THE TEMPORAL PARAMETERS OF LEXICAL ACCESS IN DYSLEXIA

by

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Abstract

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According to the literature, dyslexia is a generalized linguistic coding deficiency arising at the point of lexical access. Recent theories have been emphasizing problems with temporal processing. Furthermore, recent research attests to temporal processing problems among Broca's aphasics manifesting in delayed patterns of automatic activation at the point of lexical access. While the acquired aphasias and the developmental dysphasias cannot be considered to be identical syndromes, there are parallels between them. In addition, dyslexia is postulated to be a later manifestation of developmental dysphasia. It was thus hypothesized that the temporal disruptions evidenced by dyslexics are a manifestation of the same delayed availability of lexical-semantic information found among Broca's aphasics. The aim of the present research was to examine the temporal parameters of automatic activation of both orthographic and lexical-semantic information among dyslexics at the point of lexical access.

3 Experiments were conducted to examine the temporal parameters of priming presumed to provide a measure of automatic activation. The first was a masked priming experiment which examined orthographic and lexical-semantic priming at the initial stage

of lexical access. The second and third experiments used a continuous list paradigm to examine the temporal parameters of lexical access in both visual and auditory modalities. In the visual modality semantic priming was examined at ISIs 500, 800, 1100 and 1400 and in the auditory modality it was examined at SOAs 800, 1100 and 1400.

A sample of 24 dyslexic boys and 24 normal controls aged between 13 and 15 was used.

Results provided evidence of temporal processing delays among dyslexics in the auditory modality. In addition, there was suggestive evidence of temporal processing delays in the visual modality. There was no strong evidence, however, for delayed patterns of priming among dyslexics in either visual or auditory modalities. The fact that normal controls in the age group used in the present research primed at a later point along the temporal continuum than normal adults raised the possibility that ISIs/SOAs used were not long enough to capture priming among dyslexics. Directions for future research were discussed.

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CHAPTER 1

INTRODUCTION AND HISTORY

INTRODUCTION

Reading, one of several subprocesses within the language domain, is a temporal process requiring the dynamic interplay of component subprocesses along a temporal dimension. While it is recognized that the core deficit in dyslexia is in the phonological domain, more recent theories have been emphasizing problems with temporal processing as possible underlying bases. Wolff, Michel & Ovrut (1990), maintained that "the interaction of temporal variables, rather than any single variable, best described the nature of the impairment" and explained their findings in terms of a generic deficit in "temporal resolution." Wolf and Obregon (1992), in their studies of developmental dyslexia, postulate a possible temporal processing mechanism responsible for rapid rates of activating and integrating relevant subprocesses. They conceive of a failure in temporal resolution as underlying the deficit, resulting in reduced time to basic lower-level cognitive and linguistic processes which directly prohibits the development of automaticity necessary in word-retrieval and decoding, and indirectly prevents higher-level processes like reading comprehension from occurring (p. 241).

Recent evidence indicates temporal disruptions in lexical access among aphasics resulting in delayed availability of lexical-semantic information. While the acquired aphasias and the developmental dysphasias cannot be considered to be identical syndromes

there are parallels between them. Furthermore, according to Rapin (1988), dyslexia is a later manifestation of developmental dysphasia and "the young dysphasic children of today are likely to be the reading and learning disabled children of tomorrow"(p.153). These parallels between the developmental and acquired aphasias, and the fact that dyslexia is a possible later manifestation of developmental dysphasia raise the possibility that the rate of processing difficulties in dyslexia could in fact arise from the same underlying disturbances as those that have been found in aphasics. In addition to these disruptions in the availability of lexical-semantic information, the literature also provides evidence of temporal problems in the accessing of orthographic information among dyslexics.

The present research thus proposed to examine problems with temporal processing among dyslexics. It proposed that these temporal processing disturbances would manifest in the language domain by causing disruptions in the temporal parameters of lexical access of both orthographic and lexical-semantic information.

DEFINITION OF LEXICAL ACCESS

For the purposes of the present study, lexical access is defined as a process by which a lexical item is contacted by either a visual or an auditory stimulus and information stored with that lexical entry is made available to the language processor. It involves an initial contact phase during which form-based information, including phonological and orthographic information, is encoded mentally, providing a basis for a match with the

sensory input. When this match is completed and the correct lexical entry selected, the stored knowledge associated with the lexical representation, including lexical and semantic information, is made available to the language system (Tyler & Frauenfelder, 1987). A disruption in lexical access could be hypothesized to result in different rates at which these different information types are made available to the language system.

HISTORY

DEFINITION OF DYSLEXIA

In 1968 the World Federation of Neurology proposed the following two definitions of dyslexia (Critchley, 1970):

1. Specific Developmental Dyslexia: "A disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin."

2. Dyslexia: "A disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities."

According to these definitions, dyslexia is a disturbance in the processing of written language. These definitions were not explanatory of dyslexia, however, which

manifests with varying constellations of symptoms. There are several theoretical conceptualizations of the disorder, attesting to its complexity.

EARLY THEORIES OF DYSLEXIA

The earliest theories of dyslexia had their origins in the structural models of the acquired alexias and conceived of it as representing a disruption in visual perceptual functions. Subsequent theories proposed problems with intersensory integration (Birch, 1962); directional confusion in association with a developmental Gerstmann syndrome (Hermann, 1959); serial memory deficits (Bakker, 1970) or rule learning deficiencies (Morrison & Manis, 1982).

Because these unitary explanations did not account for the multiplicity of reading deficits observed, attempts to categorize the various "syndromes" resulted in the development of subtyping studies (Mattis, French & Rapin, 1975; Denckla, 1979; Fisk & Rourke, 1979; Doehring, Trites, Patel & Fiedorowicz, 1981; Morris, Blashfield & Satz, 1986). These subtyping studies, however, were not very useful theoretically. While enumerating the symptomatologies associated with so-called syndromes of dyslexia, they never attempted to establish causality or to develop explanatory constructs. In addition, the studies were fraught with methodological flaws. Furthermore, very few of them used similar variables, children of similar ages or similar techniques for validation of their results, contributing to lack of agreement between investigators as to the nature of subtypes (Ellis, 1985). Nevertheless, while the subtyping literature does not concur on the

nature of the possible syndromes, there is general agreement that the preponderance of dyslexic problems are language-based which led to language-based theories of dyslexia.

DYSLEXIA: A LANGUAGE-BASED DISORDER RESULTING FROM PROBLEMS IN ACCESSING LEXICAL CODES:

Theories conceptualizing dyslexia as a language-based disorder propose that it results from generalized linguistic coding deficits. Other researchers conceive of the problem as resulting from difficulties in accessing these codes.

Vellutino (1979) proposed that dyslexic children suffer from a generalized verbal deficit resulting from aberrant development in the knowledge and functional use of linguistic codes, including semantic, syntactic and phonological codes.

Perfetti's (1985) verbal efficiency theory emphasizes problems with accessing linguistic codes. According to him, efficient word decoding depends on adequate linguistic coding processes in which an inactive memory responds to a linguistic symbol in any modality, by a rapid retrieval of that symbol's codes in memory. Thus inefficient lexical access could impact on decoding in different ways. For example, it could produce low-quality codes characterized by insufficient semantic activation, insufficient phonetic activation or code asynchrony. By code asynchrony is meant that the longer a lexical process takes in its total execution the greater the possibility that the activation of its component codes will be out of "phase." For example, if there is early phonetic activation and late semantic activation then the overall quality of the word code is reduced.

Deficient lexical access could also interfere with working memory by taking resources away from holding onto the already assembled propositions and partly assembled ones in working memory.

Perfetti's theory is a resource-based theory in which the language processor is conceived of as a limited-capacity mechanism. The fewer attentional resources required by lower-level, decoding processes, the greater the amount of processing resources that can be alocated to higher-level comprehension processes. Thus, comprehension is dependent on fluent, effortless decoding and the major obstacle to reading achievement is at the level of decoding which, according to Perfetti, originates at the point of lexical access.

Miles and Ellis (1981) also espouse a general verbal coding deficiency in dyslexia and pinpoint the locus of difficulty at the point of lexical access. According to them, a deficiency at the level of lexical encoding, the process by which "codes" or representations of relevant features of traces are matched to entries in the lexicon, is a result of failure in the activation of entries in the lexicon. Using as a measure the number of items correctly reported and plotted against exposure times, they showed that when arrays of letters or digits are presented at short exposure times and are followed immediately by a pattern mask consisting of a jumble of overlapping digit parts, dyslexic chilren identify significantly fewer letters or digits than chronological-age matched controls. Since the slope also increased as stimuli changed from nonsense, non-verbal stimuli to easily named stimuli, it was argued that the slope reflected the rate of lexical encoding. In further experiments Ellis (1980) demonstrated that dyslexic children are affected by phonemic

similarity, word length and articulatory suppression (whereby subjects are prevented from rehearsing items when required to articulate some irrelevant item) as much as their controls. He concluded that the problem is not one of articulatory encoding but is rather at the "lexical" level, involving access to the lexicon and the retrieval of appropriate lexical codes.

DYSLEXIA: A DISORDER IN PHONOLOGICAL CODING

Investigations of generalized linguistic coding deficits led to the establishment of phonological coding difficulties as the "core" coding deficit in dyslexia. There is a significant body of literature attesting to the involvement of phonological coding deficits among dyslexics (Wagner & Torgesen, 1987; Stanovich, 1992; Rack, Snowling & Olson, 1992). The evidence is bolstered by longitudinal correlational studies indicating that phonological awareness and reading are related independent of general cognitive ability. Also, several investigators (Bradley & Bryant, 1983, 1985; Vellutino & Scanlon, 1987; Wagner & Torgesen, 1987) have demonstrated that phonological tasks account for a statistically significant proportion of variance in reading ability after the variance associated with standardized intelligence measures has been partialled out.

According to Liberman and Shankweiler (1979) poor readers are impaired in acquiring alphabetic letter-sound mapping skills because they have not developed a functional awareness of the phonetic structure of speech and that spoken words can be segmented at the level of the phoneme. Liberman, Shankweiler, Fischer and Carter (1974) found significant positive correlations between tests of phonemic segmentation in pre-first

grade children and tests of reading ability given to the same children in first and second grade. Vellutino & Scanlon (1982) found that poor readers in second and sixth grades performend significantly below the level of their normal reading peers on a test of segmentation ability requiring auditory analysis of words and pseudowords. On inter- and intramodal matching of pronounceable pseudoword pairs Snowling (1980) found significant differences between normal and reading impaired children favoring the normal readers only on the visual-auditory task. Furthermore, while the normal readers improved with age, poor readers manifested no such improvement. Evidence also comes from reading-level match designs, where older reading-disabled children performed worse on phonological tasks than younger nondyslexic children matched on word recognition level (Bradley & Bryant, 1983; Snowling, 1980, 1981).

The poor reader's tendency to weak phonetic coding is apparent on measures of short- and long-term memory for linguistically coded material (Liberman, Shankweiler, Liberman, Fowler & Fischer, 1977; Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). Furthermore, poor readers manifested a greater tendency to encode a word's semantic rather than its phonological properties on short-term memory tasks, while the reverse pattern was observed in normal readers (Vellutino,Scanlon & Tanzman, 1990; Huba, Vellutino & Scanlon, 1990). These authors also found that phonological encoding was more disrupted in second than sixth grade on a shadowing task, suggesting that older poor readers' sensitivity to phonological information is more like that of normal readers (Huba, Vellutino and Scanlon, 1990). Studies measuring sensitivity to meaning and structural attributes of printed words (Vellutino, Scanlon and Tanzman, 1990) found that

poor readers were no less sensitive than normal readers to the meanings of printed words but were especially insensitive to the phonological attributes of printed words.

Several investigators concluded that the fact that training of phonological skills resulted in significant improvements in reading skills provided evidence for phonological deficits being causative of reading disabilities (Bradley & Bryant, 1983; Vellutino & Scanlon, 1987). Furthermore, because normal readers maintained their superiority over poor readers and profited more from the training than did poor readers, they concluded that poor readers' difficulties in phoneme perception were rather "basic" and not easily remediated (Vellutino & Scanlon, 1987).

Rack, Snowling & Olson (1992), however, in reviewing a large number of studies which compared dyslexics and reading-level matched normal readers on nonword reading measures, found that approximately two thirds of the studies found specific phonological reading problems in the dyslexic group. They concluded that the fact that not all dyslexics were deficient in nonword reading failed to provide evidence for reading problems being specifically phonologically based. While methodological difficulties contributed in part to these findings, they maintained that "phonological processes are important, but they don't tell the whole story. The weight of the evidence suggested that most dyslexics are able to acquire word recognition skills beyond the level that would be predicted from their phonological skills" (p. 50). Thus, they caution that "it is more appropriate to consider that there will be differing contributions of phonological processes depending on the particular word, the subjects' levels of skill, and the subjects' stage in reading

development." They also recommend that "it seems sensible to consider dimensions of individual differences in dyslexia rather than discrete subtypes" (p.50).

These ideas are echoed in Stanovich's conceptualization of reading disability as resulting from a core deficit in the phonological domain which, over time becomes a more broad-based syndrome as the impact of associated and resultant deficits of reading failure impact on reading development. He conceptualizes reading disability as manifesting in differing constellations of reading related skills occurring along a continuum in multidimensional space (Stanovich, 1988). Space was represented along intersecting axes with phonological skills on the one hand, and more broad-based cognitive skills on the other hand. According to Stanovich (1992), the human mind comprises both modular systems and central systems. Modular systems are autonomous, encapsulated sensory systems functioning independently of higher-level cognitive influences. Central systems, on the other hand, are characterized by the free interaction of higher and lower -level information (Fodor, 1983). Stanovich explains reading difficulty as resulting from a disruption in the "phonological" module. He hypothesizes, however, that there are developmental changes in the degree to which the deficits of reading-disabled children display cognitive specificity. While upon entering school the performance of these children is characterized by a relatively high degree of specificity in the phonological domain, this core modular deficit becomes less modular and more diffuse with development.

DYSLEXIA: PROBLEMS WITH ORTHOGRAPHIC CODING

In addition to identifying the phonological module as the core module affected in dyslexia, Stanovich (1992) suggests the involvement of other modules, including those that underly the formation of visual-orthographic representations or the processes underlying the induction and use of spelling-to-sound knowledge. He concludes that dyslexics may experience "a severe inability to form accurate orthographic representations, to access orthographic representations, or both" (Stanovich, 1992, p. 319). According to Berninger (1990), "reading disability may stem from a failure of one or more of the multiple orthographic codes to develop, from a failure of corresponding codes to become connected, or from a failure of the multiple code connections to function temporally in concert" (p. 523).

In fact, recent evidence shows that not only phonological skills but also othographic skills are important in learning to read. There are individual differences in the ability to establish orthographic representations that are independent of phonological abilities and spelling-to-sound decoding skill (Stanovich, 1992), and, according to Berninger (1990), "taking into account both phonology and orthography explains more variance in reading achievement than either phonology or orthography alone" (pg 518). Manis, Szeszulski, Holt and Graves (1988) found a significant cluster of reading disabled children characterized by orthographic processing skill poorer than their reading recognition scores would predict. Olson, Kliegel, Davidson and Foltz (1985) found greater independence of phonological and orthographic skills within a sample of disabled readers than within normal readers, for whom skills were strongly correlated.

Problems at the orthographic level have been found to occur in the utilization of spatial redundancy in that poor readers were less effective in utilizing the more frequent occurrence of certain letters in certain positions (Mason, 1975). Poorer readers also failed to abstract orthographic regularities such as permissible letter sequences (Venezky, 1979). There is much evidence, however, for the interactive development of phonological and orthographic skills (Berninger, 1987; Reitsma, 1989). Ehri (1984) provides an alternative conceptualization to the dichotomy between visual and phonological routes of dual route theory in proposing a "visual route that is paved with phonological information leading into lexical memory" (Ehri 1992, p. 114). According to her, phonetic segments provide a base to which letters are secured as orthographic images are formed in memory (Ehri, 1980) and an orthographic image allows beginning readers and spellers to see what they hear and say. When children learn to read, an orthographic identity is added to a phonological, syntactic and semantic identity for each word in the lexicon or mental dictionary. This orthographic identity amalgamates with the other identities, forming an integrated unit, and thus can replace phonology as an address to find words in memory. One implication of Ehri's amalgamation theory is that disabled readers who have deficits in phonological coding for phonemes and/or syllables may not create adequate orthographic images because the links between the sounds and visible language are more difficult for them to grasp (Berninger, 1990).

In a study showing that some disabled readers have specific problems in forming visual-orthographic representations, Reitsma (1983) gave first-grade children practice at recognizing a set of words. When tested on recognition of the practiced words and a

matched set of homophonic spellings of the words, only four trials of practice led to superior performance on the standard spellings for both the skilled and less-skilled first grade readers but a learning-disabled group two years older matched on reading level did not perform better on the standard spelling even after six trials of practice. In a further experiment, Reitsma (1989) provided evidence for a developmental trade-off between the use of phonological information and word-specific orthographic information in a group of normal beginning readers. With practice in normal beginning readers, there was increasing knowledge about the orthographic specifications of words and the need for extensive phonological recoding decreased, but not in retarded readers. Reitsma maintains that retarded readers have difficulty in both phonologically decoding written words and in storing orthographic information in their long-term lexical memory and he concludes that the ability to use phonological structures properly and the ability to acquire orthographic knowledge are "interactively connected and mutually dependent" (p. 68).

DYSLEXIA: DEFICIENT ACCESS OF SEMANTIC CODES

(a) Off-line studies of semantic coding deficits

In addition to phonological and orthographic information, lexical entries also contain semantic information i.e. the meaning of words and morphemes (Caramazza, 1988). Investigators stressing generalized language impairments in dyslexia (Vellutino, 1979; Perfetti, 1985; Miles & Ellis, 1981) have implicated semantic coding deficits as an underlying difficulty. Vellutino (1979) maintains that while poor readers do not suffer

from any significant deficits in semantic processing, access to specific word meanings or meanings coded contextually is not always "efficient."

Golinkoff & Rosinski (1976) in a study measuring reaction time on a picture-word interference task, found that poor readers had no more difficulty than normal readers in accessing the basic meanings conveyed in single words (p. 257). In an experiment supporting these findings, Perfetti, Hogaboam and Bell (1979) found that there were no significant differences between skilled and less skilled readers in matching oral and printed words and also oral words and pictures. They found there were significant differences, however, between these groups when the child was required to match a category word (e.g. "animals") to pictures or words of exemplars (e.g. "dog"). They interpreted these findings as indicating that lower level feature matching is adequate in the less skilled readers but that retrieval of semantic information associated with a word or picture name is slower. Perfetti et al. suggest that these limitations in speed of semantic decoding are due to impairments in "rapid access, retrieval and use of information about word meanings" (p. 68).

In a study demonstrating less efficient "use" of semantic information by poor readers, Vellutino, Scanlon & Tanzman, (1988) measured encoding and retrieval by contrasting subjects on memory for lists of words in taxonomic categories. Encoding was assessed by cued presentation in which category "cues" were designed to alert the individual to the semantic similarities among given words on a stimulus list. Retrieval was assessed by constrained retrieval, in which category cues were presented after all stimuli had been administered and immediately before recall of items in respective categories.

Encoding was presumed to be subserved by semantic processes, while retrieval was presumed to be subserved by phonological processes. There was a developmental difference between second and sixth grade poor readers so that in the lower grades phonological factors were most significant while at higher grades semantic factors were most significant. Semantic deficits become exaggerated over time, in part, because of protracted reading disability (p. 238). In this study the "use" of phonological and semantic codes was inferred and they were thus unlikely to be pure measures of these coding effects. Furthermore, these studies were assessing strategic processes which are known to occur postlexically.

(b) On-line studies of semantic access

The abovementioned studies were off-line studies which were not measuring processing as it occurs in real time and were thus not sensitive to the temporal parameters of automatic activation. On-line studies used priming paradigms in which words preceded by related words or sentence contexts are responded to faster than those preceded by unrelated words or sentence contexts.

