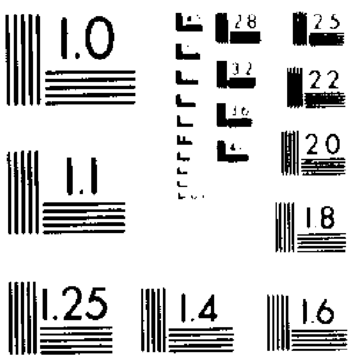
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SPEECH PERCEPTION IN DYSLEXIC CHILDREN

by

SHERRY LYNN PALLAY

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1986

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Abstract

SPEECH PERCEPTION IN DYSLEXIC CHILDREN

by

Sherry Lynn Palley

Advisor: Professor Jeffrey J. Rosen

There is strong evidence that at least some forms of reading disability stem from a deficit in language and in particular phonological processing. Poor readers have been shown to have short term memory deficits for phonological information, to lack a linguistic awareness of the phonetic structure of words, to have difficulty perceiving speech in noise, and to have trouble perceiving acoustic cues for a place distinction. This study was undertaken to further investigate these issues. In particular, the aim was to investigate whether some poor readers have a deficit of phonetic and/or temporal perception. Two related but differing hypotheses were studied. One is that dyslexic children have a perceptual deficit that is specific to phonetic information. The other is that these children have a disorder of temporal perception (i.e. a difficulty processing brief information) that is not specific to phonetic information but is in fact based on a disorder of nonphonetic perception. Such a deficit would affect phonetic processing because rapidly occurring information is

characteristic of speech sounds. To this end, dyslexic and normal readers were compared on three speech and one nonspeech task. All required temporal processing. One speech task required identification and discrimination of a /ba/-/wa/ continuum, varying in the first formant transition. A second speech task consisted of a /da/-/ta/ continuum varying in voice onset time. The nonspeech task consisted of the isolated first formant transition from the /ba/-/wa/ set. A third speech task required the perception of words which were compressed in time by 30 and 60 percent. Although the groups did not differ in performance on the identification tasks, they were found to be significantly less efficient at discriminating the phonetic information as compared to the normal readers. In addition, they were found to be more adversely affected on the 60 percent time compressed task than the normal readers. In contrast, the groups did not differ in performance on the nonspeech discrimination task. The findings support the notion that some dyslexic children have a perceptual deficit that is specific to speech. Although evidence was presented that some dyslexic children are less efficient at discriminating temporal speech cues there was no evidence to support the view that poor readers have a deficict processing "brief" temporal information in general. The results provide additional evidence that some poor readers have difficulties in the phonological domain.

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INTRODUCTION

Some children learn to read easily; others have considerable difficulty. Although in many cases the reason for a child's reading disability seems readily apparent, (e.g. the result of environmental influences or neurological insult) in other cases the cause is less well understood. That is, despite the fact that children may appear otherwise indistinguishable on medical, intellectual, educational and cultural variables they may none the less differ greatly at becoming successful readers. The reasons for this disparity are open to question. The answers are of interest to researchers who attempt to understand the cognitive development and function of the brain, to educators and parents who look for ways to teach these children and to children who struggle to learn to read like their normally reading peers.

It is generally agreed that reading disability in a large majority of children arises from a disorder of verbal processing (Vellutino, 1979; Stanovich, 1986). This notion has been widely accepted for a number of reasons. One, theories arising from this perspective make intuitive sense. Reading seems to be a predominantly linguistic skill since text is essentially language in written form. Therefore a difficulty in learning to read would be most likely to arise from a disorder at some level of linguistic processing. Two, many of the theories which are in line with this view are supported by good empirical evidence.

Although many language processes are involved in reading, one area which has become particularly deserving of investigation, for the study of dyslexia, is speech perception. There are several reasons for this. All language depends upon speech perception since speech is the building block upon which words are made. A deficit at the level of speech perception would be likely to hinder language learning and in turn, reading acquisition. That is, in order to be able to decode printed symbols the reader must be able to (1) establish phonetic or sound representations of those symbols, and (2) have a sophisticated awareness of the phonetic structure of words. Previous work has demonstrated that children who are poor readers have trouble using a phonetic code in processing language and lack a sophisticated awareness of the phonetic structure of words (Mann, 1984). It would seem that a deficit at the level of speech perception might contribute to these difficulties. That is, a perceptual difficulty might limit the degree to which one could become a masterful user of phonological information as is required in reading (Liberman and Shankweiler, 1979; Tallal, 1980).

It is the purpose of this study to investigate whether some poor readers have a speech perception deficit. Two related but differing views will be explored since they are particularly relevant to the study of speech perception in dyslexic children. One is that these children have a perceptual deficit that is specific to phonetic information. The other is that these children have a disorder of temporal perception (i.e. a difficulty processing brief information) that is based on a disorder of nonverbal perception. Such a deficit would affect phonetic processing because rapidly occurring information is characteristic of speech sounds.

