in these patients. As discussed above, the direction of the word frequency effect could be interpreted as consistent with an off-line guessing or inferential strategy, but the benefit of large neighborhoods is not consistent with this explanation. The neighborhood size effect indicates that, similar to normals, the patients contact a lexical representation immediately, and the identification of the word is affected by the type of neighborhood to which it belongs.

While a large neighborhood appears to be beneficial for normal readers on both naming and lexical decision tasks, the effects for naming performance in the patients are less consistent and typically weaker or absent. Does this indicate that implicit information has no effect on the compensatory strategy? One possible explanation, which appears very unlikely, is that there is no connection between the initial activation of the entire word and the compensatory reading strategy. This type of explanation would be similar to Coslett et al.'s (1993) suggestion of two distinct and anatomically separate systems. Based on the argument of these authors, one could conjecture that lexical decisions are affected by orthographic and lexical variables because the processes responsible for lexical decisions have access to information from the activated representation, while the system responsible for naming does not. However, this seems unlikely given that the lexical decisions of two of the patients (IH and JL) do not appear to be an implicit, automatic process. That is, these patients seem to be using the same slow, explicit strategy for lexical decisions that they use for naming.

The other possibility is that there is a connection between the initial activation of a word and the compensatory strategy used for both of these tasks. The patients' naming responses may be appear to be less affected by the variables which affect normal readers (and lexical decisions in the patients) because naming requires contact with additional components of the system (primarily phonology) and this may be the area of difficulty. It may be that the patients are able to use the initial activation to specifically contact the orthography of the word, but that mapping from the lexical representation to the correct pronunciation is impaired. Indeed, the findings reported by Bowers et al. (1996) support this speculation. The authors found that a patient with pure alexia contacted the exact lexical representation of the word and that this was accomplished under a very brief exposure duration.

While lexical decisions are typically slower than naming responses in normal readers, the opposite trend is demonstrated by the patients. While lexical decisions are far from being rapid, they are generally faster than naming responses. This pattern may also support the notion that a similar mechanism is used for both lexical decisions and naming. Naming, however, requires contact with an additional part of the system which adds time to the overall response latency. In normal readers, connections to other necessary components of the system are likely automatic. It may be that when a normal reader is naming words, the system goes directly from lexical identification to phonology. It is possible that in pure alexia the connections to other components are weakened and therefore no longer automatic. The compensatory strategy must then explicitly identify the word before mapping from the lexicon to phonology or semantics can occur. This explanation is also consistent with findings that some patients are able to make 'rapid' lexical decisions, but are unable to do the same for semantic categorizations.

Another hypothesis of the current study was that patients with pure alexia do not read in a strict left to right, letter-by-letter fashion. Bub and Arguin (1995) suggested that the compensatory strategy is actually a clean-up process for the initial activation. These authors claimed that the initial activation is normal, but in other respects too weak for the patients to explicitly identify the word. The patients then 'fix up' only the letters or features of letters that were not activated strongly in the initial representation to allow explicit identification. The findings from the current study are consistent with the idea that the reading strategy of these patients is not strictly letter-by-letter or 'left to right'. Two particular findings supported this claim. The first finding was that the patients' performance was not facilitated when the target word had fewer positions which yielded neighbors. According to the Cohort model, performance would be expected to improve because when fewer positions need to be resolved less time would be necessary to identify the word. The finding that fewer positions with neighbors helped neither the normal readers nor the patients suggests that instead of processing each letter individually, thus yielding four separate cohorts, words are likely processed in parallel. If the patients were identifying letters explicitly one letter at a time, letters with no neighbors would be identified very quickly and if a word had several positions without neighbors, the entire word should be processed more quickly. The absence of this result was taken as evidence against a letter-by-letter approach.

A second finding provided evidence against a left to right approach. If the patients were starting at the left of the word and explicitly identifying one letter at a time, then a word with an earlier 'unique' point (i.e. point of resolution) should be recognized faster.

The patients did not demonstrate this pattern. In fact, all three patients performed better when the unique point was later, rather than earlier in the word. While I did not expect to find a facilitatory effect of an earlier unique point, the fact that the patients' results indicated a facilitatory effect of a later unique point was surprising. A possible explanation for this finding was discussed above (following Experiment 6). Regardless of the interpretation of this result, it clearly counters the statement that patients with pure alexia read from left to right. Taken together, these two findings provide a solid argument against the claim of a letter-by-letter and/or a left to right reading strategy.

While it seems that the current study offers strong evidence against claims that pure alexia is what it appears to be on the surface (i.e. a letter-by-letter reading strategy), there are several limitations which must be considered. First, the data which was investigated for the purposes of this study may not be representative of the patients' true responses to the target words. That is, each word was only presented once for each task. Given the variable nature of the patients performance, it is possible that on a second trial many of the response latencies would be very different. Ideally, the same experiments should have been repeated several times in order to gain a stable measurement of performance. The normal readers demonstrated extremely consistent reaction times (i.e. small standard deviations) and performed as expected with regard to standard variables (e.g. word frequency). This indicates that the procedures used in this study were acceptable and that any deviations which were present in the patients were likely due to the nature of their deficit. However, it is still the case that the current study would be more convincing if the mean of several response latencies had been used rather than just one.