According to Stanovich (1992), difficulty at using semantic contexts to facilitate the recognition of words is not a major cause of reading failure or a major determinant of variability in reading achievement. In fact, several studies show greater contextual effects among poor readers than normal readers. Schvaneveldt, Ackerman & Semlear (1977) using a pairs paradigm examined the effect of a single-word semantic context on lexical-decision times. They found that the previous presentation of a highly associated word

facilitated the lexical-decision times of both second and fourth graders. The effect of semantic context was greater for the second grade readers and, within each grade, the correlations between standardized reading measures and the magnitude of the context effect were all negative, indicating greater use of context by the poorer readers. Pring & Snowling (1986) using a modified version of the pairs paradigm devised by Neely (1977) created novel links between pairs of words in order to measure attentional priming as opposed to automatic priming. For example, when children saw a "signal" word (e.g. FRUIT) they should next see a color word (e.g. green). They found that the effect of semantic context was greater for children of lower than for children of higher reading ability. West and Stanovich (1978) using a Stroop color-naming paradigm studied the effect of sentence context on word recognition by having fourth-graders, sixth-graders and adults to name the color of the ink of a target word that had been preceded by either an incomplete sentence that was congruent with the word, or one that was incongruent with the word, or a no-context condition. They found that within each age range, correlations involving a standardized reading measure indicated a slight tendency for poorer readers to show a greater contextual facilitation effect.

The abovementioned studies were concerned with the magnitude of contextual effects rather than with the temporal parameters of lexical access. Although there is paucity of studies concerned with the temporal deployment of activation among dyslexics, an on-line study by Merrill, Sperber and McCauley (1981) indirectly assessed the temporal parameters of contextual effects among dyslexics.. They used a Stroop type task to examine contextual effects for target words representing contextually emphasized

(appropriate) attributes and nonemphasized (inappropriate) attributes of the target words. They found that for skilled readers there was an inhibition effect for contextually appropriate words but not for nonemphasized attributes. However for low-ability readers, the inhibition effect was found for both emphasized and nonemphasized words. They interpreted these findings as showing that skilled readers were locked into the contextually relevant encoding of the sentence within one second after reading it. For low-ability readers, however, more of the word's general semantic features were still "activated" so that multiple meanings were still available at that point. They concluded that high-ability readers may have a more rapid "dampening" process. That is, for high ability readers, the activation of inappropriate meanings is more quickly suppressed or dampened following initial activation." This finding provided some evidence for delayed semantic processing but the fact that the study measured inhibition rather than facilitation indicated that it was concerned with strategic processing rather than automatic processing.

Thus, while these studies provided evidence of greater contextual facilitation among dyslexics when compared to normal readers, the paradigms used measured strategic attentional processing rather than automatic lexical access. For example, studies contained pairs-paradigms likely to elicit strategic processing (Schvaneveldt, Ackerman & Semlear 1977) as well as paradigms examining expectancy-based priming rather than automatic priming. (Pring & Snowling, 1986). These studies also based their claims for automatic processing on measures (inhibition) known to reflect strategic processing (West & Stanovich, 1978). Furthermore, automatic lexical access for sentential contexts in adults, whereby all meanings of an ambiguity are activated, has been shown to occur

within a 200 msec window (Onifer & Swinney, 1981). After that point, context constrains lexical access to a single interpretation. In the abovementioned studies (West & Stanovich, 1978), the temporal parameters of lexical access were not the major focus. Target onsets were experimenter controlled so that the temporal windows between contexts and targets were variable and imprecise.

DYSLEXIA: A DISORDER OF TEMPORAL PROCESSING

In addition to these theories stressing coding problems, recent theories of dyslexia have been emphasizing problems with temporal processing. Wolff (1992) sees dyslexia as one of the manifestations of a domain general disruption in temporal resolution and cites evidence in studies of the perception of linguistic sequences (Vellutino, 1979); in the processing of visual as well as nonlinguistic auditory stimuli (Lovegrove, Martin & Slaghuis, 1986; Tallal, 1980) and deficits of temporal organization in the production of nonverbal and verbal motor patterns (Wolff, Michel & Ovrut, 1990). Deficits in both language and motor domains were rate dependent, being evident at fast but not at slow performance rates.

Tzeng and Wang (1984) propose a temporal processing mechanism which is lateralized in the left-hemisphere because of the left-hemisphere's ability to process sequential information at a faster rate than the right hemisphere. Dyslexia results when an impaired left-hemisphere timing mechanism prevents the rapid utilization of a sequential strategy to code the correct letter sequence in written language. Dyslexics are thus unable

to employ grapheme/phoneme correspondence rules rapidly enough to achieve reading fluency.

(a) TEMPORAL PROCESSING PROBLEMS IN THE LANGUAGE DOMAIN

Rate of naming problems in dyslexia:

There is a considerable body of literature examining rate of naming in dyslexia. According to Rudel (1983), the most frequently found characteristic in children with dyslexia outside of their primary reading impairment is "subtle dysnomia" or naming disorders. Denckla and Rudel (1974) and Spring and Capps (1974) demonstrated that dyslexic children were slow at letter naming and Ellis (1980) found dyslexics slower to name the most highly familiar visual symbols, graphological symbols, including letters (Ellis, 1980). Furthermore, these rate problems were found when naming times were assessed on continuous lists (Denckla & Rudel, 1976; Spring & Capps, 1974; Wolf, Bally and Morris, 1986) and on discrete trials for digits and letters (Bowers and Swanson 1991) and for objects (Levy & Hinchley 1990).

These rate problems have been found to be correlated with different components of reading. Speed to name digits is highly correlated with latency of word recognition (Bowers & Swanson, 1991), as well as with accuracy for both word and nonword reading (Spring & Davis, 1988). Wolf, (1991) found that rapidly naming automatized symbols such as letters and numbers maintained a strong relationship with the more basic, lower-level requirements involved in word recognition, and the more semantic-based requirements

involved in object-naming contributed to a strong relationship with the higher-level processes of reading comprehension.

Prediction studies indicate the involvement of naming speed in reading difficulties. Jansky and de Hirsch (1973) have suggested that the two best predictors of "reading readiness" are object naming and alphabet-letter naming. Furthermore, in a five-year longitudinal study, prereaders' naming speed for letters, digits, objects and colors predicted all later reading skills - word recognition, oral reading and comprehension (Wolf et al. 1986). In addition, the speed to name alternating alphanumeric stimuli (i.e. letter, number, letter, number) in kindergarten successfully predicted the reading status in grade 4 of each of the most profoundly reading impaired children (Wolf et al. 1986). The fact that naming speed deficits are specific to reading disability rather than characterizing other learning disorders (Denckla & Rudel 1976) also suggests specificity of the problem to reading difficulty.

Naming speed deficits appear to be developmentally invariant, persisting as a characteristic of severely disabled readers (Bowers & Wolf, 1993) suggesting a constitutional basis. Wolff (1992) also claims that that these temporal deficits are neurologically based and developmentally invariant. Adults who were diagnosed as dyslexic readers in childhood retain a slow rate of digit and letter naming speed (Wolff, Michel & Ovrut, 1990) and there were no differences between remediated and unremediated dyslexics (Wolff et al., 1990). Furthermore, although naming speed increases markedly with age in childhood, Swanson (1986) and Bowers (1992) report one

and two year test-retest reliability for digit naming speed during these years of 0.9 and 0.85 respectively.

Studies in naming are not consistent in their claims as to the locus of these problems in rate of naming. While Mackworth and Mackworth (1974) proposed that naming difficulties arise either after visual encoding, at the level of access to the internal lexicon where lexical codes are generated, or at the next stage which involves articulatory encoding, Spring and Capps (1974) showed that, as stimuli became more nameable in the procession from pictures to colors to digits, so the dyslexic subjects named these items relatively more slowly than the controls. Spring and Capps account for their results in terms of slow speech-motor encoding in dyslexic subjects. Ellis & Miles (1981), however, argued that the difficulty is prior to articulatory encoding and lies in the connection or translation of visual to lexical codes. Other studies (Wolf, Bally and Morris, 1986; Wolf, 1991) imply that temporal processing problems occur at the point of word production.

(b) TEMPORAL PROCESSING PROBLEMS IN THE VISUAL DOMAIN

When Vellutino (1979) dispelled the notion of visual perceptual disturbances as underlying dyslexia, studies cited were based on paradigms which were not sensitive to the temporal dimensions of visual processing. When temporal parameters were taken into account, however, differences between dyslexics and average readers became apparent (Willows, 1991).

Studies using backward masking tasks and separation thresholds provide evidence of problems with information access in the initial stages of visual information processing. The results of several experiments have shown that disabled readers process visual information more slowly than normal readers. Mazer, McIntyre, Murray, Till and Blackwell (1983), using a backward masking paradigm found that reading disabled children exhibited longer ISIs for recognizing letters. Di Lollo, Hanson and McIntyre (1983) and Lovegrove and Brown (1978) using a backward masking paradigm found dyslexics slower to process both letters and nonverbal information. Stanley and Hall (1973) found that both separation and identification thresholds for letters were longer for dyslexics than normals on tasks varying the interstimulus interval and using a backward mask to interfere with detection. O'Neill and Stanley (1976), using nonverbal stimuli, found that separation thresholds for dyslexic children were significantly longer than normal controls on a task requiring them to state at what point they perceived pairs of identically-oriented and spatially-overlapping straight lines as separate.

In their investigations into temporal disruptions in visual systems, Lovegrove, Martin & Slaghuis (1986) proposed "transient" and "sustained" systems. The transient system is predominantly a flicker or motion system transmitting information about simulus change. The sustained system is predominantly a pattern system transmitting information about stationary stimuli (p. 233). Citing Breitmeyer's (1980) earlier hypothesis, Lovegrove et al. described how reading a line of print requires a precise orchestration of transient and sustained visual systems. Using as their measure ability in processing spatial frequencies, pattern-contrast sensitivity and temporal-contrast sensitivity, they found that

disabled readers are less efficient at processing information within transient systems which play an important role in processing stimuli exposed very briefly in quick temporal succession. They were no different, however, from normals at processing information within sustained systems. Thus dyslexic children's "sustained" visual system which facilitates detection of visual detail when exposures are longer, is intact. Lovegrove et al. hypothesized that these processing difficulties within transient systems results in the timing of subprocesses being "off." As a result, images right after a saccade or in certain contrast conditions might take longer to emerge due to "masking-by-integration" effects (p. 258). In support of these findings, Di Lollo, Hanson and McIntyre (1983) have also found that disabled readers have longer visible persistence than normal readers.

Lovegrove et al.'s analysis has been bolstered by recent data from Livingstone, Rosen, Drislane and Galaburda (1991), describing characteristics of magnocellular (transient) and parvocellular (sustained) systems in dyslexic and average reading adults, using evoked potential records as well as anatomical analyses. They suggest that deficits in the magnocellular system may account for dyslexics' slower processing of visual information under certain conditions of stimulus frequency and contrast.

Bowers and Wolf (1993) integrate theories of phonological and temporal processing deficits in their double-deficit theory of dyslexia. Using Ehri's developmental model, Bowers and Wolf speculate that precise timing mechanisms are necessary for the development of orthographic codes and their integration with phonological codes. According to Ehri and Wilce (1983), the attainment of automaticity precedes the attainment of speed and maximum speed of word reading occurs "...when all of the

associative links between codes in the various memory and response systems are completely integrated or unitized in memory, thus enabling the learners to execute the idenfication process at the top speed thay are capable of for their age and level of cognitive maturity" (p. 4). Thus Bowers and Wolf conclude that along with a core phonological deficit, temporal processing disturbances preclude the efficient formation of orthographic representations and their quick retrieval.

FORMULATION OF THE PROBLEM

a. Parallels Between Dyslexia and the Acquired Aphasias

The literature cited here supports the fact that the preponderance of dyslexic problems occur in the language domain. Furthermore, although the developmental dysphasias and the acquired aphasias cannot be considered to be identical syndromes, there are parallels between them. Rapin & Allen (1983) using adult models of acquired aphasia as a heuristic in deriving their six syndromes of developmental dysphasia, claim that while syndromes of delayed language development do not precisely parallel the syndromes of acquired aphasia in adults, it "would not be parsimonious to think that the organization of childrens' brain is fundamentally different from the organization of the adult brain. It is likely that similar symptoms reflect pathology in the same general systems in both children and adults" (p. 165). Furthermore, according to Rapin (1988), dyslexia is a later manifestation of developmental dysphasia and "the young dysphasic children of today are likely to be the reading and learning disabled children of tomorrow" (p. 153).

These associations of aphasia with dyslexia present a possible explanation for recent findings that both agrammatic aphasics and dyslexics experience temporal processing difficulties. These findings raise the possibility that developmental dyslexia may in fact arise from the same processing disturbances as those that have been found in agrammatic aphasia.

b Temporal Disruptions in Automatic Access in Broca's Aphasia

Studies in Broca's aphasia have revealed temporal processing abnormalities in accessing meanings of ambiguities. Milberg & Blumstein (1981) using a visual pairs priming paradigm, found no reliable visual semantic priming among Broca's aphasics. In contrast, Blumstein, Milberg & Shrier (1982) using the same methods and stimuli as Milberg & Blumstein but in the auditory modality, found auditory semantic priming in both Broca's and Wernicke's aphasics. Chenery, Ingram & Murdoch (1990) using the auditory pairs paradigm used by Blumstein et al. replicated their research. They found that both low and high comprehension aphasics evidenced facilitation and this facilitation effect was most obvious in the significantly more accurate response to related targets. In a later auditory semantic ambiguity study using word triplets (Milberg, Blumstein & Dworetzky, 1987), however, Broca's aphasics showed no facilitation. Broca's aphasics have also been found to experience difficulties with lexical access in sentence-priming studies. These studies, however, used procedures which were likely to elicit controlled rather than automatic processing, including the use of pairs paradigm and a relatively high proportion (33.3%) of related pairs versus unrelated pairs. In addition, the long SOA

(2000msec) in the study done by Milberg & Blumstein, 1981, could also result in controlled processing. Swinney, Zurif, & Nicol (1989) used an on-line, cross-modal priming paradigm to measure access of semantic ambiguities within sententially appropriate or inappropriate contexts. The subject was required to make a lexical decision to a letter string representing either the most frequent or less frequent meaning of an ambiguity appearing on a screen immediately upon the offset of the ambiguity. Thus, the ISI was 0 msec so that any activation evidenced could be considered automatic. They found that, in contrast to the findings for neurologically intact listeners where there was exhaustive, automatized access of semantic ambiguities, agrammatic aphasics accessed only the most likely interpretation of an ambiguity, regardless of context. Among Wernicke's aphasics, however, access was both exhaustive and autonomous.

These findings led Swinney et al. to speculate that it was not that the meanings of ambiguities were not available but that the subjects were slower at activating all relevant word meanings. Specifically, they proposed that the lexical access component operates with a slower-than-normal "rise" time where the normal frequency-ordered activation of access is protracted. On this view, only the most frequent meaning representation is engaged within the time frame imposed by the experimental paradigm. The facilitation for all senses of an ambiguous word should eventually be shown, but at a point in the sentence that is noticeabley later than that which is shown normally. Thus, automatic lexical access is slowed rather than unavailable (p. 32).

In line with this reasoning, Prather, Zurif, Stern & Rosen (1992) presented a Broca's aphasic with a "continuous" list where a response to a letter string initiated a fixed

inter-stimulus interval (ISI) terminated by the next letter string. The subject's task was to make lexical (word/non-word) decisions about each string. Results revealed that priming was active at long ISI's (1500 msec) rather than the normal 500 or 800 msec. Those effects diminished rapidly, a pattern of results the authors interpreted as being consistent with an inference that the effects were automatic rather than strategic. If subjects were using intentional strategies effects would be expected to increase at longer word intervals (Neely, 1977).

The parallels between the developmental dysphasias and the adult aphasias as well as the fact that it is possible that dyslexia is a later manifestation of developmental dysphasia suggest that dyslexics may experience the same temporal disruptions in automatic lexical access found among Broca's aphasics.

c. Summary Statement of the Problem

The present research proposed that temporal processing problems contribute to dyslexia and aimed to examine the temporal parameters of lexical access among dyslexics. Because there are parallels between the acquired aphasias and the developmental dysphasias, and dyslexia is postulated to be a later manifestation of developmental dysphasia, it was hypothesized that the temporal disruptions evidenced by dyslexics in the literature cited above, are a manifestation of the same delayed availability of lexical-semantic information found among Broca's aphasics. Furthermore, the fact that dyslexics also evidence temporal processing difficulties with visual information suggests a temporal basis to their orthographic difficulties. Thus, the present research proposed to examine

the automatic access of semantic and orthographic information among dyslexics. Lexical access was considered to be an automatic process, but it was hypothesized that the rise of activation among dyslexics would be delayed temporally resulting in its manifesting at a later point along the temporal continuum. In other words, the "rise" time of automatic activation would be delayed.

While the literature cited provides evidence of contextual facilitation among dyslexics, studies used paradigms which were more likely to be assessing strategic rather than automatic processes. Furthermore, the studies cited were concerned with the magnitude of contextual effects rather than with the temporal parameters of automatic activation as it is deployed over time. The aim of the present research was thus to examine automatic activation among dyslexics and to determine whether the temporal processing disruptions they experience are the result of delayed patterns of automatic activation at the point of lexical access.

RATIONALE FOR PROPOSED PARADIGMS:

a. Measures of activation:

The research proposed to use priming paradigms in which priming represents a measure of activation based on the premise of automatic spreading activation throughout a lexical network. A prime is presumed to activate a lexical representation in memory and when the prime is semantically or orthographically related to a target it will facilitate response time to that target because of activation of these information types associated

with the target. Priming is measured by the difference between response times to targets preceded by semantically and orthographically related primes when compared to targets preceded by unrelated primes. Facilitation results when responses to related targets are faster when compared to neutral targets, while inhibition results when responses to unrelated targets are slower than to neutral targets.

b. Priming mechanisms.

Two-process models of information-processing (Posner & Snyder, 1975) assume that contextual priming effects can be mediated by two separable mechanisms. One is an automatic, spreading-activation process which is fast, uses little cognitive capacity, and causes facilitatory but not inhibitory context effects. The other is a conscious-attention, expectancy mechanism that operates more slowly, utilizes attentional capacity and causes facilitation and inhibition.

In addition to these two processes, Neely & Keefe (1989) propose a third process, a postlexical retrospective semantic matching strategy. In the prelexical expectancy generation strategy subjects read the prime and generate a possible target or targets. Subjects can respond "word" faster when the target matches one of the expected words than when it does not. If the target is not a member of this expectancy set, lexical access for that target is inhibited, relative to the neutral priming condition. In the retrospective semantic matching strategy subjects assess the semantic relation between the prime and target before making their decision to the target. Because the presence of a relation between the prime and target indicates that the target is a word, subjects can use the

presence of a relation to aid their "word" decision. Consequently, subjects are faster to respond "word" on related than on unrelated trials.

The present research aimed to examine automatic processes by using paradigms which eliminate strategic processing, including expectancy-based strategies as well as retrospective semantic matching strategies.

c. Lexical Decisions:

In sentence priming paradigms lexical decisions have been found to be sensitive to post-lexical decision making processes (Seidenberg, Waters, Sanders and Langer, 1984) and naming responses were considered a purer measure of automatic processing. Lexical decisions and naming responses, however, have been found to detect context effects of approximately equal magnitude in several single-word priming experiments (Becker & Killion, 1977). In addition, recent evidence indicates that the pronunciation task is not as free from subjects strategies as previously thought in that Keefe and Neely (1990) obtained a proportion effect in a naming task. Furthermore, using a single-presentation paradigm in which subjects responded to every word in the list, McNamara and Altarriba (1988) demonstrated that the lexical decision task resulted in automatic priming. Thus with certain paradigms lexical decisions reflect automatic rather than controlled processes, justifying their use in the present research.

d. The Relatedness Proportion Effect:

One finding indicative of subject strategies is that increasing proportions of related words have been found to result in increased priming, which Neely (1977) called the Relatedness Proportion effect. This effect was particularly evident at longer ISIs (Neely, 1977; Tweedy, Lapinski & Schvaneveldt, 1977; den Heyer, Briand & Dannebring, 1983) and was held to be due to an expectancy mechanism as the subject comes to expect relations between prime and targets. De Groot (1984) found the relatedness proportion effect to be evident at shorter as well as longer SOAs, especially as the proportion increased from .50 to .75. Thus, in order to eliminate any expectancy-based strategies, proportions of related versus unrelated words must be kept low.

e. Pairs paradigms:

According to Stern, Prather, Swinney and Zurif (1991) there are a number of reasons why the traditional pairs paradigm is prone to elicit strategies and expectations of relatedness among words and thereby to allow or even encourage controlled processing. First, there is typically a delay between paired test items, and setting the pairs apart (or presenting the members of the pair simultaneously) suggests that the words somehow belong together, even if the task instructions are neutral. Second, there is time after the presentation of each pair to reflect upon the connection between the paired words just viewed. In order to separate automatic and controlled processing so that they could map out the rise and fall of automatic priming effects independently of any effects of controlled processing, Prather, Pasquotto, Seimen & Lawson (1986) developed the continuous list

paradigm in which words were presented in continuous lists rather than as discrete pairs Shelton & Martin (1992) have also used a single-presentation paradigm rather than a pairs-paradigm as a measure of automatic processing

f. The Continuous-list paradigm

Shelton and Martin (1992) using a single-presentation lexical decision paradigm in which subjects made a lexical decision for every letter string, compared priming results with priming obtained in two paired presentation conditions a high proportion and a low proportion paired condition. In the low proportion, single-presentation condition they found significant facilitation for both direct prime-target pairs (e.g. lion - TIGER) and mediated prime-target pairs (e.g. lion - STRIPE where "tiger" was a mediating prime between the prime and the target) but no inhibition, while the pairs paradigms showed both facilitation and inhibition. Facilitation is presumed to reflect automatic processing while inhibition is presumed to result from strategic processing. Thus, the single-presentation lexical decision paradigm can be considered a measure of automatic processes.