This introductory chapter will be organized as follows: One, evidence will be presented that phonological processing plays a particularly important role in reading acquisition and that some reading disordered children have phonological deficits. Two, the view that reading disability may stem from a speech perception dysfunction will be discussed. A discussion about the complex nature of speech and the relationship between speech and print will be presented. In addition, studies of speech perception and dyslexia will be reviewed. Three, research will be reported to support an alternative view that reading disability may stem from a temporal deficit.

BACKGROUND OF THE STUDY

Dyslexia and Phonological Processing

Although it is generally agreed that many linguistic processes are important for reading, there is evidence that phonological processing plays a particularly significant role. This notion gains support from studies by Fowler, Liberman, and Shankweiler (1977) and Fowler, Shankweiler and Liberman (1979). In these studies the researchers analyzed the oral reading errors of beginning readers, reasoning that oral reading patterns might offer some information about the way printed words are processed. They found that when a child made consonant substitution errors the substituted consonant often shared one or two phonetic distinctive features with the intended consonant, e.g. the children would tend to substitute /t/ for /d/ (which shares two distinctive features, i.e. place and manner) rather than for

/f/ (which does not share these features with /d/). It was reasoned that since the errors were phonetically related to the intended consonants the readers must have coded the information phonetically. Further, the authors suggested that the input might be in a form that resembles a phonetic feature matrix.[1] Alternatively, when the children made vowel errors they tended to substitute phonological segments that had some relation to the orthographic pattern of the letters, i.e. they tended to substitute sounds that were orthographically possible if placed in a different context (e.g. they would be more likely to pronounce the segment (have) as /heIv/ than as /hɛv/, presumably because the phoneme /eI/ typically corresponds to the vowel spelling (a-e), while the phoneme /ɛ/ does not). The authors noted that the differences in the error patterns between consonants and vowels were congruent with the fact that they form different phonetic classes in speech.[2]

Additional evidence to support the view that reading involves phonological processing comes from studies which focus upon the contribution of short-term memory to the reading process.[3] For example, Conrad (1964, 1972) suggested that normally developing and mature readers code words phonologically when they read. In one of his studies

(1964), children aged three to six years were compared on a memory task in which they were required to recall sets of rhyming (R) and nonrhyming (NR) verbal items. The R set contained items such as _cat_, _rat_, _bat_. The other set, consisted of items such as _fish_, _spoon_, _girl_. Conrad found that up to the age of five, children recalled R and NR items equally well. However, children older than five, like adults (e.g. Baddeley, 1966), recalled NR items significantly better than R items; that is, they made more errors when recalling strings of items that rhymed than those that didn't. Conrad concluded that the older children must have processed the words phonologically since the phonological characteristics (rhyming) of the items appeared to adversely affect their performance. He reasoned that if these children were not using a phonetic coding strategy, they would not have been so sensitive to the phonetic characteristics of the words to be memorized. In contrast, the younger children were not affected by the phonetic characteristics of the rhyming set, i.e. they were apparently not using a phonetic code as effectively.

If it is the case that phonological processing is of cardinal importance in learning to read, then it would necessarily follow that reading disability in some children may be caused by a deficiency in phonological processing ability. There are a number of studies which lend support to this hypothesis. In general, two areas of research have focused upon this issue: one group of studies has shown that beginning poor readers are deficient in linguistic awareness of the phonetic structure of words (i.e. they seem to be less aware of the internal phonological structure of words, and thus find it difficult to analyze a word into its component parts); the other group of studies has shown that poor readers tend to be inefficient at using a phonetic code in short-term memory. A discussion of some representative studies will be presented below.

It has generally been found that poor readers lack an awareness of the phonetic structure of words. For example, when given words to rhyme (e.g. ball, mouse) poor readers have been found to be significantly less able to produce rhymes than good readers (Bradley and Bryant, 1978). Similarly they have been shown to be less aware of the sounds in words, e.g. that /kaet/ and /kau/ start with the same phoneme or that /kaet/ ends with /aet/ (Fox & Routh, 1975; Golinkoff, 1978; Rosner & Simon, 1971; Savin, 1972). Likewise Savin (1972) demonstrated that poor readers have greater difficulty learning phonological word games, e.g.

Pig Latin. In addition, it has been shown that tasks requiring the manipulation of syllables or phonemes in a word can predict future reading ability (Mann and Liberman, 1982). (This last study will be discussed in greater detail below.)