An additional restriction on the conclusions of this study is that the data were limited to four letter words. It is unclear if and how the current findings would generalize to other word lengths. Word length does affect the response latencies of patients with pure alexia. If this variable were examined it may be that the effects of certain orthographic and lexical variables would interact with the effects of word length. While there is no reason to believe that four-letter words would be affected differently than longer or shorter words by the variables examined in this study, the generalizability of the current findings is unclear.

It is also obvious that only a limited number of orthographic and lexical variables were investigated in this study. There are certainly several more which may have an influence on reading in both normal readers and patients with pure alexia. The variables were chosen in order to investigate specific questions, but were not considered to be all inclusive. For example, when investigating neighborhood frequency effects, I did not consider the difference in frequency between the target word and the higher or lower frequency neighbors. A word was consider higher frequency if it occurred even one more time (per million) than the target word. If the neighbors were grouped according to frequency differences, an alternative result may have emerged. Other variables which were not considered are those related to the phonological neighborhood of a word. A phonological database including variables similar to the orthographic ones used for the current study could be developed. This would offer further insight into the relationship between orthography and phonology in the patients as compared to normal readers.

Furthermore, while this study was successful in providing evidence 1) to support a link between the initial 'normal' activation of a word and the compensatory strategy and 2) against the claim that the compensatory strategy used by patients with pure alexia is letter-by-letter or left to right, there is still little to say regarding what it is the patients are actually doing to recover the identity of the word. The results seem to be generally consistent with the explanation that the compensatory strategy in these patients is a clean-up mechanism for weak initial activation (Bub & Arguin, 1995). While it may be that the compensatory strategy is responsible for cleaning up and/or clarifying the initial activation, the parts of the word that require 'fixing' remains unclear. The finding (in Experiment 6) that a unique fourth position is more helpful than a unique third position, seems to indicate that certain letter positions are activated more strongly initially. It is clear that follow-up studies investigating this question are needed.

In addition, researchers have suggested that the connections from the lexical word form system to other parts of the reading system are impaired. Given that the patients are able to correctly pronounce words, it appears that the ability to contact and use phonology has not been destroyed. It seems more likely that this part of the system can no longer be accessed directly, as it is in an intact reading system. It may be that because the initial activation is unable to reach phonology or semantics directly, explicit identification of the lexical representation is necessary in order to contact these components through an alternative or damaged route.

It seems the next important step is to determine how much and what type of information is necessary for the initial activation to effectively activate the other components of the reading system. What part(s) of the word is initially processed at an adequate level and what requires 'repair'? Unfortunately, the data used for this study are unable to offer any specific answers to a question of this sort. However, we (Dr. Bub and I) are extremely interested in examining questions of this nature. We feel quite confident that the findings of his previous work (Bowers et al., 1996; Bub & Arguin, 1995; etc.) coupled with this study are strongly indicative of the proposed 'clean-up' strategy. This strategy is not thought to be random, but instead is believed to have specific constraints which are based on orthographic and lexical variables and guided by the initial activation of a word.

A study which we believe would lead to considerable progress in the understanding of pure alexia will be described. This study would follow from the current study in that it would be based on the assumptions that the compensatory strategy is not letter-by-letter and that it is affected by higher level information. The hypothesis which would be tested by this proposed study is that the compensatory strategy is an organized approach to fixing the initial activation in order to explicitly identify a target word. This strategy is affected (as I have shown in the current study) and guided by information which is available as a result of the initial activation.

First, a measurement of letter identification in each of the four letter positions would be needed. A patient with pure alexia would be asked to identify a particular letter based on a specified letter position in a random letter string. The target letters in the set of random letter strings would include all letters of the alphabet in each letter position (i.e. 26 x 4 trials). In order to maintain a consistent measure of single letter identification, all letters in each position would be measured several times (ideally, 10 times). The second critical measurement in this study would follow the same procedure, but this time the letters would be presented in the context of words. Again, the patients would be required to name a single letter in a specified position. These two measurements would reveal the time needed to identify individual letters as well as determine if an overall word superiority effect (WSE) is present. The presence of a WSE would indicate higher level effects and would indicate that this measure be used (rather than that of random letter strings) for the remainder of the experiment.