Another effect in the lexical decision task typically attributed to strategic effects is backward priming in which priming is seen for prime-target pairs associated in a backward direction. Seidenberg, Waters, Sanders & Langer (1984) have argued that priming for these word pairs (e.g. hop - BELL) comes about if subjects were using a poslexical checking strategy. Shelton & Martin (1992) provided further evidence that the single-

presentation paradigm was assessing automatic processing in that they also demonstrated a lack of backward asymmetrical priming using this single presentation procedure.

In another demonstration of automatic priming, Shelton & Martin (1992) showed that priming for semantically related, unassociated pairs occurred in the two paired conditions but not in the single-presentation condition. Relationships between associated words is presumed to be mediated by automatic processing while semantic relationships require strategic processing.

Studies using the single-presentation or continuous list paradigm have demonstrated patterns of priming across the temporal continuum reflecting automatic activation. Neely (1977) tried to separate the temporal parameters of automatic from conscious processing by manipulating both SOA as well as "expectancy" as one of the strategies used in controlled processing. He found automatic priming as a function of relatedness, at between 250 and 400 msec and controlled processing effects as a function of expectancy, starting after 400 msec with maximal effects observed at 700 msec. Controlled processing was still evident at 2000 msec, while automatic effects decayed. This decay of activation was representative of automatic processing.

Prather, Zurif, Stern & Rosen (1992) in their single-case study of a Broca's aphasic, found no significant priming at the smaller ISIs, significant priming with increasing ISIs and a decay in priming at a point further along the temporal continuum at the longer ISIs. Even though these studies used ISIs which were longer than those that have been shown as the time frame for automatic activation in normal adults (500-800 msec), the pattern of decay of activation was presumed to reflects automatic effects. If

subjects were using intentional strategies effects would be expected to increase at longer word intervals.

Thus, by using paradigms which have been shown to measure automatic activation, the present research aims to examine the temporal parameters of automatic activation among dyslexics.

GENERAL HYPOTHESES

The first set of hypotheses addressed the issue of whether dyslexics differ from normal controls in the activation of orthographic and lexical-semantic information at the earliest stage of lexical access. Orthographic manipulations of primes result in activation of orthographic information, while identity priming results in activation of both orthographic and lexical-semantic information.

It was hypothesized that:

1. Because dyslexics are slower to activate orthographic and lexical-semantic information than normal controls, they would not evidence any orthographic or identity priming at the initial stage of lexical access when compared to normal controls.

2. Nonword targets are nonlexical. Because normal controls would evidence early activation of lexical-semantic information there would be significant priming when targets were words but not when they were nonwords. Because of delayed availability of lexical information, dyslexics would show no difference in priming when targets are words or nonwords at the earliest stage of lexical access.

The second set of hypotheses addressed the temporal parameters of the availability of lexical-semantic information in both visual and auditory modalities.

It was hypothesized that:

When compared to average readers, dyslexics would exhibit delayed "rise" times for lexical-semantic activation in both visual and auditory modalities.

CHAPTER 2

METHODS AND RESULTS

The present research proposed to examine automatic activation and whether it exhibited a delayed pattern among dyslexics. It aimed to use on-line priming methods to examine the temporal parameters of the automatic spread of orthographic and lexical-semantic activation during lexical access. The first experiment used a masked-priming paradigm. Masking of the prime results in it being unconscious, preventing any strategic processing. This form of priming is thus presumed to reflect purely automatic processing (Marcel, 1980). The second and third experiments used a continuous list paradigm to measure automatic activation as it occurs across the temporal spectrum. By eliminating strategic processing resulting from pairs-paradigms and by keeping the proportion of related words low as well as introducing distractor strategies, the paradigm aimed to eliminate any conscious strategic processing.

EXPERIMENT 1

The first experiment examined whether dyslexics experienced difficulties with access of orthographic information at the initial stage of lexical access. According to Caramazza (1988), lexical entries contain perceptual level information (i.e. orthographic and phonological information) as well as semantic information (i.e. the meaning of words and morphemes). To examine the initial stage of orthographic access, a forward masked priming paradigm was used in which the prime was preceded by a mask consisting of six

hash marks (######). Because a masked prime is presumed to be unconscious (Marcel, 1980), no strategic processing takes place and therefore access is automatic. Orthographic priming occurs when the prime facilitates perceptual recognition of a subsequently presented target, and the prime and target have the same or similar forms (Forster & Davis, 1984). Orthographic primes were created by transposing 2 medial letters of targets or by substituting the third letter of targets. Lexical-semantic activation was measured by identity priming in which word primes were identical to targets. Identity primes were presumed to activate orthographic information as well as lexical-semantic information.

SUBJECTS

EXPERIMENTAL GROUP:

Subjects were 24 boys aged 13-15 (Mean Age: 14.37) who were attending the Kildonan School, which is a school for children diagnosed as having dyslexia. Criteria for admission were an average/above average level of intelligence. In addition, scores for decoding and spelling were required to be at least 2 standard deviations below the mean.

According to Stanovich, reading disability results from a core deficit in the phonological domain which, over time, gives way to a less modular, more broad-based syndrome as the impact of associated and resultant deficits of reading failure impact on reading development. He thus hypothesizes that there are developmental changes in the degree to which the deficits of reading-disabled children display cognitive specificity. While upon entering school the performance of dyslexic children is characterized by a

relatively high degree of specificity in the phonological domain, over time this core modular deficit becomes more diffuse, implicating other areas of cognitive functioning such as memory. Based on this conceptualization it is apparent that by the time children become adolescents the phenotype of dyslexia is not easily characterizable.

Subjects chosen for the present experiment had all experienced significant reading difficulties since they began reading and upon admission to the Kildonan School their reading was significantly impaired (more than 2 standard deviations below the mean) on standardized reading measures. They were all of average verbal intelligence (Mean Verbal I.Q.: 102.71) and possessed no physical, emotional or intellectual handicapping conditions. In addition, subjects who were receiving medication to treat attention deficits or seizure disorders were eliminated from the study. Five of the dyslexic boys were left-handed, but a Chi-Square analysis determined that this number was not significantly different from the number of boys in the control group who were left-handed.

The following standardized screening measures were obtained (See Table 1):

Non-Verbal I.Q.	
Matrices Subtest	
Stanford-Binet Intelligence Scale (4th Edition)	
MEAN I.Q.	102.29
Standard Deviation:	14.46
Range:	88 - 126

Word Identification

Woodcock Reading Mastery Tests

MEAN STANDARD SCORE:	84.83
Standard Deviation:	11.34
Range:	62 - 99
Percentile	21.22

Reading Comprehension

Gates MacGinitie Reading Comprehension Test

MEAN GRADE LEVEL:

7th Grade:	5.36
Standard Deviation:	2.92
Range:	2.6 - 11.1
8th Grade:	6.16
Standard Deviation:	4.26
Range:	2.7 - 7.6
9th Grade	5.2
Standard Deviation:	1.96
Range:	3.2 - 8.4

Subjects at the Kildonan school all received intensive remediation using The Orton-Gillingham method which is a phonics-based approach. While the average standard score for word identification among the group was in the low average range, these standardized scores did not reflect their decoding which was often effortful and slow even though many of them decoded accurately. Average reading comprehension scores, however, were significantly below expected grade levels.

Since spelling difficulties are known to be more resistant to remediation than reading and since spelling and reading are subserved by the same mental representations (Ehri, 1986), a measure of subjects' spelling ability was obtained.

Test of Written Spelling	
Total	
MEAN STANDARD SCORE:	81.62
Standard Deviation	11.11
Range	58 - 105
Percentile	16.00

Predictable Words	
MEAN STANDARD SCORE:	83.10
Standard Deviation:	9.91
Range:	64 - 107
Percentile	16.90

Unpredictable Words	
MEAN STANDARD SCORE:	80.24
Standard Deviation:	11.43
Range:	58 - 100
Percentile	14.71

Even after intensive phonics based remediation these boys were still experiencing spelling difficulties. Average standard scores for spelling were approximately 1 standard deviation below the mean for phonologically regular, predictable words and more than one standard deviation below the mean for unpredictable words which could not be phonologically mediated.

Because the present research proposed that the rate of word retrieval difficulties reported in the literature reflected delayed lexical access, a measure of naming rate was obtained using the Test of Rapid Automatized Naming (R.A.N.). On this task, letters and objects were arranged in separate matrixes and subjects were required to name them sequentially as quickly as possible.

Test of Rapid Automatized Naming (R.A.N.)

Objects	
MEAN REACTION TIME	46.01
Standard Deviation:	11.11
Range	29.09 - 69.45

Letters	
MEAN REACTION TIME	30.95
Standard Deviation	12.18
Range	16.94 - 69.62

The first experiment originally used a 500 msec target exposure. Eight dyslexic subjects were unable to complete the task under these circumstances. In order to establish a manageable target duration, these 8 subjects were used as a pilot group. As a result, the remaining 16 boys from the abovementioned experimental group constituted the experimental group for this experiment.

CONTROL GROUP

Subjects were 16 randomly selected boys from a group of 24 boys aged 13-15 (Mean Age: 14.62) who were paid volunteers from the local public schools, The Edgemont High School and New Rochelle High School. According to teachers' reports they were of average/above average intelligence, experienced no learning difficulties and had never and were not presently receiving Special Education or supplemental Resource Room facilities. Furthermore, a screening questionnaire administered to the boys indicated that they possessed no physical, emotional or intellectual handicapping conditions.

The following standardized screening measures were obtained:

Non-Verbal I.Q.
Matrices Subtest
Stanford-Binet Intelligence Scale (4th Edition)

MEAN I.Q.	115.83
Standard Deviation	11.73
Range:	96 - 132

Word Identification
Woodcock Reading Mastery Tests

MEAN STANDARD SCORE:	112.42
Standard Deviation:	7.16
Range:	103 - 128
Percentile	76.83

Test of Rapid Automatized Naming (R.A.N.)

Objects	
MEAN REACTION TIME	35.16
Standard Deviation	4.52
Range	28.09 - 43.56

Letters	
MEAN REACTION TIME	18.04
Standard Deviation	2.39
Range	14.84 - 23.28

The chronic reading difficulties of the dyslexic group, as well as their significant difficulties on measures of written language, even after remediation, confirm the diagnosis of dyslexia. In addition, the dyslexic group was significantly poorer than normal controls on measures of naming rate.

TABLE 1

GROUP COMPARISONS ON SCREENING MEASURES

	DYSLEXICS		CONTROLS	
	MEAN	S.D.	MEAN	S.D.
MEAN AGE	14.37	0.99	14.62	0.86
NON-VERBAL I.Q.	102.29	14.46	115.83	11.73
WORD IDENTIFICATION STANDARD SCORE	84.83	11.34	112.42	7.16
R.A.N. OBJECTS REACTION TIME	46.01	11.11	35.16	4.52
R.A.N. LETTERS REACTION TIME	30.95	42.18	18.04	2.39

1. Statistical analyses using t-tests revealed that the groups were significantly different on measures of Non-Verbal I.Q. $t(df\ 46) = 4.96$, $p<.001$. Post-hoc statistical analyses, however, revealed no significant correlation of Non-Verbal I.Q. and reaction time for either dyslexic ($r = .4261$) or control groups ($r = .0298$).

2. The groups were significantly different for Word Identification $t(df\ 46) = 14.32$, $p<.001$ and they were also significantly different for rapid automatized naming of objects $t(df\ 46) = 6.66$, $p<.001$ and letters $t(df\ 46) = 8.51$, $p<.001$.

HYPOTHESES

1 Dyslexics would be slower than the control group for all levels of primes at the initial stage of lexical access.

2 Because of delayed activation of orthographic information, dyslexics would not show automatic activation of orthographic information at the earliest stage of lexical access. They would show no priming for either transposed or substituted primes. Normal controls, on the other hand, would exhibit early activation of orthographic information by showing significant priming for both transposed and substituted primes.

3 Because dyslexics experience delayed access of lexical-semantic information, they would show no identity priming at the earliest stage of lexical access. Normal controls would show early lexical-semantic activation by significant identity priming.

4 Because no lexical information is available in nonword targets, neither dyslexics nor normal controls would show significant priming for nonword targets.

METHOD

Forster, Davis, Schoknecht &Carter (1987) maintained that their form-priming effects resulted from primes being from low-density neighborhoods, where the prime resembles a small number of words in spelling patterns. Primes from high density neighborhoods result in activation being spread over too many words of similar spelling patterns to produce any significant priming effects. Target stimuli used in the present experiment were low density targets used by Forster et al. Word targets consisted of 48

four-letter words with a relatively low number of neighbors (the mean being 2.86) such as IDEA, INCH, SOFA, DENY, URGE, OBEY, ABLE. These word targets were preceded either by an identical prime (e.g. able - ABLE), a substituted prime (e.g. abre - ABLE), a transposed prime (e.g. albe - ABLE) or a control prime (e.g. sink - ABLE). The substituted primes were chosen so that they differed from the target word by only one letter, and the position of this difference was kept constant across all conditions in the third position. The transposed primes were ones in which the two internal letters of their corresponding targets were switched. While tranposed and substituted primes were nonwords and thus nonlexical, identity primes were real words which would activate lexical-semantic information in addition to orthographic information. Also included were 48 non-word targets which were nonlexical which were preceded by the same types of primes as the words.

Lists thus consisted of 8 cells, 96 prime-target pairs, 48 word prime-target pairs and 48 nonword prime-target pairs in random sequence, 12 pairs in each condition. Counterbalancing of materials across the four priming conditions was achieved by constructing four different sets of materials so that each target appeared in each condition, permitting subjects to see each target once.

DESIGN

The design was a Word (2) x Prime (4) x Group (2) mixed factorial with Word and Prime within-subjects factors and Group a between-subjects factor. In addition, predictions of the study concerned pair-wise comparisons of differences between

Substitution, Transposition and Identity levels of prime and Control primes. These would be statistically examined by planned comparisons.

PROCEDURE

Subjects were seated in front of a button box and rested one finger on each of the two buttons. They were instructed to respond to the single word in upper-case letters presented in the center of the screen by pressing the right button labeled "yes" if the viewed word was an English word, or by pressing the left button labeled "no" if the viewed word was a meaningless nonword. The letter string remained on the screen until the subject responded and the subject's response terminated target exposure.

Each trial consisted of the sequential display of the three members of a triad. The first was a forward mask consisting of a row of 6 hash-marks (duration 500 msec). This was immediately followed by the prime (duration 60 msec) which was in turn immediately followed by the target (duration 4000 msec). The subject's response terminated the target duration. Time between trials was 2500 msec. The prime was in lower-case letters, while the target was in upper-case letters. A typical sequence was as follows:

######

plia

PLEA

Subjects were given a practice list consisting of 16 trials to familiarize themselves with the task before proceeding with test items.

APPARATUS

The 192 test items were presented visually on a Panasonic video monitor connected to a Compaq Computer with an internal clock (Metrabyte CTM05) accurate to milliseconds.

RESULTS

Before proceeding with the statistical analysis of the data obtained, all lexical decision reaction times that were outliers were removed from the database. Outliers were treated as errors and were defined as reaction times that were more than two standard deviations from the mean reaction time for each subject. Other errors included incorrect responses, failure to respond within the given time and premature responses before the stimulus had appeared on the screen. The grand means for error data can be found in Table 2. A frequency analysis was done to determine distribution. Kurtosis was high justifying log transformation of scores.

The average percent of incorrectly identified targets by the dyslexic group was 24.17% and by the control group was 11.75%. The average percent of incorrectly identified word targets was 22.17% and for nonword targets was 13.58%.

The mean reaction times of each subject (See Appendix B) were entered into a 2 x 2 x 4 repeated measures analysis of variance using group (dyslexic vs. control), word (word vs. nonword) and prime (substitution, transposition, identity and control) as factors (See Table 3). The grand means for reaction times at each level of prime can be found in

TABLE 2

EXPERIMENT 1

TABLE OF GRAND MEANS

ERROR DATA

	WORDS				NONWORDS				
	PRIME				PRIME				
	SUBST	TRANSP	IDENT	CONTR	SUBST	TRANSP	IDENT	CONTR	
DYSLEXICS	3.38	3.75	3.12	3.82	2.56	1.56	2.4	1.75	2.9
CONTROLS	1.69	1.94	1.75	2.47	1.06	0.94	1.19	1.00	1.41
			2.66				1.63		

TABLE 3

ANOVA SUMMARY TABLE

EXPERIMENT 1

SOURCE	SS	df	MS	F	
GROUP	19.435	1	19.435	27.88	**
ERROR BETWEEN	20.918	30	0.697		
WORD	0.280	1	0.280	12.17	*
GROUP x WORD	0.204	1	0.204	8.87	*
ERROR WITHIN 1	0.701	30	0.023		
PRIME	0.142	3	0.047	4.70	*
GROUP x PRIME	0.004	3	0.001	0.10	
ERROR WITHIN 2	0.891	90	0.010		
WORD x PRIME	0.161	3	0.053	4.80	*
WORD x PRIME x GROUP	0.018	3	0.006	0.55	
ERROR WITHIN 3	0.978	90	0.011		

NOTE: * $p < .01$ ** $p < .001$

Table 4. There were significant main effects of group $F(1,30)=27.88, p<.001$, and word $F(1,30)=12.17, p<.01$, and prime $F(3,90)=4.7, p<.01$. Overall reaction times of dyslexics were significantly slower than those of the control group and overall reaction times to words were significantly faster than those to nonwords. There was also a significant interaction between group and word $F(1,30)=8.87, p<.01$ and of word and prime $F(3,90)=4.8, p<.01$. In the group by word interaction, (See Figure 1), dyslexics' latencies for words and nonwords were longer than those of the controls and dyslexics experienced more difficulty with nonwords than controls. In the interaction between word and prime (Figure 2) nonwords were responded to more slowly than words. There were no significant differences between levels of prime in the Nonword condition. At the Word level, reaction times at the Identity level were significantly faster than at all other levels. Reaction times at the Transposition level were faster than at the Substitution and Control levels and at the Substitution level they were faster than the Control level.