In addition to inferior metalinguistic skills, studies of reading ability and short-term memory have indicated that poor readers are less efficient at using a phonetic code in processing language. For example, Shankweiler and Liberman (1976) and Shankweiler, Liberman, Mark, Fowler and Fischer (1979) extended Conrad's (1964) studies (noted above) to groups of good and poor readers. These authors proposed that children with reading disabilities may have a problem using a phonetic memory strategy (i.e. coding incoming information phonetically). In their study second grade good and poor readers were given a task in which they were required to recall strings of consonants whose names rhymed (eg. BVTCP) and strings of consonants whose names did not rhyme (e.g. XWQRH). They found that the good readers were negatively affected by rhyme (phonetic confusability). That is, while they performed better than the poor readers on the nonrhyming lists their performance on the rhyming sets declined to about that of the poor readers. It was suggested that the poor readers made less effective use of phonetic representation since they did not profit from a reduction in phonetic confusability. This pattern was seen whether the stimuli were presented visually or auditorilly (Shankweiler, Liberman, Mark, Fowler and Fischer, 1979). Subsequent work by other investigators supported the view that poor readers perform poorly on tasks which required recall of other linguistic information. For example, Mann, Liberman and Shankweiler (1980) found that poor readers had short-term memory deficits for word strings and for sentences. In their study the subjects were again second graders with good and poor reading skills. This time they were asked to recall phonetically confusable and nonconfusable word strings (e.g. sing, ring, sting, king, wing v.s. slip, time, thought, pill, top) and also phonetically confusable and nonconfusable sentences (e.g. "Kate ate a steak and a plate of date cake that Jake baked." vs. "Sam drank a coke and a glass of fruit punch that Joan made."). The same pattern of results was demonstrated with both types of stimuli. The poor readers appeared to be relatively insensitive to rhyme, and thus to the phonetic characteristics of the stimuli.

Mann and Liberman (1982) investigated both linguistic awareness and phonetic coding in memory in poor readers. They found that reading success in first grade could be predicted by a child's performance in kindergarten on a task requiring phonological awareness (i.e. a syllable segmentation task in which the child was required to count syllables in a word by tapping) and on a verbal short-term memory task (where the child had to recall phonetically confusable and nonconfusable word strings). The children who became good readers in first grade (as measured by teacher ratings and subtests of the Woodcock Mastery Test) tended to be more "phonetically aware" (capable of segmentation), to perform better on the nonrhyming word strings (than on the rhyming strings), and to be more penalized by phonetically confusable words in both kindergarten and first grade. In contrast, performance on a nonphonetic short-term memory task (i.e. on Corsi blocks sequences; Corsi, 1972) did not correlate with first grade reading skill. The authors suggested that since phonetic coding was not required on the Corsi task, the poor readers were not deficient. That is, their nonlinguistic memory capabilities equaled that of the good readers. These findings were consistent with those of Liberman, Mann, Shankweiler and Werfelman (1982) who found that good and poor readers did not differ on tasks requiring short-term memory for faces or nonsence designs (see also Katz, Shankweiler and Liberman, 1981).

The reason why poor readers have difficulty with the phonological components of words is open to question. Shankweiler et. al. (1979) suggest that the deficits of poor readers might stem, at least in part, from a disorder in phonetic perception. They reasoned that if a speech signal was not adequately perceived, one would be inefficient at representing and retaining the phonetic information. They noted that a speech perception deficit would necessarily be subtle, and only appear with demanding techniques, since reading problems are often present in children who have no obvious speech perception difficulties. In particular it was suggested that synthetic speech sounds such as those used with adults be used to investigate this issue. The advantage of using tasks of this sort is that one has precise control of stimuli since a single acoustic cue can be varied. Further, linguistic redundancy and contextual cues can be virtually eliminated so that the task is demanding and stimulus-specific. To further discuss these issues, it will be necessary to digress a bit to consider the nature of speech and its relationship to reading.

Speech Perception

Researchers investigating the properties of speech have been extremely successful at isolating many of the acoustic cues which provide the basis for segmental (consonant and vowel) perception. Experimental work, beginning in the 1950's, commonly used synthetically manipulable spectrographic displays to analyze the sounds of speech. Procedures were developed whereby one would synthesize an approximation of a speech sound, make specific changes in portions of the acoustic signal and then observe the effect of the change on the identification of the sound. In this way many acoustic cues were identified which appeared to contribute critical information for the identification and discrimination of speech sounds. Three instances of cues that were discovered by using these techniques are shown in Figures 1, 2, 3. In all of the patterns, time is shown along the ordinate and frequency along the abscissa. In the first case the perception of the sound varies from /da/ to /ta/ with a change in the timing of the onset of the first formant[4] relative to the second formant. When the F1 occurs before or slightly after the onset of F2 /da/ is heard; alternatively, when F1 onset occurs after the onset of F2 /ta/ is perceived. The acoustic cue, therefore, is temporal in nature (Liberman, Delattre and Cooper, 1958). In the second case (Figure 2) the perception of the sound varies from /ba/ to /wa/ as the duration of the initial formant transitions increase. Listeners classically categorize the signal as /ba/ if the duration of the frequency change in the F1 transition is less than 40 milliseconds. When the duration of the frequency change is extended to approximately 40 to 50 milliseconds the syllable is perceived as /wa/. Again the cue is temporal in nature (Liberman, Delattre, Gerstman and Cooper, 1956; Miller and Liberman, 1979). In the last case (Figure 3), the perception varies from /ba/ to /da/ to /ga/ depending upon the direction of the F2 transition. If the F2 transition rises /ba/ is perceived; if the transition remains relatively flat /da/ is perceived; if the transition falls /ga/ is perceived. In this case the cue is nontemporal in nature, i.e. direction of F2 transition.