The next step would be to measure the naming latencies of whole words. The patient would be asked to explicitly identify the target word as quickly as possible. A comparison would then be done between the naming response latencies of whole words to the combined effects of identifying individual letters within word contexts. If the patients' overall naming latencies are consistent with the combined reaction times of the four individual letters (which were presented in the same locations), one could conclude that the patients process words one letter at a time and that the initial activation does not help the compensatory strategy. Given the results of the current study, this would not be expected. Alternatively, if the patient(s) does not demonstrate a straight one-to-one relationship between naming latencies and the sum of individual letter reading this would provide strong proof that the context of the letters affects the reading strategy.

From this point, based on variables similar to those investigated in the current study, we will attempt to model pure alexia so that the reading times of specific words can be predicted. This model would involve a clean-up strategy of lexical representations based on variables which are critical to the initial activation of a word. Further studies based on the database used in this study and the addition of variables discussed above will be conducted prior to the development of this model in order to determine the role of a wider range of variables. Unfortunately, there is currently no validated model of normal reading on which to base the impaired model of pure alexia. The current study, while not intended to draw favor for either of the specific models, appeared to offer more support for an Interactive-Activation model versus a Cohort model of word recognition. The IA model may therefore be a good candidate for an initial model of pure alexia. However, the reader should recall that all IA assumptions and predictions were not supported by the performance of the normal readers or the patients in the current study. Specifically, the prediction that several higher frequency neighbors would lead to facilitation was not supported.

While this may seem like a rather ambitious project, I believe it is necessary in order to offer a qualitative explanation of the reading deficit in pure alexia. While the primary goal of such a study would be to develop a model which is able to predict the performance of patients with pure alexia, this type of work would also offer important findings for normal models of reading. Traditionally, the goal of cognitive neuropsychology is to elucidate the functional architecture of normal cognitive processes by investigating the abnormal behavior of brain damaged individuals. Assuming that no new cognitive structures are created following brain injury, these behaviors are thought to reveal the functioning of the system with some specific impairments. Studies of brain damaged individuals often reveal unique information about cognitive processes that are not readily observable when the system is operating normally. In other words, theories of normal functioning must be well-supported by both cognitive psychological investigations of normal subjects as well as cognitive neuropsychological investigations of brain-injured patients.

However, cognitive psychologists and cognitive neuropsychologists often fail to incorporate each other's work into their current models. Researchers of normal reading make little attempt to insure that specific reading disorders can be explained by their models. Similarly, explanations of pure alexia, as well as other language disorders, do not appear to be based on an impaired version of a well-supported model of normal reading. In order to understand a disorder resulting from damage to a normal system, it is important to have an adequate understanding of the relevant components which, when damaged, yield the abnormal behavior under consideration. Conversely, for an understanding of normal functioning to fully progress, it is imperative that results of case studies be considered. The proposed study would be an attempt to combine a well-supported model of normal reading with findings and assumptions regarding pure alexia. Ideally, this venture would lead to an explanation of normal reading that when damaged could predict the performance of patients with a variety of reading disorders.

In addition, the findings of the current study challenge other researchers in this area to investigate new questions. The strong support for the assumption that normal activation occurs and that the compensatory strategy is affected by this activation suggests that researchers should now focus on how the explicit strategy is affected. Further definition of the variables that affect initial activation and explicit identification is needed. In addition, the role of phonology and semantics in these patients is a vastly under-researched area. Unfortunately, the past century seems to have been dedicated to protecting interpretations of pure alexia which are similar to Dejerine's original explanation. That is, many researchers have continued to support the idea that the compensatory reading strategy observed in patients with pure alexia is completely independent of any form of initial activation. Dejerine described this deficit as a disconnection, whereas others have suggested an abolishment of the lexicon. Regardless of the site of the lesion within the reading system, most research has continued to assume that the compensatory strategy is, as it is often labeled, letter-by-letter.

At an applied level, the results of the current study may lead to some beneficial developments in the rehabilitation with patients of this type. Often simply educating patients as to what is known (and unknown) about their disability is helpful. Teaching them to first attempt a whole word approach to reading may increase the initial activation allowing it have a greater impact on the compensatory strategy. Another possibility is that focusing on the middle letters of a word when reading may speed up the process. If it is true that the representation of the end letters is stronger in the initial activation, focusing on what needs to be 'fixed up' could improve performance. While these suggestions are merely conjectures, they are based on past and current research findings and may prove to be useful for teaching patients with pure alexia ways to ameliorate their difficulties.

Overall the current study appears to offer strong support against the traditional view of pure alexia. This reading disorder is not simply a compensatory strategy for a system that is unable to process words in a normal fashion. Instead, it appears that the compensatory strategy is used to clarify the identity of a word and is guided by the initial activation of the word. The current study is certainly not alone in providing support for this type of explanation. Other researchers (Bowers et al., 1996; Bub & Arguin, 1995) have reported findings which also suggest that the compensatory strategy is not what it appears to be. It seems that in order to make further progress we must abandon the incorrect use of (and belief in) the term 'letter-by-letter' reading. Future research should be an attempt to move towards the development of an appropriate explanation of pure alexia.

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