TABLE 4

EXPERIMENT 1

TABLE OF GRAND MEANS FOR REACTION TIMES

	WORDS				NONWORDS				
	PRIME				PRIME				
	SUBST	TRANSP	IDENT	CONTR	SUBST	TRANSP	IDENT	CONTR	
DYSLEXICS	1312.8	1267.5	1251.3	1376.1	1380.2	1414.72	1378.7	1379.9	1345.1
CONTROLS	726.45	706.19	629.65	737.88	732.61	754.44	736.94	752.17	722.04
	1000.98				1066.20				

FIGURE 1

EXPERIMENT 1
GROUP BY WORD INTERACTION

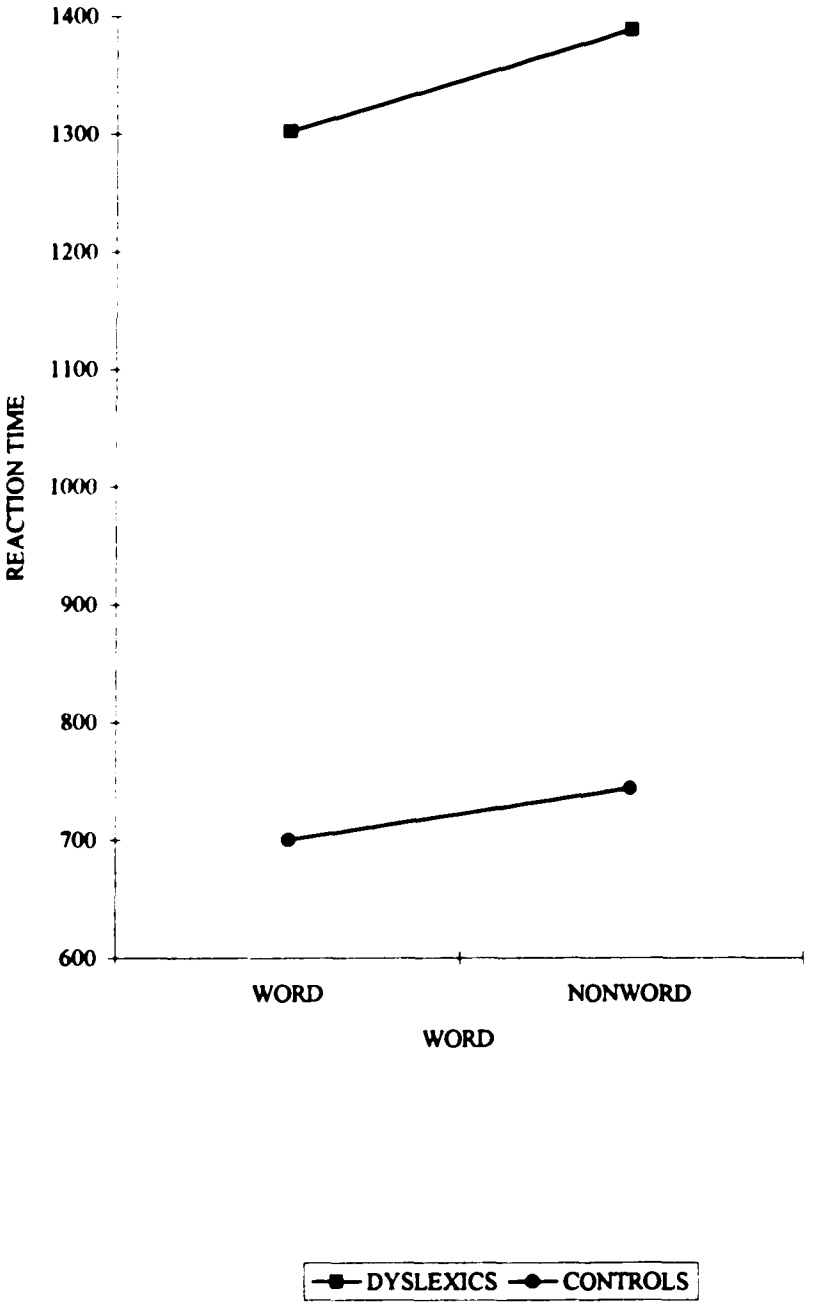
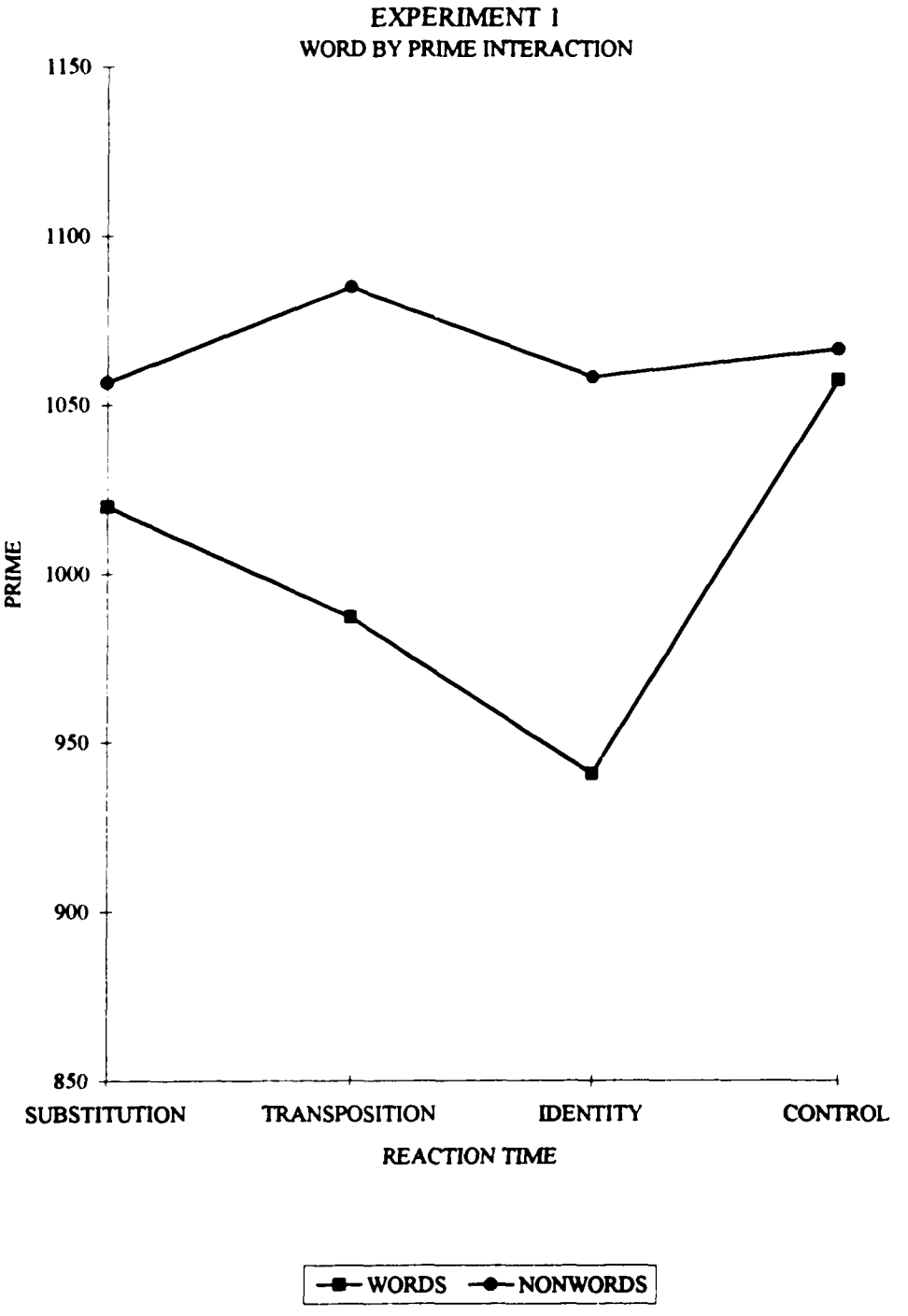


FIGURE 2


EXPERIMENT 1
WORD BY PRIME INTERACTION
1150
1100
1050
1000
950
900
850
PRIME
SUBSTITUTION
TRANSPOSITION
IDENTITY
CONTROL
REACTION TIME
WORDS
NONWORDS

Two-Way Comparisons

Detailed post hoc analysis was carried out using the Tukey HSD for comparisons within and between conditions. See Appendix C for a listing of significance levels associated with all individual comparisons.

Two-way comparison of the word by prime interaction (See Figure 1) revealed that latencies to identical, substitution and transposition targets were significantly shorter than targets preceded by control primes overall Substitution and transposition targets were significantly longer than identity targets but they were not different from each other.

At the nonword level, there were no significant differences between any levels of prime.

Planned Comparisons

In order to obtain a measure of priming effects,. reaction times for different levels of the prime were each compared to the control prime by t-tests. Results revealed significant identity priming effects at the word level for the control group $t(df\ 30)=3.05$, $p<.01$. There were no other significant priming effects at the word level or nonword level (See Table 5).

TABLE 5

EXPERIMENT 1

PRIMING EFFECTS BY TYPE OF PRIME

WORDS

	DYSLEXIC				CONTROL			
PRIME	R.T.	S.D.	PRIMING EFFECT		R.T.	S.D.	PRIMING EFFECT	
IDENTITY	1251.52	588.34	124.60	N.S.	629.65	83.25	108.23	•
SUBSTITUTION	1312.79	581.46	63.34	N.S.	726.45	134.89	11.43	N.S.
TRANSPOSITION	1267.50	676.44	108.63	N.S.	706.19	103.12	31.69	N.S.
CONTROL	1376.13	674.79			737.88	114.96		

NONWORDS

IDENTITY	1378.67	533.72	1.18	N.S.	736.94	142.80	15.23	N.S.
SUBSTITUTION	1380.19	641.26	-0.34	N.S.	732.61	121.41	19.56	N.S.
TRANSPOSITION	1414.72	699.49	-57.20	N.S.	754.44	139.83	-2.27	N.S.
CONTROL	1379.85	620.08			752.17	141.26		

NOTE: • $p < .01$

Error Analysis

The overall error analysis revealed significant main effects for group $F(1,15)=7.778, p<.05$, with dyslexics making significantly more errors than controls. There were also significant main effects for word $F(1,15)=9.461, p<.01$ with more errors at the word level than the nonword level (See Table 6).

DISCUSSION

This experiment sought to demonstrate that dyslexics experience a disruption in the automatic activation of orthographic and lexical-semantic information at the initial stage of lexical access.

In keeping with previous findings of slower rates of responding among dyslexics, the dyslexics were significantly slower overall than controls to respond to both word and nonword targets. Patterns of priming were the same for both groups at the word level. Both groups exhibited the greatest amount of priming at the Identity level followed by the Transposition level with the least amount of priming at the Substitution level. While there were no significant priming effects for either the dyslexics or the controls in response to varying the orthographic properties of the prime, the controls evidenced statistically reliable priming in response to a prime identical to the target. Because an identical prime contains both orthographic and lexical-semantic information, and there were no group differences in orthographic priming, this finding indicates automatic activation of lexical-semantic information at the initial stage of lexical access among the controls. Further

TABLE 6

ANOVA SUMMARY TABLE

EXPERIMENT 1

ERROR DATA

SOURCE	SS	df	MS	F	
GROUP	138.022	1	138.022	7.778	*
ERROR BETWEEN	266.157	15	17.744		
WORD	64.266	1	64.266	9.461	**
WORD x GROUP	4.565	1	4.565	0.672	
ERROR WITHIN 1	101.900	15	6.793		
PRIME	1.671	3	0.557	0.161	
PRIME x GROUP	3.257	3	1.086	0.313	
ERROR WITHIN 2	155.948	45	3.465		
WORD x PRIME	9.016	3	3.005	0.767	
WORD x GROUP x PRIME	2.783	3	0.928	0.237	
ERROR WITHIN 3	11.761	3	3.92		

NOTE: * $p < .05$ ** $p < .01$

evidence that these identity effects were lexically based is evidenced by the fact that the enhanced identity facilitation seen at the word level was not found for either dyslexics or controls at the nonword level. Since Forster, Davis, Schoknecht & Carter (1987) found statistically significant findings using the same paradigm and since subjects used in their experiment were adults it is possible that the age of the boys may have contributed to the absence of statistically reliable orthographic priming.

Although patterns of activation were the same for both groups, the fact that only the controls evidenced significant priming at the Identity level suggests that the dyslexics were responding differently. Even though priming effects among dyslexics were greatest at this level, the fact that they were not statistically reliable raises the possibility of diminished or inconsistent activation.

The fact that the dyslexics experienced more difficulty with the nonwords was consonant with theoretical claims of dyslexics experiencing difficulties at the phonological level. Nonword reading requires a phonological approach to reading and is frequently used as a measure of phonological processing suggesting phonological difficulties as a likely basis.

Further examination of the data was undertaken to see whether there were subgroups exhibiting the predicted patterns of statistically reliable priming. Analysis of variance of groups subdivided by age (ages 13, 14 and 15) yielded no significant findings. Furthermore, removing outlier subjects who responded more than 1 and 2 standard deviations slower or faster than the mean did not result in any statistically reliable findings.

Furthermore, removing outlier subjects who responded more than 1 and 2 standard deviations slower or faster than the mean did not result in any statistically reliable findings.

Because of the significant variability in the dyslexics' performance, we must be cautious in concluding that they did not prime in any condition. Nevertheless, the fact that 8 of the dyslexic subjects were unable to perform the task with 500 msec target exposure while the normal controls experienced no difficulties, suggests that the dyslexics were experiencing problems with temporal processing of orthographic and lexical-semantic information.

EXPERIMENTS 2 AND 3

Experiments 2 and 3 addressed the question of whether there are differences in "rise" times of semantic information availability (Prather, Shapiro, Zurif & Swinney, 1991) between dyslexics and other groups, as well as whether the hypothesized temporal processing disruptions occur in different modalities (visual and auditory).

SUBJECTS

Subjects were the same as in experiment 1 except that the eight subjects used as a pilot group in experiment 1 to establish a manageable target duration were included in the next two experiments. Subjects thus comprised 24 dyslexic boys in the experimental group and 24 normal controls.

HYPOTHESES

Dyslexics would exhibit a delayed pattern of automatic activation of semantic information which would be reflected in priming at a later point along a temporal continuum. They would thus exhibit priming at longer ISIs than normal controls.

METHOD

To examine the temporal properties of semantic access in the visual domain, the continuous-list priming paradigm of Prather, Pasquotto, Seimen & Lawson (1986) was used. In this paradigm, the subject responds to each word in the list.

The rationale for this paradigm is that since the subject is responding to a continuously running list of stimuli, which only occasionally has one word followed by an associatively related word, it is difficult for subjects to notice (and therefore to anticipate) connections between words. Further, subjects are too busy with the continuous responding to invoke intentional strategies, particularly at short interstimulus intervals. Finally, by including a repeated word "word," subjects develop expectations about the appearance of that word and are therefore distracted from developing strategies specific to the appearance of associatively related words (Stern et al., 1991).

The experimental materials included 112 related word pairs (e.g. hoof-horse) and 112 matched control pairs (e.g. beam-horse) wherein the prime word, which was a monosyllabic word comprised of 4-5 letters, was replaced by a word of the same length and frequency but unrelated in meaning to the target word (with frequencies taken from

Kucera & Francis, 1976). Associates were selected on the basis of published norms (Jenkins, 1970; Battig & Montague, 1969) plus data obtained by polling 40 boys aged between the ages of 13 and 15 at the local public school, Edgemont High School. The boys were required to generate their first and second preferred associates to a list of monosyllabic words with frequencies ranging from 10 per million to 60 per million. The final set of associates represents the experimenter's selections, based on those norms and polled associations of a set of associated lexical items (See Appendix A).

Two lists, List 1 and List 2, each containing 56 related pairs, were constructed. Each list also contained 56 control pairs sothat if the related pair for a particular target word was in the first list, then its matched control was in the second list, and vice versa. Thus a target word occurred only once in each list. The total of words came to 224 words per list, and an equal number of nonwords was included. In addition, each list included 40 nonexperimental filler words which were 4-5 letter words within the same frequency range as the experimental words. Finally, the word "WORD" appeared randomly one time in every 15 items across both lists. Where possible, these words had a 50-50 chance of preceding a word or a nonword. There were 15 "word"-word pairs (unrelated) and 17 "word"-nonword pairs (unrelated).

The two lists were then each divided into four segments corresponding to ISIs of 500, 800, 1100 or 1400 msec. Each segment included 14 related target and 14 control target pairs, as well as 10 filler words and 66 nonwords and 8 or 9 "word" words, totalling 140 words for two segments and 141 for the remaining two segments. The lists were counterbalanced to control for order of ISI. There were 4 matched pairs of lists each pair

having different orders of ISIs. Thus the same related and unrelated pairs of words were always seen at the same ISI but in different orders.

The proportion of related sequences (56) to unrelated (376) was 0.149 or 15%. Thus by keeping the proportion of related sequences to unrelated sequences to 15%, the present experiment eliminated any expectancy mechanisms in order to examine priming which was due to automatic spreading activation

DESIGN

The design was a Group (2) x ISI (4) x Relatedness (2) mixed factorial design with ISI and Relatedness as within-subjects factors and Group as a between-subjects factor. In addition, predictions of the study concerned pair-wise comparisons of differences between related and unrelated primes and targets at the different ISIs. These would be statistically examined by planned comparisons

PROCEDURE

Subjects were seated in front of a button box and rested one finger on each of the two buttons. They were instructed to respond to the single word presented in the center of the screen by pressing the right button labeled "yes" if the viewed word was an English word, or by pressing the left button labeled "no" if the viewed word was a meaningless nonword. The letter string remained on the screen until the subject responded. ISI began immediately with the subject's response so that an ISI of 500 msec represented the elapsed

time between the response to one word and the presentation of the next word. To discourage controlled processing, they were told to look for the word "word."

Initially, subjects viewed a 40-word long practice list which had the same proportions as the real list to familiarize them with the task.

Following the practice list, subjects were presented with an extended series of real English words and nonwords. These lists were presented visually (Experiment 2) and auditorily (Experiment 3). The subject was required to make a word/non-word lexical decision to every word in the list. Stimulus duration was 4000 msec. and a subject's response terminated the target duration and initiated a fixed inter-stimulus interval terminated by the next word for 562 consecutive trials, 140/141 per segment.

APPARATUS

The 562 test items were presented visually on a Panasonic video monitor connected to a Compaq Computer with an internal clock (Metrabyte CTM05) accurate to milliseconds.

RESULTS

Before proceeding with the statistical analysis of the data obtained, all lexical decision reaction times that were outliers were removed from the database. Outliers were treated as errors and were defined as reaction times that were more than two standard deviations from the mean. Other errors included incorrect responses, failure to respond

within the given time and premature responses before the stimulus had appeared on the screen. The grand means for error data can be found in Table 7. An analysis of variance was conducted using group, order of ISI, relatedness, and ISI as factors. There was no significant order effect nor was there a significant effect for any order by factor interaction. A frequency analysis was done to determine distribution. Kurtosis was high justifying log transformation of scores.

The average percent of incorrectly identified targets by the control group was 6.62 for related and 7.71 for unrelated targets. The average percent of incorrectly identified targets by the dyslexic group was 12.45 for related targets and 10.84 for unrelated targets.

The mean reaction times of each subject were entered into a 2 x 4 x 2 repeated measures analysis of variance using group (dyslexic vs. control), ISI (500 msec, 800 msec, 1100 msec and 1400 msec) and relatedness (related vs. unrelated) as factors (See Table 8). The grand means for each prime condition can be found in Table 9.

There was a significant main effect of group $F(1,46)=38.63, p<.001$ (See Table 8). Dyslexics were significantly slower than the controls. There was also a significant main effect of relatedness $F(1,46)=25.88, p<.001$, with related targets being responded to significantly faster than control targets. Finally, there was a significant main effect of ISI $F(3,138)=12.5, p<.001$ with reaction times increasing across ISIs 500, 800 and 1100 and decreasing at ISI 1400. There was also a significant interaction of ISI and group $F(3,138)=17.0, p<.001$. Reaction times for dyslexics increased across ISIs 500, 800 and 1100 and decreased at ISI 1400. Reaction times for controls, however, remained constant across all ISIs (See Fig. 3).