Speech is Complex & The Alphabet is an Abstraction From It

If it is the case that reading depends merely upon adequate speech perception, then why should it be potentially difficult to acquire? This will be elaborated upon below but in general the reasoning is that (1), there are a number of different characteristics of speech that make it complex and potentially difficult to process and (2), reading acquisition not only depends on this knowledge but requires an additional transformation that is not straightforward. Two reasons are first presented as to why speech is recognized as complex.

1) Speech is not a simple cipher, as is a phonetic alphabet where one sound is represented by a single letter, but is instead a code (Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967). Each segment of the acoustic signal cannot simply be converted to a corresponding speech sound in a one-to-one fashion. Rather, listeners must somehow restructure the information which the acoustic signal comprises in order to represent it phonetically. One reason for this is that phonetic segments are often tied together acoustically in the syllable, i.e. they are not discrete like alphabetic characters. Essentially, listeners must exploit the diverse acoustic properties which are scattered across the acoustic signal in order to form it into a phonetic percept. The following example discussed by Liberman, Mattingly and Turvey (1972) (see Figure 4) should make this point clear. The labial articulation /b/, which is the first phonetic segment in the spoken utterance

/baeg/, is represented in the acoustic signal by the initial two-thirds of the second formant. It spans the first and middle sections of the spectrographic display of the acoustic signal. That this is so can be shown by the fact that if the utterance is changed from /baeg/ to /gaeg/ there is a corresponding change in the display at the first two thirds of the second formant. The same holds true for the final consonant /g/, at the second two thirds of the second formant. Similarly, the vowel /ae/ is represented throughout the second formant which extends across the entire utterance. Again, if the vowel is changed from /ae/ to /i/ the entire formant is altered. Thus phonetic information about each segment is smeared across the entire syllable and much of the information about the adjacent segments contained in the signal is presented to the listener simultaneously.

2) Speech segments do not occur in specific unvarying forms. The acoustic structure of a speech sound can vary depending on the person who is producing it or the context it is produced in. Rate of articulation can also influence the acoustic shape. The perceptual reality of some of this was demonstrated in a simple experiment (as described in Denes and Pinson, 1963). A group of adults was presented

with a word which was placed in different linguistic contexts. The listeners identified the word as "bit", "bet", or "bat" depending upon the context. So although the acoustic structure of the presented word did not change, the listener's perceptions did. Thus, one can see that the signal is highly and complexly encoded; there is no strict one-to-one correspondence between the acoustic and phonetic representation of the linguistic message and the shape of the phonetic segment is highly influenced by its context. It seems that linguistic information is represented at two levels of processing in different forms and the task of the listener or speaker is to produce the complex match. In order to perceive the acoustic signal in a linguistically relevant way, some type of recoding must take place. (Liberman, 1970; Liberman, Mattingly and Turvey, 1972).

Although an alphabetic orthography represents speech, it is actually an abstraction from speech and the relationship can be difficult for the child to interpret (Liberman, 1982). Some of this comes from the fact, as noted in this chapter, that phonemes are not represented as discrete segments in the acoustic stream, as they are in the alphabet. For example, although the word "cat" is represented in one segment in the acoustic signal, the beginning reader must learn to divide it into three phonetic segments (i.e. cuh, a, tuh ([kʰə] + [æ] + [tʰə])). However the process becomes even more complicated in that the segments have to then be recombined. If the child merely reads letter by letter s/he might attempt to connect cuh, a, tuh [kʰə] + [æ] + [tʰə]) and read cuhatuh ([kʰəætʰə]). The child must come to realize that the three segments must, in a different way, be recombined. Thus, in practice, the beginning reader must be able to both isolate and chunk the relevant information. This is a skill that is above and beyond that required by the listener. For example, the competent listener can hear the difference between the words "cat" and "hat" yet be completely unaware that they are each composed of three phonemic segments. Further, the listener does not have to become consciously aware that the initial phonemes differ. However, the beginning reader must be explicitly aware of these facts, especially during the decoding stages of reading. This skill requires linguistic awareness, and as noted previously, poor readers appear to lack such awareness (Mann, 1984).

In order to become a sophisticated user of phonological information and make the link between speech and written language it would seem necessary to be keenly aware of speech sounds. In particular, it is suggested that a child should have perceived speech well and have stored the sounds s/he perceived in reliable form. Using this store, the beginning reader could then link what s/he sees with what s/he knows. If the child has difficulty in the perception of these sounds then it would seem to follow that problems would arise in reading.

Phonetic versus Auditory Processing

The notion that reading disability is a language related disorder, i.e. specific to speech, comes from studies comparing readers on verbal versus nonverbal tasks as noted above. The distinction made between language and other auditory information comes from a comparison of psychophysical and phonetic studies of speech perception. Some of this literature will be reviewed here.

It has often been suggested that speech perception requires a special mode of processing which is distinctly different from that which is required for auditory processing. Researchers in support of this view generally partition sounds into those which are linguistic and those which are not. The psychological reality of this distinction can be seen to some extent in the following example. Although the encoded sounds of speech are transmitted in an acoustic form they are not perceived as auditory stimuli. That is, one does not hear, for example, the frequency changes in the formant transition of the stop consonant. Instead a linguistic event is heard. If however, the formant transition is isolated, it is heard as a chirp or glissando and the linguistic event mysteriously disappears. Thus two percepts are derived from the same acoustic signal (Liberman, Mattingly and Turvey, 1972). Additional evidence for the reality of the phonetic-auditory distinction is given by studies demonstrating the phenomenon of categorical perception (Studdert-Kennedy, Liberman, Harris and Cooper, 1970). It has been consistently shown that listeners tend to perceive encoded speech sounds as "categorical linguistic events". They tend to discriminate consonant sounds that are perceived as belonging to different linguistic categories and they do not clearly discriminate sounds belonging to the same linguistic category, even though the physical differences between the members of the two sets of consonants are the same. This type of responding is qualitatively different from they way nonspeech sounds are perceived. In nonspeech, many more stimuli can be discriminated than can be labeled and the ability to discriminate is not usually dependent on categorical identification.[5]

Speech Perception and Dyslexia

As noted above there is considerable evidence that some poor readers have difficulty with the phonetic aspects of language. Why this is so remains to be determined. It is conceivable that the problem lies in the perception of speech (i.e. the acoustic cues) as noted above. Clearly the problem must be subtle since reading disordered children often do not evidence obvious oral language difficulties.

In support of the theory that poor readers have some deficit at the level of speech perception, Brady, Shankweiler and Mann (1983) found that while good and poor readers performed similarly on a speech perception test in quiet, they performed differently when noise was added. That is, poor readers performed significantly worse than their better reading peers when speech was placed in noise. Thus, when their perceptual capabilities were stressed (the speech signal was degraded) they had problems. Apparently their speech perception skills were less efficient than those of good readers. Further, the difficulty could not be attributed to group differences in vocabulary level: words of both high and low frequency of occurence were used, and the effect of this variable was comparable for both reading groups. In addition, the authors suggested that the perceptual deficit was specific to speech since the groups did not differ on an "environmental sounds" perception test. In a more recent study, Brady, Poggie, and Merlo (1985) found that poor readers also have difficulty perceiving speech presented without noise if the stimuli are phonetically demanding. Good and poor readers were compared on repetition tasks which varied in difficulty: monosyllabic, multisyllabic, and pseudoword stimuli were employed. While the groups were found to perform comparably on the monosyllable words, the poor readers performed significantly worse than the normal readers on the multisyllable and pseudoword stimuli.

One way to study perceptual processing in good and poor readers is to look at categorical perception. There have only been a few studies which have attempted to do this. These studies have used identification and discrimination speech tasks to investigate the relationship between dyslexia and speech perception and their results are conflicting (Brandt and Rosen, 1980; Godfrey, Syrdal-Lasky, Millay and Knox, 1981). Brandt and Rosen (1980) compared the performance of 12 dyslexic and 4 normal reading controls, ages 8-12, on CV syllable identification and discrimination tasks. One series varied from /da/ to /ga/ in eight steps by equal increases of the starting frequency of the third formant. The other series varied from /ba/ to /da/ by changes in the starting frequencies of the second and third formants. The investigators did not find significant differences between the dyslexic and normal reading groups on either of the speech perception tasks. However, Godfrey, Syrdal-Laskey, Millay and Knox (1981) suggested that the statistical analyses were incomplete in the Brandt and Rosen study and that a perceptual difference in performance between the groups seemed likely from an inspection of their published data. They noted for example, that in the Brandt and Rosen study the discrimination peaks of the dyslexic subjects were lower than those of the normal subjects. However, the only statistical comparison that Brandt and Rosen made on the discrimination test was correct "same" discrimination response. The only group comparison that they made on the identification tasks was that of phoneme boundaries. Using the same types of stimuli as that used in the Brandt and Rosen study Godfrey et. al. compared the performance of 17 dyslexic children and 17 normal reader controls, ages 7-15. Reading level was assessed with the Boder Test of Reading-Spelling Patterns (1973) and the dyslexic children were classified into dysphonetic and dyseidetic groups by Boder's methods. (Boder's test is designed to differentiate among children whose errors on reading and spelling tests can be ascribed to auditory and phonetic confusions (dysphonetic), visual and spatial confusions (dyseidetic) or both (mixed dysphonetic-dyseidetic). Godfrey et. al. found that the dyslexic group differed from the normal reading group on every speech perception task: 1) they were not as consistent in their classification of the stimuli; 2) they did not discriminate as well between stimuli from different phonetic categories. However, no differences were found between the dysphonetic (N=11) and dyseidetic (N=6) groups. (Apparently none of their subjects fit the criteria for the mixed group). The authors also found that the dyslexic children were better able to perform with the /ba-da/ as opposed to the /da-ga/ stimuli. The authors suggested that the extra cue (two formant changes rather than one) in the /ba/-/da/ series made the perceptual differences easier to detect. Finally, the groups did not differ on an environmental sounds task which supported the conclusion that the deficit in the dyslexic group was specifically phonetic in nature.