TABLE 7

EXPERIMENT 2

TABLE OF GRAND MEANS

ERROR DATA

	DYSLEXICS				CONTROLS				
	ISI				ISI				
	500	800	1100	1400	500	800	1100	1400	
RELATED	1.75	1.67	1.42	2.00	1.33	0.75	0.79	0.88	1.32
UNRELATED	1.75	2.17	1.71	1.17	1.13	0.88	1.08	1.29	1.40
			1.70				1.02		

TABLE 8

ANOVA SUMMARY TABLE

EXPERIMENT 2

SOURCE	SS	df	MS	F	
GROUP	30.212	1	30.212	38.630	*
ERROR BETWEEN	35.954	46	0.782		
RELATEDNESS	0.220	1	0.220	25.880	*
REL x GROUP	0.032	1	0.032	0.376	
ERROR WITHIN 1	0.392	46	0.009		
ISI	0.074	3	0.025	12.500	*
ISI x GROUP	0.111	3	0.034	17.000	*
ERROR WITHIN 2	2.916	138	0.002		
ISI x REL	0.009	3	0.003	0.337	
GROUP x ISI x REL	0.010	3	0.003	0.337	
ERROR WITHIN 3	1.240	138	0.009		

NOTE: * $p < 0.01$

TABLE 9

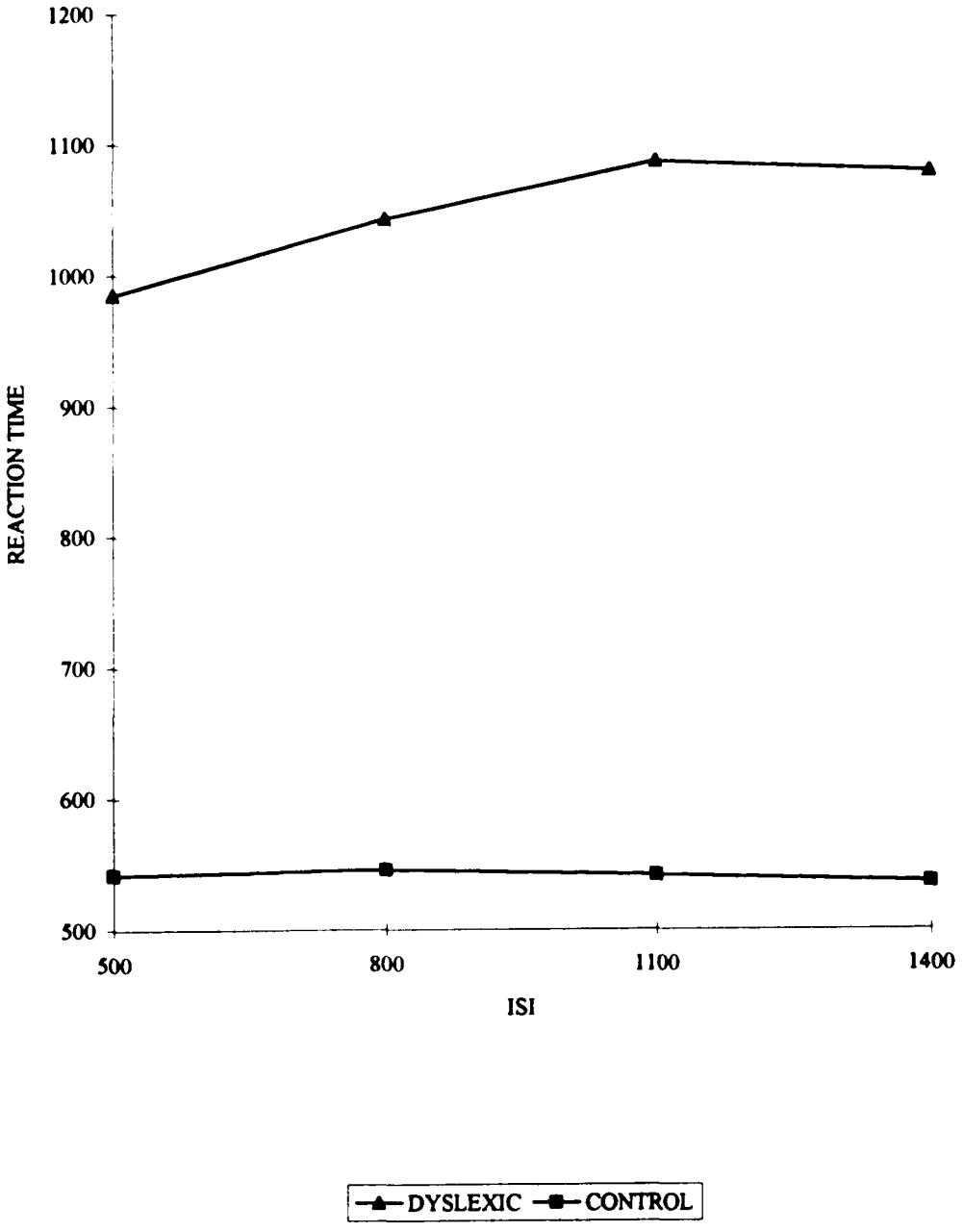
EXPERIMENT 2

TABLE OF GRAND MEANS FOR REACTION TIMES

	DYSLEXICS				CONTROLS				
	ISI				ISI				
	500	800	1100	1400	500	800	1100	1400	
RELATED	966.08	1007.96	1045.73	1037.39	537.15	539.58	530.09	527.53	773.94
UNRELATED	1003.59	1077.06	1126.35	1118.54	546.62	551.77	552.38	545.22	815.19
			1047.84				541.29		

FIGURE 3

EXPERIMENT 2
ISI BY GROUP INTERACTION



Two-way Comparisons

Detailed post hoc analysis was carried out using the Tukey HSD for comparisons within and between conditions (See Appendix C). As can be seen from Figure 3, the dyslexics were slower at all ISIs. In the ISI by group interaction, the controls' reaction times at all ISIs were not significantly different from each other, with the exception of ISI 800 which was significantly slower than ISIs 1100 and 1400. The dyslexics, on the other hand, responded significantly more slowly across ISIs 500, 800 and 1100, plateauing between ISIs 800 and 1100 and decreasing slightly between ISI 1100 and 1400.

Planned Comparisons

In order to obtain a measure of priming, each subject's mean for each level of ISI x Relatedness was calculated based on their non-error log-transformed reaction times. t tests were used to determine whether there were any significant differences between related and unrelated means at each ISI (See Table 10). Referring to Table 10, the pattern of priming between the dyslexics and the normal controls differs. Among the dyslexics priming effects continue to increase across ISIs. Among the controls, however, the difference between related pair and control pair target reaction times increased across ISIs 500, 800 and 1100 but decreased slightly at ISI 1400. None of these differences between related and control pairs, however, were statistically reliable although the greatest

TABLE 10

EXPERIMENT 2

PRIMING EFFECTS BY ISI

GROUP	ISI	RELATED PRIME (msec)	S.D.	CONTROL PRIME (msec)	S.D.	PRIMING EFFECT (RELATED-CONTROL) (msec)	
DYSLEXIC	500	966.08	503.24	1003.59	431.50	37.51	N.S.
	800	1007.96	512.93	1077.06	601.49	69.10	N.S.
	1100	1045.73	661.14	1126.35	672.05	80.62	N.S.
	1400	1037.39	509.24	1118.54	522.61	81.15	N.S.
CONTROL	500	537.15	83.71	546.62	68.49	9.47	N.S.
	800	539.58	57.09	551.77	73.52	12.19	N.S.
	1100	530.11	96.33	552.38	84.17	22.27	N.S.
	1400	527.53	66.52	545.22	61.21	17.69	N.S.

effects were evident at ISI 1100 suggesting that the "rise" time for automatic priming among normal adolescents is later than normal adults who evidenced reliable priming at ISIs between ISIs 500-800 (Stern et al 1991).

Further examination of the data to see whether there were any subgroups who would exhibit the desired effects was undertaken. Analysis of variance of groups subdivided by age (ages 13, 14 and 15) yielded no significant findings. Furthermore, removing outlier subjects who responded more than 1 and 2 standard deviations slower or faster than the mean did not result in any statistically reliable findings. In addition, covarying for age, non-verbal IQ and word identification did not result in any significant findings. Nevertheless, caution should be exercized before concluding that there was no significant priming among the dyslexics because of the significant variability in their performance. It is also possible that providing longer ISIs than those used in the experiment would have captured the temporal delay of the availability of information.

The mean reaction times of each item were entered into a one way analysis of variance with frequency as a factor (high frequency = 31-60 per million occurrences; low frequency = 10-30 per million occurrences). Overall frequency effects were not significant. Further examination of group frequency effects by separate one way analyses of variance for each group revealed no significant frequency effects for either dyslexics or controls.

The fact that several target words were longer than 4-5 letters, while all non-words were 4-5 letters raised the possibility that rather than engaging in automatic processing, subjects were using strategies based on length of words. Thus reaction times to each

word were entered into a one-way analysis of variance with "length" as a factor (long words = more than 5 letters; short words = 4-5 letters) There were no significant overall effects. Further examination of group effects by separate one way analyses of variance for each group revealed no significant length of word effects for either dyslexics or controls.

Another possibility was that subjects were engaging in strategic processing with increasing practice across lists. Thus average reaction times to words in the first third of lists were compared to average reaction times in the last third of lists using t-tests. Responses were significantly faster in the last third of the lists $t(df\ 47)=2.53, p<.01$ suggesting that with increasing involvement in the task subjects were using strategies to improve their performance.

A power analysis was conducted to determine the sample size necessary to detect significance given the effect size which was calculated based on data from the visual continuous-list experiment. The effect size was found to be .055. The minimal acceptable power was .80 and alpha was .05. Therefore, according to the power calculation, the sample size necessary to detect this effect size was 557 subjects.

Error Analysis

The overall error analysis revealed significant main effects for group $F(1,23)=5.988, p<.05$, with dyslexics making significantly more errors overall than controls. There were no significant main effects of relatedness or ISI and there were no interactions (See Table 11).

TABLE 11

ANOVA SUMMARY TABLE

EXPERIMENT 2

ERROR DATA

SOURCE	SS	df	MS	F	
GROUP	45.375	1	45.375	5.988	*
ERROR BETWEEN	174.281	23	7.577		
RELATED	0.510	1	0.510	0.339	
GROUPxRELATED	0.667	1	0.667	0.444	
ERROR WITHIN 1	34.573	23	1.503		
ISI	2.844	3	0.948	0.498	
GROUPxISI	5.771	3	1.924	1.010	
ERROR WITHIN 2	131.136	69	1.901		
ISIxREL	5.177	3	1.726	0.345	
ISIxRELxGROUP	9.812	3	3.271	0.654	
ERROR WITHIN 3	14.990	3	4.997		

NOTE: * $p < .05$

DISCUSSION

In keeping with previous findings of slowed reaction times among dyslexics, in this experiment the dyslexics responded significantly more slowly overall than normal readers This experiment sought to examine whether the slower rates of responding among dyslexics were the result of delayed patterns of automatic activation There were no statistically reliable patterns of priming differences across ISIs, however, between dyslexics and controls Furthermore, error analysis revealed that while dyslexics made more errors overall than the controls, there were no interactions across ISIs Thus there were no speed/accuracy trade-offs across ISIs to indicate that dyslexics were experiencing greater processing difficulties with increasing time constraints

Although there was no statistically reliable priming in the experiment, the patterns of differences between related and unrelated pairs across ISIs between the groups were suggestive of the expected effects Among the dyslexics, effects plateaued between ISIs 1100 and 1400 indicating that activation was still present at the longest ISI, while among the controls priming appeared to decrease between ISIs 1100 and 1400, suggesting decay of activation Furthermore, there was indirect evidence that dyslexics and controls were responding differentially across ISIs The controls' reaction times were generally consistent across ISIs while the dyslexics' reaction times increased with increasing length of ISIs The fact that the dyslexics' reaction times increased across ISIs indicated continued processing for the duration of the ISIs The consistency of the controls' responses across ISIs, on the other hand, indicates that they did not utilize the increased

time available with increasing ISIs and that processing was discontinued at a far earlier point along the temporal continuum than among the dyslexics.

Caution should be exercised before concluding that there was no priming among dyslexics. It is is possible that the dyslexics may have primed at longer ISIs than those used in the present experiment. In addition, the variability in the dyslexics' performance contributed to the lack of statistically reliable priming. A power analysis based on the results of the experiment indicated that 557 subjects would be required to produce statistically reliable findings. It is likely, however, that the heterogeneity of the dyslexic group is reflective of different subtypes of dyslexics and that the proposed temporal processing disruptions are specific to a particular subtype of dyslexia. Furthermore, it is possible that subjects were using strategies and that the paradigm was not a pure measure of automatic processing. The fact that overall reaction times decreased across lists indicated improved performance with increasing practice, suggesting the use of strategies.

EXPERIMENT 3

HYPOTHESES

Dyslexics would exhibit a delayed pattern of automatic activation of semantic information which would be reflected in priming at a later point along a temporal continuum. They would thus exhibit priming at longer ISIs than normal controls.

METHOD, DESIGN AND PROCEDURE

Method, Design and Procedure were the same as in Experiment 2 except that the stimuli were auditorily presented through headphones. In this auditory paradigm presentation of stimuli was tape controlled so that, unlike in the visual paradigm, the subject could not terminate the stimulus duration to initiate an ISI. The interval between each pair of stimuli was thus measured from the onset of the stimulus to the beginning of the next stimulus. The unit of measurement was thus an SOA (stimulus onset asynchrony) rather than an ISI. Because in this experiment the duration of SOA was tape controlled, SOA 500 had to be dropped because subjects were unable to complete the task within the alotted time frame.

APPARATUS

Natural speech was digitized and edited using the "Sound Edit" software package for the Apple Macintosh Computer IIci and recorded on tape. A Sharp RD-771AV stereo amplifier, two pairs of headphones and a subject button box were used. Output of the amplifier was split so that one channel contained the stimulus words while the other channel contained a blip at the time of onset of the target. The blip was inaudible to subjects but served to start the relay indicator which activated the millisecond timer. The subject heard the test stimuli binaurally over headphones. The timer was stopped as soon as the subject depressed one of two buttons on a button box to signify "yes" or "no" responses.

RESULTS

Before proceeding with the statistical analysis of the data obtained, all lexical decision reaction times that were outliers were removed from the database. Outliers were treated as errors and were defined as reaction times that were more than two standard deviations from the mean reaction time on each task for each subject. Other errors included incorrect responses, failure to respond within the given time and premature responses before the stimulus had appeared on the screen. The grand means for error data can be found in Table 12. An analysis of variance was conducted using group, order of SOA, relatedness, and SOA as factors. There was no significant order effect nor was there a significant effect for any order by factor interaction. A frequency analysis was done to determine distribution. Kurtosis was high justifying log transformation of scores.

The average percent of incorrectly identified targets by the control group was 14.21 for related and 18.81 for unrelated targets. The average percent of incorrectly identified targets by the dyslexic group was 24.15 for related targets and 28.10 for unrelated targets.

The mean reaction times of each subject (See Appendix B) were entered into a 2 x 2 x 4 repeated measures analysis of variance using group, relatedness and SOA as factors (See Table 13). The grand means for each prime condition can be found in Table 14. There were significant main effects of group $F(1,46)=55.86, p<.001$, with the dyslexics responding significantly more slowly than the controls; relatedness $F(1,46)=40.25, p<.001$, with related targets responded significantly faster than unrelated targets; SOA $F(2,92)=80.00, p<.001$, with reaction times increasing across SOA (See Table 14).

TABLE 12

EXPERIMENT 3

TABLE OF GRAND MEANS

ERROR DATA

	DYSLEXICS			CONTROLS			
	ISI			ISI			
	800	1100	1400	800	1100	1400	
RELATED	6.00	4.21	2.21	2.96	1.71	1.38	3.08
UNRELATED	6.67	4.96	3.08	4.17	1.79	2.04	3.78
		4.52			2.34		

TABLE 13

ANOVA SUMMARY TABLE

EXPERIMENT 3

SOURCE	SS	df	MS	F	
GROUP	0.4860	1	0.48600	55.86	*
ERROR BETWEEN	4.0250	46	0.00870		
RELATEDNESS	0.1610	1	0.16100	40.25	*
REL x GROUP	0.0140	1	0.01400	3.50	
ERROR WITHIN 1	0.1930	46	0.00400		
SOA	2.8750	2	1.44000	80.00	*
SOA x GROUP	0.5770	2	0.28900	16.05	*
ERROR WITHIN 2	1.6860	92	0.01800		
SOA x REL	0.0040	2	0.00200	10.00	*
GROUP x SOA x REL	0.0003	2	0.00015	0.75	
ERROR WITHIN 3	0.0220	92	0.00020		

NOTE: * $p < .01$

TABLE 14

EXPERIMENT 3

TABLE OF GRAND MEANS FOR REACTION TIMES

	DYSLEXICS			CONTROLS			
	ISI			ISI			
	800	1100	1400	800	1100	1400	
RELATED	716.71	942.27	1012.90	747.79	820.80	836.15	846.10
UNRELATED	757.94	972.43	1028.9	773.19	891.47	896.47	886.73
		905.19			827.64		

There was also a significant interaction of SOA and group $F(2,92)=16.05, p<.001$ (See Fig. 4). The dyslexics responded more slowly across all SOAs while the reaction times of the controls were slower at SOA 1100 than SOA 800 but there were no differences between SOAs 1100 and 1400.

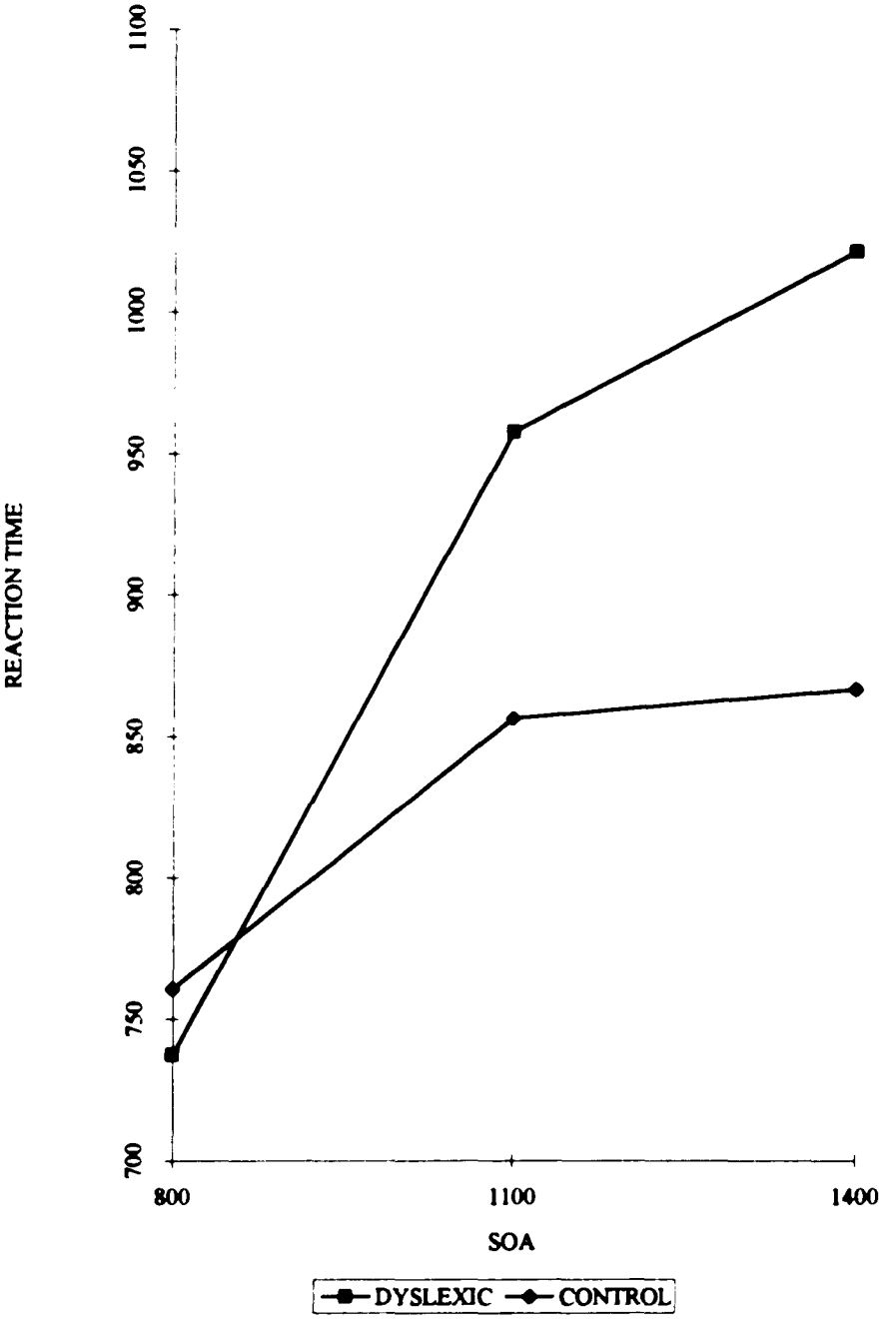
The mean reaction times of each item were entered into a one way analysis of variance with frequency as a factor (high frequency = 31-60 per million occurrences; low frequency = 10-30 per million occurrences). There were significant differences overall between high and low frequency items $F(1,82)=5.256$, $p<.02$ with high frequency items responded to significantly more quickly than low frequency items. Further analysis revealed that both dyslexics $F(1,82) = 3.823$, $p<.05$ and controls $(F1, 82) = 5.975$, $p<.01$ evidenced significant frequency effects, responding significantly faster to high frequency words when compared to low frequency words.