Godfrey et. al. noted that the shapes of their functions and the differences between the groups appeared similar to those reported by Brandt and Rosen.

Godfrey et. al.'s findings, in light of the research reported in Chapter I (i.e. that some poor readers have phonological processing difficulties) is particularly interesting. Further, their argument against the Brandt and Rosen study seems reasonable. However, additional investigation is required to resolve the issue of whether dyslexic children do in fact have trouble with categorical perception of speech.

Temporal Processing and Dyslexia

From the above work, it seems reasonable to propose that a reading disorder may be related to some dysfunction in speech perception, i.e. in the ability to perceive relevant acoustic cues which are embedded in a speech signal. Tallal and her colleagues (1973, 1974, 1975, 1976, 1980a, 1980b, 1981, 1983) propose an alternate, although related, view. They have published a series of research studies examining deficits first in language disordered, and then reading disordered subjects. As in the literature reported above, they suggest that reading disability can be seen to covary with deficits of speech perception. However, they theorize that the dysfunction is specifically temporal in nature. In particular they suggest that there exists a subgroup of dyslexics who are unable to process "brief or rapidly changing temporal events." These children appear to have difficulty analyzing auditory information at a normal rate and are thus constrained by the speed of their auditory processing. Further they suggest that the deficit is perceptual in nature rather than purely linguistic. However, the deficit is evident in linguistic processing because rapidly changing events are characteristic of many of the segments in speech sounds, e.g. the formant transitions associated with stop consonants. In addition, they suggest that this perceptual dysfunction in discrimination contributes to the deficits seen at higher levels of processing, e.g., sequencing and memory. Central to this thesis are studies of nonverbal perception. A digression describing this work should help to elucidate this point of view.

Numerous investigators have stressed the importance of temporal processing in aphasic and reading disordered children. As early as 1937 Orton suggested that the speech and language problems of children stemmed in part from a difficulty in auditory temporal sequencing, i.e. recalling sounds in their proper order. Using a paradigm developed by Efron (1963), Lowe and Campbell (1965) found that dysphasic children (diagnosed on the basis of psychometric and language evaluations) were impaired as compared to normal developing children on a temporal processing task. Whereas the normally developing group needed an interval of 15 to 80 milliseconds between two tones to indicate which came first, the dysphasic children needed 55 to 700 milliseconds. Similar findings had been observed with adults, e.g. aphasics (noted as having left hemisphere lesions) generally required more time than normal controls to make judgements about the order of sounds (Efron, 1963). Zurif and Carson (1970) extended this type of work to poor and normal readers. The poor readers were approximately one grade behind and the normal readers were at grade level on the Gates Reading Test. They found that the poor readers had difficulty with temporal information, i.e. these children were inferior to normal readers at judging whether two quickly tapped rhythmic patterns (of increasing length) and also two series of light flashes (with an increasing number of beats) were the same or different. Similarly, Corkin (1974) found that poor readers (selected on the basis of teacher ratings) had serial ordering deficits. When compared to average readers, these children performed less well at correctly recalling the serial position of visual (order of cubes tapped) or auditory (strings of digits) stimuli after a short delay.

Tallal and her colleagues (1973, 1974, 1975, 1976, 1980a, 1980b, 1981, 1983) used a nonverbal operant conditioning paradigm to investigate dysphasic, and later reading disordered, children's abilities to identify (detect), discriminate/associate, sequence, and recall sounds. In the initial studies the sounds used as stimuli were complex tones composed of frequencies within the speech range (1973, 1980). They were generated at three formant frequencies and differed only in their fundamental frequency. In what Tallal referred to as the detection test the child was trained to press one panel in response to one tone and another panel in response to a different tone. Then in what was referred to as the association test, the tones were presented in random order and the child was instructed to press the appropriate corresponding button. In the sequencing task the child was presented with the tones in pairs and was required to reproduce the order of the tones by pressing two corresponding buttons. In a set of tasks which did not require a sequential motor response, and which was referred to as the Same Different Method, the child was again presented with the tones in pairs. This time the child indicated (by again pressing buttons) whether the two tones were the same or different. (The recall tasks will not be discussed here.) On some of the trials on the paired tasks the interstimulus interval (ISI) between the tones was held constant at 428 milliseconds. In other trials the ISI was varied and placed at either 8, 15, 30, 60, 150, or 305 milliseconds. By varying the ISI's and also the duration of each tone (using either 75, 125, 175, or 250 millisecond items), the authors thus varied the rate at which the children were required to process the information.

In their initial study Tallal and Piercy (1973) compared the performance of normal developing and dysphasic children on these tasks. The dysphasic group was diagnosed on the basis of a variety of expressive and receptive language tests. (Of note is that it is not clear whether these subjects were clinically different from Lowe and Campbell's (1965) group.) Both groups had normal nonverbal intelligence as measured by the Ravens Progressive Matrices Test. In each study the dysphasic children were significantly impaired, in comparison to the normal group, on the tasks involving rapid perceptual processing. Further, it was found that poor performance by the dysphasic group on the paired tests, was directly related to the rate of presentation of the two items. That is, the children in the experimental group were incapable of processing two brief tones (75 milliseconds in duration or less) or tones seperated by short ISI's (150 milliseconds or less). When the rate was reduced, either by increasing the duration of the tones or the ISI between the tones their performance improved. For example, if the tones were 175 milliseconds in duration then the children needed an ISI greater than 15 milliseconds to process the information. This was the case whether sequencing was required or not. Thus it appeared that the dysphasics were unable to perceive the auditory information at a normal rate, and it was suggested that time was the critical factor. Further, Tallal reasoned that if the experimental children could not adequately perceive the items, then they certainly could not perform higher level operations on them, e.g. sequence them. Therefore they suggested that a deficit in sequencing was secondary to a deficit in perception of the information.

Tallal and Piercy (1974, 1975) then extended their research to include verbal stimuli (stop consonant syllables and vowels). They hypothesized that if these children did in fact have a temporal deficit then it might show up on tasks which required the processing of verbal information since some segments in speech occur rapidly in time, e.g. the brief (approximately 50 milliseconds) formant transition which is the critical cue for the perception of the stop consonant. They used the same procedures and apparently the same subjects as in their prior (1973) study. Consistent with their notions these studies revealed that the dysphasic children had difficulty processing (i.e. discriminating and sequencing) consonant-vowel syllables (C-V) with formant transitions of 43 milliseconds but had no problem when the transitions were extended to 95 milliseconds or longer. The same held true for brief steady state vowels and stimuli which comprised an initial vowel of 43 milliseconds (steady state) connected to a different vowel (steady state) of 207 milliseconds. Thus, these findings were consistent with their early studies using tones (described above) and with their suggestion that the deficit was in auditory temporal perception.

Using the same basic procedures with tones described above, Tallal (1980a, 1980b) investigated these temporal processing issues with reading disordered groups. Tallal hypothesized that a deficit in auditory perception would affect a child's ability to acquire phonic skills in reading. In this study, the poor readers were reading at least one year below grade placement and the normal readers were reading at or above grade as measured by the Metropolitan Reading test. All the children were of average to above average intelligence as measured by the Wechsler Intelligence Scale for Children-Revised. In addition to the tone tests, the reading disabled children were given the Nonsense Word Production subtest of the Kennedy Institute Phonics Test in order to assess their ability to use phonics rules in reading. Consistent with her hypothesis, Tallal found that some of the dyslexic children had deficits on the auditory perceptual tasks. She foound that, when the ISI between the tones was reduced, 45 percent of the reading disordered group performed poorly. This was the case for both the discrimination (when temporal order was not required) and sequencing (when temporal order was required) tasks. She concluded that some poor readers have a difficulty with temporal perception. In addition, Tallal found that the reading disordered group's performance on the tone tests correlated with their ability to decode nonsense words. Tallal concluded that some reading disordered children have temporal processing deficits which affect their ability to learn phonics and to read.

There have only been a few studies in which the authors have attempted to replicate the results of Tallal's et. al.'s work on language impaired populations (Blumstein, S.L., Tarttre, V.C., Nigro, G. and Statlender, S., 1984; Riedel, K., Studdert-Kennedy, M., 1985). The authors of these studies have used a different paradigm, but, in my opinion, tested the theory. For example, Riedel and Studdert-Kennedy investigated missile-wounded left brain damaged fluent and nonfluent aphasics' ability to identify and discriminate CV syllables (/ba/ and /da/). They questioned whether performance would improve by 1) extending formant transitions and 2) increasing the ISI between syllables, as had been shown by Tallal (Tallal and Newccmbe, 1978). They did not replicate her findings and found no evidence to support her thesis. The aphasics' performance on the identification tasks did not improve as a result of formant transition extensions. Further, there was no difference in performance between the 50 and 500 millisecond ISI conditions, by the group or individuals, on the discrimination task. In fact, some aphasics performed better in the shorter ISI condition.

It should be possible to test the hypothesis that poor readers have deficits in temporal perception using a paradigm slightly different from that used by Tallal. Poor readers should perform less well than normal readers on identification and discrimination tasks in which the acoustic cue is purely temporal in nature (this will be elaborated below). In addition, one would imagine that a temporal-related deficit of this sort would also be evident on a task in which speech is compressed in time. That is, an increase in the presentation rate of speech simuli should impair speech perception in children who have temporally disordered systems. A study of this sort, using a time compressed speech task was performed by Freeman and Beasley (1978). They presented monosyllabic words that were of normal duration and also monosyllabic words that were time compressed to 60 percent of normal duration to a reading disordered group and to a control group. The reading impaired children were at least two years behind their grade equivalent on the Lindamood Auditory Conceptualization test and on a reading performance index developed by the school. (Although not noted, it is assumed that the control group was reading at least at grade level, since they were referred to as normal readers.) The authors found that, in general, the reading impaired group performed significantly worse than the normal readers (i.e. on the normal duration and 60 percent condition combined). In addition, they reported that, in general, the children performed significantly worse at 60 percent time compression. Although it was noted that the mean difference between the normal duration and 60 percent condition was greater and more variable in the reading disordered group, no mention was made as to whether the difference between the groups on this difference measure was statistically significant. Thus, in terms of temporally related issues, their results merit further investigation.