The fact that several target words were longer than 4-5 letters, while all non-words were 4-5 letters raised the possibility that rather than engaging in automatic processing, subjects were using strategies based on length of words. Thus reaction times to each word were entered into a one-way analysis of variance with length as a factor (long words = more than 5 letters; short words = 4-5 letters). There were no significant overall effects. Further examination of group effects by separate one way analyses of variance for each group revealed no significant length of word effects for either dyslexics or controls.

Another possibility was that subjects were engaging in strategic processing with increasing practice across lists. Thus average reaction times to words in the first third of

FIGURE 4

EXPERIMENT 3
GROUP BY SOA INTERACTION



lists were compared to average reaction times in the last third of lists using t-tests. There were no significant differences between reaction times in the first and last thirds of lists.

A power analysis was conducted to determine the sample size necessary to detect significance given the effect size which was calculated based on data from the auditory continuous-list experiment. The effect size was found to be 0.7. The minimal acceptable power was .80 and alpha was .05. Therefore, according to the power calculation, the sample size necessary to detect this effect size was 100 subjects.

Two-Way Comparisons:

Detailed post hoc analysis was carried out using the Tukey HSD for comparisons within and between conditions. As can be seen from Appendix C, overall reaction times at SOA 800 were significantly faster than at 1100 and 1400 but there were no significant differences between 1100 and 1400. In the SOA by group interaction (Figure 4) the dyslexics responded increasingly more slowly across SOA with 1400 significantly slower than 1100. There were no significant differences among the controls across SOA. In the SOA by related interaction, reaction times at both the related and unrelated levels increased across SOAs and there were significant differences between all SOAs at both levels with the slowest reaction times at SOA 1400 and the fastest at SOA 800.

Planned Comparisons

In order to obtain a measure of priming, planned comparisons were conducted. Each subject's mean for each condition of SOA x Relatedness was calculated based on their non-error log-transformed reaction times and t tests were used to determine whether there were any significant differences between related and unrelated means at each SOA (See Table 15). Referring to Table 15, the pattern of the data collected from the dyslexics and the normal controls differs. Among the dyslexics priming effects decrease across SOAs. None of these differences, however, was statistically reliable. Among the controls priming increased between SOA 800 and 1100 and diminished between 1100 and 1400. Priming at SOA 1100 was statistically reliable ($p<.05$).

Error Analysis

The overall error analysis revealed significant main effects for group $F(1,23)=18.088, p<.001$, with dyslexics making significantly more errors overall than controls (See Table 16). There was also a significant main effect of relatedness $F(1,23)=13.122, p<.01$, with significantly more errors at the unrelated level than the related level. In addition, there was a significant main effect of SOA $F(2,46)=32.63, p<.001$. Detailed analysis was carried out using the Tukey HSD for comparisons within and between conditions (See Appendix C). There were significantly more errors at SOA 800 than at SOA 1100 and 1400. In the group by SOA interaction (See Table 17) among the dyslexics there were significantly more errors at SOA 800 than at SOA 1100 and there were significantly more errors at SOA 1100 than at SOA 1400. Among the controls there

TABLE 15

EXPERIMENT 3

PRIMING EFFECTS BY SOA

GROUP	SOA	RELATED PRIME (msec)	S D	CONTROL PRIME (msec)	S D	PRIMING EFFECT (RELATED-CONTROL) (msec)	
DYSLEXIC	800	716 71	108 86	757 94	138 36	41 23	N S
	1100	942 27	121 81	972 43	107 39	30 61	N S
	1400	1012 90	129 74	1028 91	122 75	16 01	N S
CONTROL	800	747 79	80 35	773 19	80 38	25 40	N S
	1100	820 80	110 53	891 47	124 41	70 67	•
	1400	836 15	132 82	896 46	136 44	60 31	N S

NOTE • $p < .05$

TABLE 16

ANOVA SUMMARY TABLE

EXPERIMENT 3

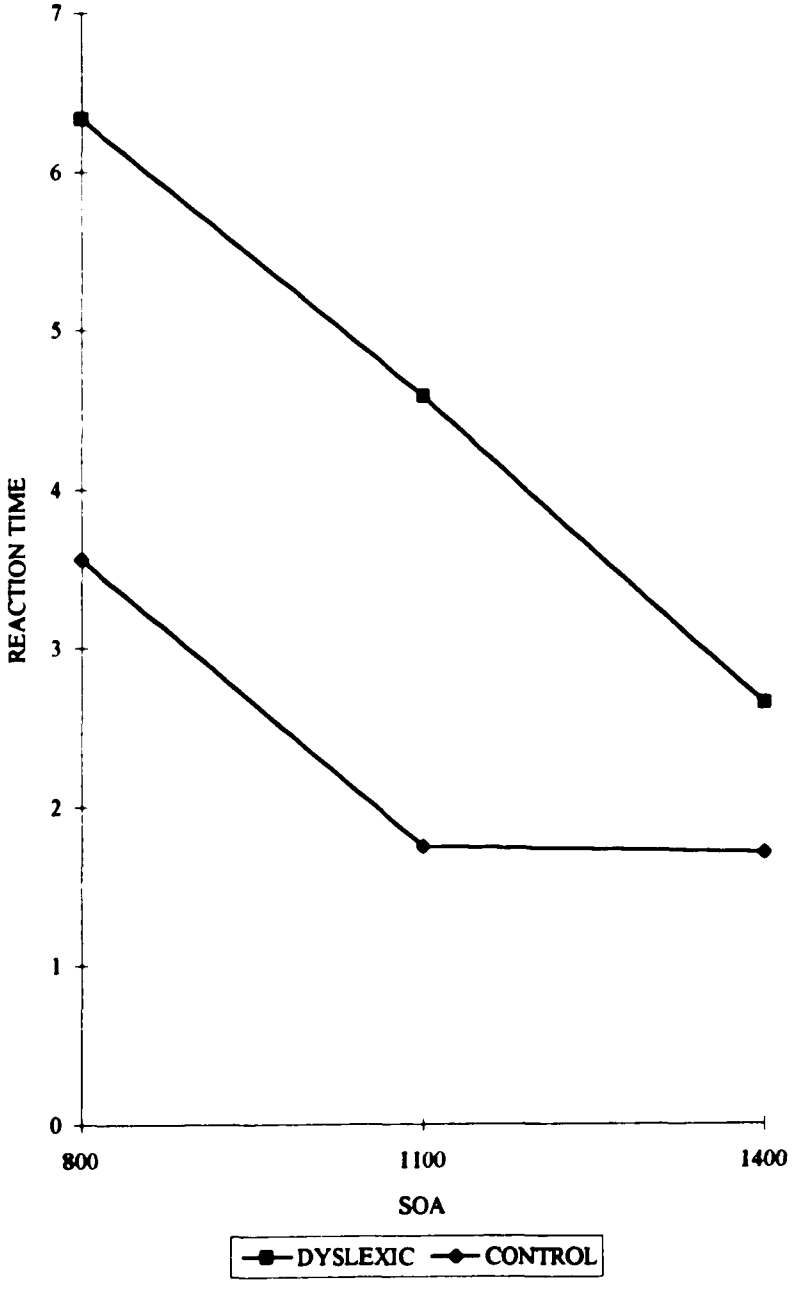
ERROR DATA

SOURCE	SS	df	MS	F	
GROUP	342.347	1	342.347	18.088	***
ERROR BETWEEN	435.300	23	18.926		
RELATED	36.125	1	36.125	13.122	**
GROUP x RELATED	0.222	1	0.222	0.081	
ERROR WITHIN 1	63.320	23	2.753		
SOA	378.549	2	189.274	32.630	***
GROUP x SOA	55.674	2	27.837	4.800	*
ERROR WITHIN 2	266.777	46	5.799		
SOA x RELATED	3.396	2	1.698	0.432	
SOA x RELATED x GROUP	4.465	2	2.233	0.568	
ERROR WITHIN 3	7.861	2	3.931		

NOTE: * $p < .05$ ** $p < .01$ *** $p < .001$

FIGURE 5

ERROR DATA
EXPERIMENT 3
GROUP BY SOA INTERACTION



were significantly more errors at SOA 800 than at SOAs 1100 and 1400 but there were no differences between SOAs 1100 and 1400 (See Appendix B).

DISCUSSION

The aim of the present experiment was to examine whether dyslexics experienced temporal processing disruptions in the auditory modality resulting in delayed lexical access. The controls evidenced statistically reliable priming at ISI 1100 while the dyslexics did not. There was no statistically reliable priming among the dyslexics in the auditory paradigm.

The data were examined to see whether there were subgroups exhibiting the predicted patterns of statistically reliable priming. Analysis of variance of groups subdivided by age (ages 13, 14 and 15) yielded no significant findings. Furthermore, removing outlier subjects who responded more than 1 and 2 standard deviations slower or faster than the mean did not result in any statistically reliable findings.

Closer examination of the data, however, provided some evidence for the dyslexics responding differentially across SOAs. At the shortest SOA error analysis revealed that although reaction times did not differ significantly between the groups, error rate among the dyslexics was high, indicating that with increasing time constraints, dyslexics evidenced a far greater speed/accuracy trade-offs than the controls. Among the controls errors decreased between SOAs 800 and 1100 and plateaued between SOAs 1100 and 1400 indicating that after SOA 1100 there were no speed/accuracy trade-offs. Among the

dyslexics, however, errors continued to decrease significantly across all SOAs. In contrast to the controls, the fact that among the dyslexics errors continued to decrease between SOAs 1100 and 1400 indicates that they were still involved in lexical processing at the longest SOA providing evidence of temporal delays during lexical access. This provides indirect evidence of delayed lexical access. Furthermore, suggestive evidence for delayed lexical access was provided in the group by SOA interaction in which the dyslexics' reaction times increased more than those of the controls between SOAs 1100 and 1400 indicating that they derived benefit from the additional time provided by the longer ISI.

In priming paradigms, errors are presumed to reflect speed/accuracy trade/offs occurring during the process of lexical access. Lexical access requires an initial contact phase in which perceptual stimuli contact form-based mental representations. In the auditory paradigm, perceptual stimuli contact phonological representations so that these error data can be presumed to reflect difficulties in the phonological domain. These findings are consonant with theoretical models of dyslexia claiming a core deficit in the phonological domain. They also raise the possiblity that these phonological difficulties are the result of temporal processing disruptions.

The dyslexics did not exhibit the same variability in their responses in the auditory modality as they did in the visual modality so that it is unlikely that variability contributed to the absence of statistically reliable findings. A power analysis, however, indicated that the number of subjects would have to be increased to 100 in order to produce statistically reliable findings. Furthermore, it is possible that the pattern of activation among dyslexics was not captured by the SOAs used in the present study and that use of longer SOAs may

have revealed statistically reliable findings. In addition, the fact that there were significant frequency effects among the range of frequencies sampled, with faster responses to more frequent words suggests that selection of a smaller range of frequencies could increase the likelihood of significant findings. Nevertheless, the error data indicated that there was continued processing among dyslexics at a later point along the temporal continuum than that shown by the controls indicating a temporal processing delay.

CHAPTER 3

CONCLUSIONS

The present research aimed to examine the temporal parameters of lexical access among dyslexics. According to the literature cited the preponderance of dyslexic problems occur in the language domain and they are the result of generalized linguistic coding deficiencies. The parallels between the developmental dysphasias and the acquired aphasias as well as the fact that dyslexia was postulated to be a later manifestation of developmental dysphasia led to hypotheses that dyslexics experience the same temporal processing disruptions found among agrammatic aphasics. More specifically, recent studies indicated delayed "rise" times for automatic activation among Broca's aphasics. The fact that several researchers ascribed the linguistic coding difficulties experienced by dyslexics to problems with lexical access, raised the possibility that the delayed patterns of automatic activation found among Broca's aphasics provided a possible explanation for dyslexics' problems with lexical access.

Although there is ample evidence of contextual facilitation among dyslexics, studies used paradigms which were more likely to be assessing strategic rather than automatic processes. Furthermore, the studies cited were concerned with the magnitude of contextual effects rather than with the temporal parameters of automatic activation as it is deployed over time. The present research thus aimed to examine whether dyslexics experience delayed patterns of automatic activation of both lexical-semantic and orthographic information. More specifically, it examined the temporal parameters of

activation at the initial stage of lexical access as well as its occurrence along a temporal continuum.

Throughout all 3 experiments the results of the study indicated that dyslexics evidenced problems with temporal processing when compared to normal controls. They consistently evidenced slower rates of responding and the fact that this slowing was evident in both auditory and visual modalities attested to the fact that these problems with rates of responding were not modality specific.

The study also provided evidence of differences between the two groups in patterns of activation. In the masked priming paradigm, the normal controls evidenced statistically reliable priming in the Identity priming condition indicating lexical-semantic activation at the initial stage of access. The normal controls also evidenced statistically reliable priming in the auditory modality at ISI 1100. The dyslexics, however, evidenced no statistically significant priming in either visual or auditory modalities. While the dyslexics exhibited similar patterns of priming for the different levels of prime to the controls in the masked priming paradigm, the finding of statistically reliable priming at the Identity level for the controls indicates differences in patterns of activation between the groups at the lexical-semantic level. Neither group evidenced statistically reliable priming in response to orthographic manipulations of the prime but the fact that when there were multiple sources of information including orthographic, lexical and semantic, overlapping in the Identity prime, the prime produced sufficient activation to result in statistically reliable priming among the controls but not the dyslexics. While the variability in dyslexics' performance in all likelihood resulted in erratic patterns of activation, precluding

reliable priming, it is also possible that at a later point in time lexical-semantic activation would have been sufficient to produce statistically reliable priming.

The finding of no orthographic priming in either group could be explained by the fact that those studies reporting statistically reliable findings with this paradigm used normal adult subjects (Forster, Davis, Schoknecht & Carter (1987) and not subjects of this age. Furthermore, the fact that the continuous list paradigm in the present research revealed that normal adolescent boys primed later than normal adults (at SOA 1100 in the auditory modality, and suggested in the visual modality, as opposed to between ISI 500-800 among normal adults found by Stern et al. (1991) raises the possibility that these delayed patterns may be a manifestation of more generalized delays in activation including orthographic activation. Thus, because the masked priming paradigm measures the initial stage of activation, the orthographic processing of adolescents of these ages was not captured in this time frame.

The fact that the normal controls evidenced statistically reliable priming at SOA 1100 in the auditory modality while the dyslexics did not, again suggests different patterns of activation between the two groups. The dyslexics exhibited less variability in the auditory experiment when compared to the other experiments in the present study, so that it is not likely that variability contributed to the absence of reliable priming. Rather, when compared to the controls the dyslexics may be evidencing delayed patterns of activation and may simply be exhibiting diminshed priming at this particular point along the temporal spectrum. Furthermore, they could be expected to exhibit reliable priming at longer SOAs than those used in the present study. The fact that Broca's aphasics were found to only

prime at SOAs of 1500 (Prather, Zurif, Stern & Rosen, 1992) seems to suggest that longer ISIs were required to capture the patterns of automatic activation of lexical-semantic information in the auditory modality among dyslexics.

Although the dyslexics did not reveal any statistically reliable priming, there are several indications that they were experiencing temporal processing difficulties in activating lexical information and that these difficulties were occurring at later points along the temporal continuum than among normal controls. In the auditory continuous list experiment the error data provide statistically reliable evidence for increasing speed/accuracy trade/offs across the temporal spectrum. More specifically, there was evidence of differential responding between the two groups across SOAs. Among the controls errors decreased between SOAs 800 and 1100 and plateaued between SOAs 1100 and 1400 indicating that after SOA 1100 there were no speed/accuracy trade-offs. Among the dyslexics, however, errors continued to decrease significantly across all SOAs and the fact that errors among the dyslexics continued to decrease between the longest SOAs provided evidence of delayed processing when compared to the normal controls.

Further evidence of temporal processing difficulties with lexical access among dyslexics was provided in the masked priming paradigm measuring orthographic priming and lexical-semantic activation. The fact that 8 dyslexic subjects were unable to respond to the targets within a time frame of 500 msec while the controls experienced no difficulty suggests delayed activation of orthographic and lexical-semantic information.

There was also other evidence of delayed processing among dyslexics. Patterns of priming effects in the visual continuous list paradigm were suggestive of the expected

effects. Among the dyslexics effects plateaued between ISIs 1100 and 1400 indicating that activation was still present at the longest ISI, while among the controls priming appeared to decrease between ISIs 1100 and 1400. Furthermore, the dyslexics and controls responded differentially across lengthening ISIs in both auditory and visual modalities. The controls' reaction times were generally consistent across ISIs while the dyslexics' reaction times increased with increasing length of ISIs. The fact that the dyslexics' reaction times increased across ISIs indicating continued processing for the duration of the ISIs. The consistency of the controls' responses across ISIs, on the other hand, indicates that they did not utilize the increased time available with increasing ISIs and that processing was discontinued at a far earlier point along the temporal continuum than among the dyslexics.

Thus, the results of the study suggest that there are delays in automatic activation of lexical information among dyslexics. Error data and other evidence provide further support for these patterns of delayed activation of lexical information among dyslexics.

The absence of any statistically reliable priming among the dyslexics appears to be partly due to the fact that their performance was extremely variable, which contributed to poor power in the study. The variability in the performance of the dyslexics was particularly notable in the visual continuous-list experiment and a power analysis indicated that in order to produce statistically significant findings 557 subjects were required. On the other hand, in the auditory paradigm there was less variability in performance and a power analysis indicated that the number of subjects should be increased to 100 to produce statistically reliable findings. Although the continuous list paradigm was

presumed to measure automatic processing, the significant difference in power between visual and auditory paradigms suggests that the reading difficulties of the dyslexics impacted on the visual paradigm resulting in far greater variability.

A factor which may have contributed to the variability in the dyslexics' performance is the possibility that subjects were engaging in strategic processing rather than automatic processing. Certain paradigmatic features in the visual continuous-list paradigm facilitated the use of strategic processing. Firstly, the duration of target exposure was terminated by the subject. While duration was limited to 4000 msec., subjects had more time to process the target (and thus to engage in strategic processing) than in the auditory paradigm where target duration was tape controlled with duration extending temporally for approximately 200 msec. Furthermore, the fact that certain aspects of the visual paradigm were under subject control most likely resulted in subjects generating strategies. Initiation of each trial was under the subject's control in that his response initiated the following ISI. In the auditory paradigm, however, the onset of SOA was tape controlled. Suggestive evidence for the use of strategies was provided by statistical analyses which revealed that in the visual continuous-list paradigm reaction times improved with increasing practice across lists. This improvement, however, did not occur in the auditory paradigm. Because of the absence of subject control of certain experimental features, the auditory paradigm appears to be a purer measure of automatic processing.

A further possibility for the variability in the performance of the dyslexics was the fact that they were comprised of separate subgroups. In the present study, dyslexia was

postulated to be a later manifestation of developmental dysphasia raising the possibility that subgroups of dyslexia based on dysphasic subtypes would be more homogeneous, and would reduce the variability.

Rapin and Allen (1983) identify six syndromes of developmental dysphasia. According to them, children with the Phonologic-Syntactic Syndrome share many resemblances to patients with Broca's aphasia. The children's speech is characterized by omissions, substitutions and distortions of consonants and consonant clusters. The most common disturbances in morphology and syntax include severely limited use of function words and inflections of nouns and verbs, as well as severe limitations in the number of syntactic relations expressed within a single utterance. Semantic categories may be relatively intact. The fact that some of these children's phonologic skills were much better in repetition than in spontaneous production also suggests a deficit with phonologic programming rather than motor production.

If the phonological-syntactic syndrome is the developmental counterpart of Broca's aphasia, it is possible that this subtype of developmental dysphasia will yield the same patterns of delayed activation found among Broca's aphasics. Thus a more appropriate screening procedure should seek to identify children with this syndrome by using a language battery designed to assess phonological and syntactic functioning.

Suggested tests include the following:

1. Rosner Auditory Analysis Test

2. Clinical Evaluation of Language Fundamentals - Revised:
   Sentence Structure
   Sentence Assembly
   Formulated Sentences

3. Spontaneous Language Sample

4. Woodcock Reading Mastery Test-Revised:
   Word Attack Subtest

Another factor which may have contributed to the variability amongst the dyslexics is the use of the lexical decision task. It is possible that using a naming task may reduce the variability. Future research should thus examine the temporal parameters of lexical access using a naming task.

The error data of the auditory experiment suggest that temporal processing disruptions were occurring in the phonological domain. Error data were presumed to be reflecting speed/accuracy trade-offs occurring during the process of lexical access. The fact that error data in the visual modality did not reflect the same speed/accuracy trade-offs occurring across ISIs, suggests difficulties were occurring in the initial contact phase of accessing auditory information. In other words, the errors the dyslexics were making were occurring at the point of contact with phonological information. Findings of decreasing errors with increasing availability of time in longer SOAs and the fact that

errors continued to decrease at the longest SOAs among the dyslexics but not among the controls, suggests delayed patterns of activation of phonological information among dyslexics.

These findings have implications for Bowers & Wolf's (1993) Double-Deficit hypothesis of dyslexia in which they conclude that "along with a core phonological deficit, temporal processing disturbances preclude the efficient formation of orthographic representations and their quick retrieval" (p. 1). The findings of the present study suggest that temporal disruptions occur within the phonological domain. Thus, rather than two separable deficits, dyslexia could be explained by a single deficit in which temporal processing disturbances exist in the phonological domain and that delayed patterns of activation of phonological information underlie the "core phonological deficit" in dyslexia. Rather than using temporal processing disruptions as a separable explanatory construct for dyslexia, it is possible that these delayed patterns of activation of phonological information impact on the activation of orthographic information by way of the visual-phonological routes proposed by Ehri' (1992) and preclude "the efficient formation of orthographic representations and their quick retrieval."

While the error data in the auditory paradigm provide evidence of delayed patterns of processing among dyslexics they do not provide strong evidence for delayed patterns of automatic priming. It is possible that the absence of any statistically reliable priming among dyslexics was due to the fact that there is no automatic priming among dyslexics and that they exhibit controlled processing only.

MODEL OF LEXICAL ACCESS DURING WORD RECOGNITION

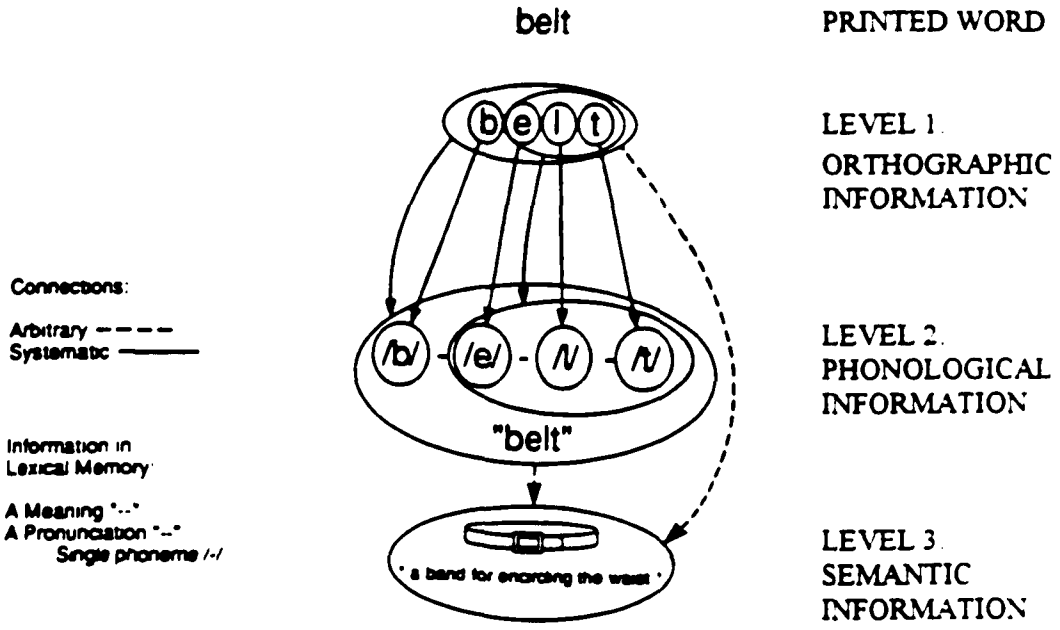
Ehri's (1992) model of word recognition provides a possible basis to conceptualize the findings of the present study (See Figure 7). Referring to Figure 7, the model can be seen to correspond to connectionist models (Rumelhart & McClelland, 1986). In accordance with connectionist theories, the lexicon can be conceived of as a network of detector units. The network consists of a series of layers representing different types of lexical information, including orthographic, phonological and semantic. Each unit in the network is connected to each unit in the adjacent layers and also to each other unit within its layers. These connections vary in strength and are both excitatory and inhibitory. Strengths of connections are based on previous learning.

Detector units in the network are activated in response to visual and auditory sensory stimuli. According to modularity principles outlined by Fodor (1983) the lexicon is an encapsulated, autonomous module which is impenetrable by higher level information from outside the lexicon. Intralexically, however, activation flows freely between the layers representing orthographic, phonological and semantic information. Lexical activation takes place when form-based orthographic or phonological information is contacted by an external stimulus providing a match with the sensory input. When sufficient activation has accrued for a particular lexical entry, the stored knolwedge associated with the lexical represenation, including lexical and semantic information, is made available to the language system.

FIGURE 6

MODEL OF LEXICAL ACCESS

(BASED ON EHRI, 1992)



According to Ehri (1992), word recognition proceeds via a "visual route that is paved with phonological information leading into lexical memory" (pp. 115). Referring to Figure 6, readers who have knowledge of how the orthographic system symbolizes units in speech form many systematic connections linking visual spelling units seen in print to pronunciations stored in memory. These connections depicted in Figure 6 form the visual-phonological route. As a result of prior recoding experiences with the word individual letters are connected to individual phonemes within the word. (Ehri used "recoding" instead of decoding to refer to the process of transforming spellings into pronunciations by application of letter-sound rules). Knowledge of letter-sound correspondences is used to form these connections. Also, individual letters are connected to the whole pronunciation because each letter-phoneme connection occupies a position within the pronunciation, making it an intrinsic part of the whole. Moreover, the whole spelling is connected to the whole pronunciation in that the sequence of letters corresponds to the sequence of blended phonemes in the pronunciation. Other connections may be formed out of letter sequences within the spelling as well, for example, the rime stem "-elt" connected to the rime unit "-elt" in the pronunciation (pp.116).

The critical connections that enable readers to find specific words in lexical memory by means of this visual-phonological route are connections linking spellings to pronunciations rather than to meanings. However, connections between spellings and meanings are easily formed in the process of establishing visual-phonological routes. These connections are depicted in Figure 6. Readers already know connections between pronunciations and meanings from speech. When spelling are connected to pronunciations

the connections extend to meanings as well, perhaps automatically. In addition, readers form direct connections between spellings and meanings when they interpret the words they read. This comes about as follows. The visual-phonological connections that readers have formed for a word make that spelling a visual symbol for its pronunciation. This means in effect that readers "see" the pronunciation when they look at the spelling, and this event creates direct links between the spelling and its meaning. Thus, readers access not only pronunciations but also meanings directly when they learn to read words by means of a visual-phonological route (pp. 116).

The findings from the present study provide suggestive evidence for delayed patterns of activation of lexical-semantic activation among dyslexics. Furthermore, the findings provide evidence that these temporal processing disruptions are occurring in the phonological domain. In terms of Ehri's model, the findings suggest problems occurring within the visual-phonological route. According to Ehri (1992), when spellings are connected to pronunciations the connections extend to meanings as well because readers' knowledge of speech provides them with connections between pronunciations and meanings. Thus, accessing lexical-semantic information involves accessing phonological information. In the present study, there were no group differences in activating orthographic information but there was suggestive evidence that problems were occurring at the phonological level and that they were temporally based. According to Ehri's (1992) model, these problems occurring at the phonological level are impacting on the activation of meaning, accounting for the delayed patterns of lexical-semantic activation found in the study. In terms of Ehri & Wilce's (1983) conceptualization of word identification, these

failures at the phonological level could be hypothesized to preclude the integration or unitization of the associative links between codes in lexical memory resulting in defective word identification processes.

The present study assessed the automatic activation of orthographic and lexical-semantic information among dyslexics. While there were no differences in automatic activation of orthographic information, there were indications of delayed patterns of automatic activation of lexical-semantic information among dyslexics. The findings suggest that these differences could be accounted for by differences in the temporal parameters of processing phonological information.

SIGNIFICANCE OF THE STUDY AND DIRECTIONS FOR FUTURE RESEARCH

1. Even though priming results did not result in any significant group differences in patterns of lexical activation, there was sufficient evidence of temporal processing difficulties in patterns of activation among dyslexics. Future research should replicate the study using more homogeneous groups of dyslexics as well as longer ISIs.

2. There has been no prior research mapping the temporal patterns of automatic activation during lexical access among normal adolescents. The present research was thus exploratory and found that among this group the "rise" time was at an ISI of 1100 msec in the auditory modality and suggested in the visual modality. This finding provides a

preliminary baseline against which future studies among this age group could proceed. In addition, the study provides a baseline of responses patterns of this age group along the range of ISIs sampled.

3. In the auditory paradigm, the patterns of errors suggests that speed/accuracy trade-offs are occurring before lexical access, at the point of contact with phonological information. This finding raises the possibility that the phonological difficulties amongst dyslexics are the result of temporal disruptions in the availability of phonological information, suggesting a temporal basis to dyslexics' phonological difficulties. Further examination of the issue by by future research could have theoretical implications for explanations as to the basis of dyslexia. The findings raise the possibility that, rather than dyslexia resulting from a double deficit in which phonological and temporal processing disruptions contributed to dyslexia (Bowers & Wolf, 1993), dyslexia results from a single deficit in the phonological domain which is temporally based.

4. The study provided some evidence of delayed activation of lexical information at the point of lexical access among dyslexics. These findings have implications for remediation of dyslexia. For example, temporal delays in automatic activation of lexical information impact on comprehension processes. Remediation procedures could thus focus on enhancing memory processes in order to retain the information long enough in order to integrate segments into meaningful units as they occur across time.

5. While the study did not resolve the issue of whether disruptions occur at the point of articulatory encoding or at the point of lexical access, it did provide further evidence for disruptions occurring at the point of lexical access.

PROBLEMS IN THE STUDY

1. There was evidence of improved performance in visual continuous-list paradigm with increasing practice across lists, suggesting the use of strategies. Certain aspects of the experiment were under subject control which may have facilitated strategic processing. Future research should address these issues by eliminating subject control of these aspects.

2. The fact that in the auditory paradigm words of higher frequency were responded to faster than those of lower frequency, indicates that the band of frequency chosen for the auditory continuous-list experiment was too broad and that future research should restrict the range of frequencies.

3. The efficacy of the screening measures used in the present research were examined by correlational analyses with the dependent variable, reaction time. None of the correlations were significant. Word identification and reading comprehension each accounted for .004% of the variance among the dyslexics in the visual continuous list paradigm. Measures which accounted for the greatest amount of variance among the

dyslexics were Rapid Automatized Naming (RAN) of objects (16%) and also overall spelling (9%).

The absence of any significant correlations between these measures and the dependent variable, reaction time, indicates the necessity for different screening measures for group selection.

4. Since the continuous list paradigm had never been presented auditorily before, experiment 3 was exploratory. There were inherent problems with the auditory paradigm. Even though primes were monosyllabic words matched for length and frequency, auditory stimuli span time and it is difficult to determine exactly the point at which words are accessed. Furthermore, while in the visual paradigm the subject's response initiated the ISI, in the auditory paradigm, ISI was tape controlled. Thus there was variability in the duration of the stimulus as well as the ISI. In an attempt to better control some of this variability, it was thought that ISI should be measured from the onset of the stimulus.

While more recent technology enables the subject's response to initiate the interstimulus interval and future research could benefit by the greater control of ISI afforded by the new equipment, the present research indicated that placing certain experimental aspects under subject control resulted in strategic processing. These considerations will have to be taken into account when conducting future research.

5. Power analyses indicated poor power for both visual and auditory paradigms. There was far greater variability in the visual paradigm resulting from paradigmatic problems so that the number of subjects indicated by the power analysis to produce statistically reliable findings was 557. There was less variability in the auditory paradigm and power analysis indicated that 100 subjects were required to produce statistically reliable findings. Thus, future research should use greater numbers of subjects. Problematic issues in the visual paradigm should be examined in an attempt to reduce variability and to reduce the number of subjects required.

APPENDIX A

Experimental Stimuli from Experiment 1

The primes and word targets are listed in groups of four. The first in each group is the substitution prime, the second is the transposition prime, the third is the control prime and the fourth is the target:

WORDS

plia	pela	sink	PLEA	epac	eipc	loop	EPIC
nolm	nrom	silk	NORM	slet	solt	defy	SLOT
emat	eimt	grin	EMIT	nagy	nvay	huge	NAVY
cley	caly	tail	CLAY	derp	depe	farm	DEEP
heor	hier	city	HEIR	joun	jion	meal	JOIN
agid	aegd	wrap	AGED	lert	lfet	girl	LEFT
dinc	dsic	cold	DISC	almo	aslo	help	ALSO
acad	aicd	soup	ACID	pulf	pfuf	sale	PUFF
unet	uint	lost	UNIT	obly	oeby	luck	OBEY
nerk	ncek	coop	NECK	folm	from	rule	FORM
edet	eidt	door	EDIT	derk	dsek	nail	DESK
dain	dman	shoe	DAMN	delt	dbet	grip	DEBT
abie	albe	bowl	ABLE	lier	lair	dope	LIAR
chif	cehf	sock	CHEF	culb	crub	task	CURB
dirl	dail	mice	DIAL	dist	drit	page	DIRT
deby	dney	wool	DENY	bies	bais	hold	BIAS
cupy	cpoy	very	COPY	acre	ahce	lace	ACHE
soga	sfoa	wide	SOFA	zemo	zreo	shot	ZERO
inth	ichn	cell	INCH	knue	kene	list	KNEE
bild	brid	lane	BIRD	eaby	esay	span	EASY
jeke	jkoe	pile	JOKE	gade	gzae	post	GAZE
baly	bbay	grin	BABY	idra	ieda	limb	IDEA
jiry	jruy	show	JURY	culf	cfuf	west	CUFF
colb	cmob	sole	COMB	urle	ugre	mole	URGE

APPENDIX A

Experimental Stimuli from Experiment 1

The primes and targets are listed in groups of four. The first in each group is the substitution prime, the second is the transposition prime, the third is the control prime and the fourth is the target.

NONWORDS

bily	bniy	rouj	BINY	drad	dird	peld	DRID
dels	daes	targ	DEAS	griv	garv	wolk	GRAV
glid	dolg	murd	GLOD	bire	bpie	malf	BIPE
pult	psut	trif	PUST	tosp	tlop	ghab	TOLP
snaf	senf	porl	SNEF	plen	piln	vots	PLIN
frad	furd	cham	FRUD	chud	cohd	malp	CHOD
hilk	hnik	lont	HINK	cadj	craj	erch	CARJ
rulk	rnuk	peej	RUNK	naif	nraf	goor	NARF
roif	rlof	suld	ROLF	vage	vtae	stof	VATE
plem	polm	naig	PLOM	daff	draf	koob	DARF
flup	felp	pord	FLEP	surs	stus	klat	SUTS
lorf	lofo	yeka	LOOF	zosk	zlok	noij	ZOLK
hosp	hsop	freg	HORP	ralg	rwag	kank	RAWG
nolg	nrog	darb	NORG	glep	gupl	lirg	GLUP
krid	kurd	mirc	KRUD	thef	tihf	avom	THIF
karu	klau	nabe	KALU	evor	eavr	sech	EVAR
thil	tahl	frem	THAL	fald	frad	spim	FARD
geds	gges	colb	GEGS	chib	cahb	snog	CHAB
hesk	hrek	lich	HERK	asri	asis	gorf	ASSI
beed	bedl	crin	BELD	cosk	clok	ando	COLK
lurp	lsup	kepa	LUSP	elip	eolp	rudi	ELOP
slom	selm	drub	SLEM	zalg	zaga	freb	ZAAG
onde	ogne	serd	ONGE	kire	kvie	noic	KIVE
wult	wsut	goft	WUST	rown	oron	torb	ROON

APPENDIX A

Experimental Stimuli from Experiments 2 and 3

Prime Word	Control Word	Target
straw	tribe	DRINK
thumb	breed	HAND
toy	ash	DOLL
coal	rank	BLACK
bone	file	SKELETON
tent	grip	CAMP
bee	lid	BUZZ
cloth	pride	SILK
smile	scale	TEETH
grain	stair	WHEAT
card	pair	CLUB
fleet	crest	SHIPS
pole	cape	ICE
toe	tie	FOOT
cast	hold	MOVIE
coin	path	NICKEL
grass	check	GREEN
joint	craft	ELBOW
sport	stone	SOCCER
lock	trapk	KEY
cork	kiss	WINE
bread	creek	CRUST
belt	drop	PANTS
fruit	queen	APPLE
tune	cult	SONG
root	load	PLANT
lens	dean	GLASSES
rose	cure	THORN
crop	mood	CORN
couch	trunk	PILLOW
stem	gift	FLOWER
slug	kick	SLIME
stove	gland	OVEN
meat	flow	COW
pond	dish	FROG
cake	flag	BIRTHDAY
gold	fool	NECKLACE
cage	slot	ANIMAL
thief	drift	LOOT
brow	sack	EYE
drill	lawn	NOISE
lamp	pill	LIGHT

Prime Word	Control Word	Target
mold	cost	ROT
skirt	trick	DRESS
stall	bush	FAIR
soap	bear	BATH
drum	clue	MUSIC
ranch	pitch	CATTLE
barn	beer	HAY
vine	sock	GRAPE
sleep	nerve	DREAM
chill	spray	COLD
nurse	craft	HOSPITAL
brain	crowd	HEAD
clock	pitch	TIME
nest	ward	EGGS
gang	herd	FIGHT
fort	mark	WAR
tank	ease	FISH
hole	code	GOLF
web	tag	SPIDER
chip	mess	POTATO
camel	shake	HUMP
link	pack	CHAIN
steel	trail	METAL
chin	dawn	BEARD
flock	paste	BIRD
mint	sued	CANDY
cook	plug	KITCHEN
cab	pan	YELLOW
shirt	guide	BUTTON
ghost	quest	WHITE
crime	plate	MURDER
gown	calf	BALL
cat	bus	WHISKER
coat	mine	FUR
cheek	prize	FACE
bride	porch	WEDDING
leaf	boot	TREE
lump	cliff	SUGAR
beef	palm	STEAK
tide	lamb	WAVE
cash	norm	MONEY
hoof	beam	HORSE
wire	skin	FENCE
moon	nose	NIGHT
cave	crash	ROCK
track	clerk	RACE
lung	fate	AIR

Prime Word	Control Word	Target
deck	scar	WOOD
star	foam	SKY
ring	lead	FINGER
sheep	charm	WOOL
storm	chart	RAIN
spark	globe	FIRE
lion	mill	MANE
plot	male	STORY
crown	graph	KING
chest	touch	HEART
lake	suit	BOAT
jar	dad	JELLY
milk	tour	CREAM
dome	mate	CHURCH
map	wit	ROAD
snow	folk	WINTER
prince	strain	CASTLE
shell	grace	SEA
pipe	boss	TOBACCO
port	dose	DOCK
wing	male	PLANE
peak	monk	MOUNTAIN
sand	tape	BEACH

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY CONDITION

EXPERIMENT 1

DYSLEXICS [WORDS]

SUBJECTS	SUBSTITUTION	TRANSPOSITION	IDENTITY	CONTROL
1	2053.10	1967.00	1660.00	2187.14
	1083.45	821.57	511.88	1033.62
2	1379.64	1357.82	1369.20	1583.22
	382.33	348.21	415.39	634.24
3	840.70	798.67	1054.78	1063.45
	229.48	209.09	381.24	413.45
4	1326.00	1595.14	1521.13	1505.90
	483.66	651.37	683.26	485.72
5	1079.89	1036.18	931.44	1055.50
	280.98	409.55	202.76	457.46
6	3010.67	3185.29	2924.20	3341.50
	698.61	624.33	864.44	153.44
7	1075.25	772.70	751.18	864.88
	347.10	86.94	125.57	124.01
8	1010.63	758.88	760.30	1023.50
	277.71	215.15	119.16	399.10
9	1537.00	1086.17	1459.57	1196.67
	803.76	339.56	477.58	409.69
10	947.56	887.43	1410.33	905.89
	192.32	131.17	584.35	145.91
11	715.13	669.88	718.29	745.40
	117.75	114.95	125.76	215.69
12	1406.00	2159.86	1814.00	1709.83
	474.61	538.90	676.17	637.59
13	1112.40	1083.75	927.73	1232.50
	328.00	300.71	190.37	565.63
14	1780.40	1320.50	1404.33	1917.88
	324.40	350.03	457.23	649.32
15	896.67	810.40	699.80	749.63
	502.52	260.47	152.06	109.83
16	833.67	790.38	614.11	935.11
	129.07	249.31	118.14	297.09

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY CONDITION

EXPERIMENT 1

CONTROLS[WORDS]

SUBJECTS	SUBSTITUTION	TRANSPOSITION	IDENTITY	CONTROL
17	622.83	646.82	559.30	619.50
	93.75	94.98	121.06	71.89
18	663.40	791.25	652.70	694.30
	69.96	166.94	74.66	86.35
19	578.00	626.11	587.20	635.55
	72.07	63.14	108.54	112.35
20	547.00	649.89	481.00	623.33
	98.31	136.35	59.83	95.11
21	733.17	518.60	560.67	712.18
	143.81	65.68	97.74	112.93
22	691.90	644.27	627.20	887.50
	119.30	95.28	79.52	166.88
23	892.55	767.92	746.82	903.91
	255.89	123.64	126.76	110.78
24	775.30	895.00	715.80	979.33
	140.52	204.35	126.61	195.19
25	728.11	782.13	704.89	784.50
	176.08	186.02	170.14	84.22
26	772.80	685.57	624.10	695.83
	221.75	146.23	104.43	140.87
27	653.90	678.38	563.82	614.30
	89.55	128.35	78.18	62.11
28	565.64	563.50	562.27	621.09
	71.12	53.62	68.20	89.56
29	678.40	692.82	569.27	692.25
	83.19	139.92	54.81	79.74
30	1015.42	837.58	787.18	847.13
	230.54	233.27	120.36	167.35
31	957.20	831.08	704.70	784.75
	267.98	139.64	76.89	80.46
32	747.60	688.18	627.50	710.70
	61.64	142.91	109.70	92.00

APPENDIX B

EXPERIMENT 2

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

DYSLEXICS

SUBJECT	ISI 500		ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
1	572.46	710.23	667.00	654.92	825.93	709.07	742.92	881.00
	140.08	273.65	107.04	110.87	199.33	118.85	211.99	239.20
2	554.85	529.86	554.64	522.36	492.77	404.08	468.69	499.43
	175.23	84.89	108.85	140.09	157.84	98.53	147.06	156.22
3	541.83	723.42	550.64	596.17	515.00	570.33	522.50	584.14
	117.49	131.58	144.07	160.20	127.13	147.53	118.30	195.31
4	880.38	957.92	826.79	774.83	744.90	944.17	971.77	1163.23
	121.87	149.95	203.18	154.43	258.49	229.66	319.13	461.35
5	695.45	660.45	685.46	807.75	618.20	685.62	820.58	816.92
	66.71	116.08	79.11	153.94	107.09	164.70	149.27	153.68
6	564.25	569.00	510.62	705.00	542.25	534.00	638.00	659.38
	128.53	151.61	92.63	182.08	182.99	173.10	108.83	140.38
7	688.67	759.77	697.21	638.69	691.31	660.46	638.69	745.64
	205.65	267.13	156.53	87.42	136.08	134.21	98.50	217.03
8	1056.17	1231.23	1054.85	1138.08	1034.31	1101.92	985.92	880.92
	197.42	340.76	301.72	321.22	287.51	306.01	280.08	226.98
9	844.23	926.60	703.77	1036.46	1034.69	1264.54	839.15	1231.46
	308.05	241.32	146.59	611.35	377.27	648.08	188.59	385.89
10	799.75	687.85	875.00	979.08	839.85	979.62	893.46	954.50
	211.26	159.83	122.63	187.12	228.49	144.71	261.81	298.52
11	1231.43	918.08	991.08	910.00	770.78	814.46	1379.64	1306.71
	638.16	334.75	429.55	281.65	189.63	236.07	536.35	517.70
12	869.83	1268.38	1161.29	762.69	861.15	1356.21	1009.15	1077.85
	313.33	1072.80	344.01	200.72	277.82	753.03	393.88	465.13
13	2200.89	1735.70	2121.20	2463.75	2646.30	2763.00	1948.00	2653.89
	465.65	682.55	688.96	933.01	715.39	808.43	969.12	908.49
14	504.55	629.69	584.70	791.10	594.00	561.31	615.07	612.79
	68.44	125.47	37.80	348.24	123.23	221.14	86.66	215.47
15	2482.50	1876.91	1610.79	2151.14	1940.31	2210.00	1535.50	1395.33
	1025.52	633.42	542.50	805.96	920.32	617.80	498.07	447.50
16	1089.54	1233.93	1063.25	1214.67	1012.92	1205.64	1029.82	1224.42
	475.60	408.48	319.93	446.53	205.73	362.48	402.59	346.81
17	801.08	869.54	1205.15	1169.36	818.64	809.17	893.62	1114.23
	122.59	253.79	397.81	425.42	154.91	256.61	176.74	301.34

APPENDIX B

EXPERIMENT 2

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

DYSLEXICS

SUBJECT	ISI 500		ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
18	870.58	886.62	741.09	755.50	762.43	1309.38	826.58	963.17
	313.28	321.48	183.52	276.01	164.64	735.42	155.54	375.39
19	914.73	847.85	1243.91	993.85	1040.31	958.67	1116.77	1094.38
	455.04	255.91	636.94	446.84	617.40	338.47	300.86	432.14
20	840.50	812.83	814.21	1020.38	763.64	892.38	878.64	813.82
	299.13	227.92	168.38	364.62	117.36	149.06	200.70	145.15
21	1659.08	2068.17	2615.55	2906.45	3004.23	2850.23	2652.33	1966.38
	716.61	745.50	636.56	740.08	1057.83	541.92	1160.64	910.72
22	451.08	463.27	516.62	529.43	499.14	509.75	478.25	553.79
	98.42	69.66	105.20	169.41	164.97	92.13	156.71	128.30
23	969.38	1477.86	1290.42	1104.82	1171.85	1014.25	1391.40	2074.46
	257.76	854.90	494.72	236.86	343.54	274.43	762.45	733.96
24	1102.80	1240.90	1105.75	1222.91	1872.70	1924.15	1621.00	1577.15
	281.07	690.14	374.25	352.69	670.04	813.51	896.66	828.08

APPENDIX B

EXPERIMENT 2

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

CONTROLS

SUBJECT	ISI 500		ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
25	456.92	461.08	459.15	449.23	481.86	534.07	502.43	480.23
	84.46	92.78	68.90	60.89	58.33	119.47	89.92	89.95
26	507.36	593.50	569.85	677.57	610.00	642.50	519.54	593.00
	134.20	101.72	83.03	161.58	111.99	115.63	144.70	162.12
27	503.23	513.00	491.54	545.75	448.23	551.54	556.43	514.21
	65.09	51.61	98.34	86.23	54.85	128.22	155.09	70.82
28	583.23	611.00	601.07	591.46	602.85	586.31	640.77	600.54
	85.04	130.31	86.87	123.14	98.42	131.38	94.12	86.04
29	457.64	449.69	435.07	433.93	423.86	433.57	380.92	429.75
	71.64	66.72	80.17	85.38	88.56	97.24	45.77	69.63
30	469.29	477.00	484.23	509.71	482.46	494.25	514.79	494.83
	120.29	103.96	103.81	81.50	100.61	48.40	86.18	85.41
31	525.93	532.58	526.36	547.08	516.38	511.15	579.50	560.69
	81.01	70.42	88.04	105.06	84.72	117.37	183.30	99.21
32	640.85	657.00	620.46	645.23	846.85	791.50	525.58	589.92
	163.02	123.41	145.63	171.16	303.49	197.77	125.69	135.95
33	477.75	539.85	466.31	447.46	432.93	519.57	487.31	499.31
	77.14	100.59	74.44	66.79	53.38	137.57	90.35	87.46
34	552.46	584.00	579.62	589.69	536.85	546.79	579.00	576.18
	98.90	77.40	78.93	66.12	73.16	130.77	113.77	144.54
35	603.85	694.77	564.62	603.29	573.69	643.46	514.38	536.21
	80.21	158.13	114.79	116.72	109.26	103.01	109.20	116.41
36	839.92	665.62	580.85	541.14	604.57	597.29	488.54	575.85
	245.17	85.17	88.38	106.06	153.55	115.20	105.92	138.82
37	575.55	597.08	539.31	526.00	546.43	534.33	522.64	646.21
	72.32	122.02	54.71	75.85	113.93	105.81	62.90	123.01
38	430.86	476.15	563.50	555.00	449.92	503.73	531.69	541.64
	122.66	136.78	180.01	144.57	133.67	105.08	53.39	64.78
39	531.00	499.62	531.07	477.50	482.92	491.50	491.86	482.00
	112.76	97.32	95.85	79.04	46.68	94.44	114.20	102.19
40	587.08	597.08	660.38	636.23	598.00	583.00	624.75	658.08
	160.80	141.80	88.48	124.96	124.84	84.57	108.45	144.17
41	470.92	456.54	491.29	510.43	453.31	413.33	441.00	471.62
	64.77	89.33	67.07	76.29	75.28	50.61	82.58	82.56
42	491.33	512.62	500.15	471.42	463.62	446.85	471.00	473.17
	86.64	64.94	44.88	86.67	99.94	100.59	98.32	73.39

APPENDIX B

EXPERIMENT 2

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

CONTROLS

SUBJECT	ISI 500		ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
43	508 75	487 00	491 21	506 38	453 62	473 50	424.29	468.08
	98 12	110.68	112 42	106 51	99.25	61.01	109.90	107.72
44	555 08	537.33	573 92	591 77	500.92	638 43	556.15	584.69
	122 74	79.95	110 52	143 76	94.94	193.60	74.60	117.53
45	589 38	563 00	523 92	610 08	525.64	598 75	572.08	551.15
	114 05	61 72	109 21	120 24	99 49	144 93	108.56	151.41
46	487.36	518 92	546 85	577 50	556 50	560.15	528.23	570.08
	51 08	77.06	74 70	122 48	151 22	147.38	84.60	116.32
47	509 46	510 46	519 38	491 77	447 54	509 00	531 31	549.38
	105 10	77 85	101 13	88 09	60 16	122.29	86.65	87.93
48	536 50	584 08	629 77	706 92	683 23	652 46	676.46	638.54
	125 68	198 50	108 97	202 63	196 84	104.93	160.44	126.74

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY SOA

EXPERIMENT 3

DYSLEXICS

SUBJECT	SOA 800		SOA 1100		SOA 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
1	789.11	865.33	917.69	954.38	888.73	1056.69
	96.36	131.61	132.56	95.28	159.28	242.37
2	787.89	848.75	928.70	974.18	1072.83	976.08
	164.95	67.70	159.79	210.57	267.00	178.32
3	785.56	815.00	1083.64	970.88	922.14	1074.60
	111.36	89.94	139.15	154.82	226.76	135.31
4	577.40	705.57	939.83	1127.17	992.46	936.83
	223.86	281.51	185.69	116.21	158.31	204.03
5	733.25	777.00	737.90	864.38	829.17	893.10
	138.60	132.92	93.53	253.60	142.55	189.38
6	660.70	693.22	722.88	841.50	1013.17	1020.50
	107.75	139.32	154.21	187.82	280.30	252.62
7	810.63	856.42	1090.77	1034.00	1114.00	1005.38
	99.51	69.15	127.56	135.62	107.48	69.85
8	839.60	833.75	1035.00	1049.90	1244.80	1280.78
	94.21	114.12	198.05	115.02	206.12	163.44
9	609.67	486.29	809.50	962.20	1188.29	881.90
	289.79	335.57	380.62	99.13	185.91	468.31
10	800.14	839.57	964.67	890.43	942.08	941.00
	108.55	118.59	167.12	134.77	92.09	165.63
11	791.88	864.71	942.00	979.91	845.85	1054.83
	179.19	83.08	210.23	179.82	221.64	270.31
12	602.33	619.38	1097.22	1115.00	1231.40	1275.64
	364.17	415.16	118.21	121.93	243.19	122.06

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY SOA

EXPERIMENT 3

DYSLEXICS

SUBJECT	ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
13	717.88	803.56	908.08	931.82	929.58	1109.20
	106.82	146.38	168.53	163.67	198.79	243.72
14	759.50	883.83	1063.80	1025.20	1112.09	1028.55
	244.16	88.37	109.63	165.28	252.19	104.00
15	585.67	575.25	768.00	790.67	928.54	799.42
	293.29	274.09	299.33	121.58	284.78	100.73
16	674.30	716.71	972.89	1007.25	1097.69	1139.00
	355.91	317.91	149.45	212.24	247.03	287.44
17	664.75	934.43	952.64	1120.20	1102.17	1063.22
	402.79	64.02	184.97	135.77	174.69	125.64
18	830.11	889.00	950.33	1034.25	908.92	894.73
	147.52	64.59	126.00	128.86	145.53	165.22
19	776.90	655.50	993.73	1036.55	893.54	941.50
	61.28	320.02	238.98	138.04	258.57	251.14
20	800.91	844.75	824.55	790.45	880.92	1021.70
	106.15	93.61	113.12	116.73	128.84	191.75
21	431.50	435.14	1016.22	836.00	1010.00	1115.92
	327.33	307.75	108.38	356.77	180.79	195.18
22	721.09	798.91	726.09	815.92	848.50	886.36
	166.21	116.25	96.86	212.13	148.81	134.51
23	575.00	557.00	1059.70	1064.00	1139.50	1119.71
	256.72	330.20	163.05	151.73	202.78	151.15
24	875.20	891.50	1109.33	1121.10	1173.31	1177.10
	47.25	84.45	150.74	117.30	185.53	145.72

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

EXPERIMENT 3

CONTROLS

SUBJECT	ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
25	731.00	783.82	825.27	897.46	866.29	949.62
	70.59	116.57	92.46	107.89	114.57	189.17
26	742.54	764.80	822.50	871.23	752.23	860.50
	90.22	139.17	214.30	123.38	238.55	189.71
27	738.80	831.40	852.67	944.92	839.54	983.75
	104.10	93.61	105.34	144.03	129.69	233.74
28	792.92	790.56	792.00	949.23	793.23	895.54
	94.33	90.53	7417.00	141.74	213.85	151.07
29	672.10	725.67	753.69	755.90	804.92	883.15
	64.17	123.77	84.75	129.23	157.78	137.34
30	664.36	682.73	673.08	748.75	653.38	654.69
	174.40	71.59	148.19	154.22	111.31	136.06
31	756.83	776.55	799.93	927.91	797.00	851.92
	136.13	148.72	143.45	126.91	124.40	83.95
32	775.78	827.89	949.80	1000.64	718.10	972.00
	175.48	86.76	92.88	117.14	310.87	137.14
33	777.82	806.30	897.54	899.23	864.15	901.64
	90.58	90.20	118.70	133.42	116.83	106.76
34	843.00	858.88	992.85	1055.69	1067.42	1154.23
	147.99	80.54	77.51	108.90	148.41	173.62
35	822.90	770.22	892.42	953.08	938.31	1057.36
	114.30	102.94	87.50	183.04	182.37	223.73
36	861.56	839.44	921.25	1013.54	1012.29	910.83
	80.55	83.13	155.99	143.67	193.85	199.35

APPENDIX B

INDIVIDUAL SUBJECT MEAN REACTION TIMES AND STANDARD DEVIATIONS BY ISI

EXPERIMENT 3

CONTROLS

SUBJECT	ISI 800		ISI 1100		ISI 1400	
	RELATED	UNRELATED	RELATED	UNRELATED	RELATED	UNRELATED
37	848.70	871.11	936.83	925.69	986.92	1073.50
	88.80	97.30	145.98	191.60	100.47	114.73
38	671.79	696.27	710.69	733.90	683.69	811.00
	112.14	139.38	149.40	79.37	107.27	97.80
39	648.54	733.90	773.92	929.15	890.08	882.93
	89.30	112.48	108.46	180.61	100.45	141.88
40	804.00	796.00	891.00	914.45	813.77	898.73
	97.39	67.39	67.79	69.69	85.79	243.53
41	731.15	815.00	851.93	958.31	949.08	951.77
	82.55	68.18	168.06	197.22	144.57	133.44
42	500.15	489.00	463.62	446.85	471.00	473.17
	44.88	104.43	99.94	100.59	98.32	73.39
43	699.23	671.38	786.38	878.23	854.75	858.31
	213.77	128.08	146.12	190.28	242.20	66.11
44	742.92	770.91	796.67	841.18	772.07	853.25
	114.49	87.53	144.92	122.60	141.25	97.80
45	719.09	803.36	767.83	893.77	821.75	846.31
	88.89	112.40	59.73	192.03	90.80	124.92
46	776.40	802.00	766.67	930.18	758.54	796.27
	120.89	112.52	154.62	145.89	123.92	103.53
47	790.67	846.60	947.75	1022.46	940.46	986.31
	80.79	96.14	159.18	187.52	176.97	107.33
48	834.60	802.67	833.00	903.55	1018.63	1008.38
	170.49	123.71	136.18	104.33	222.48	166.27

APPENDIX C

TWO-WAY COMPARISONS-SIGNIFICANCE TABLES

EXPERIMENT I

PRIME	Tukey HSD
Substitution-Transposition	NS
Substitution-Identity	NS
Substitution-Control	NS
Transposition-Identity	NS
Transposition-Control	NS
Identity-Control	.05

WORD BY PRIME INTERACTION

WORD

Substitution-Transposition	NS
Substitution-Identity	.05
Substitution-Control	.05
Transposition-Identity	.05
Transposition-Control	.05
Identity-Control	.05

NONWORD

Substitution-Transposition	NS
Substitution-Identity	NS
Substitution-Control	NS
Transposition-Identity	NS
Transposition-Control	NS
Identity-Control	NS

APPENDIX C

TWO-WAY COMPARISONS-SIGNIFICANCE TABLES

EXPERIMENT 2

ISI	Tukey HSD
500-800	.05
500-1100	.05
500-1400	NS
800-1100	NS
800-1400	NS
1100-1400	NS

ISI BY GROUP INTERACTION

DYSLEXIC

500-800	.05
500-1100	.05
500-1400	.05
800-1100	NS
800-1400	.05
1100-1400	.05

CONTROL

500-800	NS
500-1100	NS
500-1400	NS
800-1100	.05
800-1400	.05
1100-1400	NS

APPENDIX C

TWO-WAY COMPARISONS-SIGNIFICANCE TABLES

EXPERIMENT 3

SOA	Tukey HSD
500-800	NS
500-1100	NS
500-1400	NS
800-1100	.05
800-1400	.05
1100-1400	NS

ISI BY GROUP INTERACTION

DYSLEXIC

500-800	NS
500-1100	NS
500-1400	NS
800-1100	NS
800-1400	NS
1100-1400	.05

CONTROL

500-800	NS
500-1100	NS
500-1400	NS
800-1100	NS
800-1400	NS
1100-1400	NS

APPENDIX C

TWO-WAY COMPARISONS-SIGNIFICANCE TABLES

EXPERIMENT 3

ERROR DATA

SOA	Tukey HSD
500-800	NS
500-1100	NS
500-1400	NS
800-1100	.05
800-1400	.05
1100-1400	NS

SOA BY GROUP INTERACTION

DYSLEXIC

500-800	NS
500-1100	NS
500-1400	NS
800-1100	.05
800-1400	.05
1100-1400	.05

CONTROL

500-800	NS
500-1100	NS
500-1400	NS
800-1100	.05
800-1400	.05
1100-1400	NS

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