Proposal

As we have seen, there is considerable evidence that some poor readers have difficulty with the phonetic aspects of language. Why this is so remains to be determined. It is conceivable that the difficulty lies in the perception of speech. If so, the problem must be subtle and only be revealed by demanding tasks since many reading disordered children do not have obvious language disorders. In addition, it is conceivable that the difficulty would be evident on tasks which require temporal processing since temporal factors have been emphasized for their role in speech perception and dyslexia.

The aim of this study was to investigate whether some poor readers have a deficit of phonetic and/or temporal perception. Two related but differing hypotheses were investigated. The first is that dyslexic children have a perceptual deficit that is specific to phonetic information. The second is that dyslexic children have a disorder of brief temporal processing that is not specific to phonetic processing but is in fact based on a deficit of nonphonetic or auditory perception. The dysfunction is related to language because rapidly occurring information is characteristic of speech sounds. To this end, dyslexic and normal readers were compared on four sets of tasks: three were speech and one was nonspeech. All required temporal processing. They are described below.

In order to investigate a possible phonetic and temporal perception deficit in reading disordered children a /ba-wa/ contrast was used. The /ba-wa/ continuum was a natural choice since the critical acoustic cue distinguishing between these two consonants is temporal in nature, i.e. the duration of the formant transitions. In order to keep the difference between the contrasts, in this experiment, at a minimum, only the first formant transition was manipulated. The transition ranged from 30 to 100 milliseconds in 10 millisecond steps. Ten milliseconds was chosen as an appropriate difference between stimuli in order to enable listeners to perceive a difference between the shortest and longest sounds of the control stimuli (elaborated below) while keeping the range within the limits found in natural speech. Thirty milliseconds was chosen for the short end of the continuum in order to keep the transition brief and thus test for a specifically temporal deficit, as in Tallal's work.

If the reading disordered children have a phonetic deficit then they should perform poorly on this continuum.

If the deficit is temporal in nature, as Tallal suggests, then they should not only perform poorly on this continuum but in addition, they should respond to the /ba-wa/ continuum in a particular way. For example, they should identify more stimuli as /ba/ than as /wa/, as compared to the controls, since they presumably need more time to process information. The duration of the formant transition will have to be relatively long (e.g. greater than 95 milliseconds) for them to label the stimuli as /wa/. The phoneme boundary should be displaced (to the right) in the dyslexic group's identification functions. In addition the slopes of the functions in the dyslexic group should be shallower than in the normal group.

The subjects in this study were also tested on a Voice Onset Time (VOT) continuum. The complex of acoustic cues accompanying VOT was chosen for study for a variety of reasons. First, this speech continuum served as another test for a phonetic perception deficit hypothesis. If the difficulty is phonetic in nature, then the reading disordered children ought perform poorly on this task as on the /ba-wa/ continuum. However, this continuum may not be as difficult for the reading disordered children to perceive as the /ba-wa/ continuum because more cues alert the listener to the identity of the consonant.[6] Further, the synthetic stimuli more closely resemble the acoustics of natural speech, and are therefore presumably less stressful to the perceptual system. Second, this continuum served as another test of temporal processing since the predominant acoustic cue is temporal in nature. As in the /ba/-/wa/ continuum there should be a displacement of the phoneme boundary and a difference in slope as compared to the normal readers.

Third, VOT is an interesting acoustic cue since it appears to be of universal perceptual significance (i.e. perceived by many if not most cultures). Lisker and Abramson (1964) found that, in the eleven languages they investigated, speakers accurately distinguished between their various stop consonant categories on the basis of VOT. (Transition duration also appears to be a universally significant cue although it has not been nearly as much investigated as VOT). Further, it has been suggested that sensitivity to the voicing classes might be mediated by innate mechanisms (Eimas, 1971, 1974; Aslin, Pisoni, Hennessy and Perey, 1979). VOT seems to be used as a perceptual cue by infants as well as by adults. That is, infants have been found to be able to discriminate synthetic speech sounds that differ in VOT in the same way that adults do. In addition, the discrimination seems universal in that infants were found to have similar category boundaries regardless of their parents' language. As development proceeds, the category boundaries become consistent with the native language. Eimas (1971) has suggested that the auditory system of the infant is innately hardwired to perceive this acoustic-linguistic parameter and that the process is eventually altered by experience.

The isolated first formant transition of the /ba-wa/ continuum was included as a nonspeech, temporally dependent control. In initial exploratory work it was found that the stimuli were not perceived as speech, but instead as bleeps. Subjects referred to them as short or long sounds. This continuum was included to test the hypothesis that a deficit (phonetic type) on the speech continua is specific to speech and further, that the disorder is not purely temporal in nature, as Tallal suggests. If the deficit is specific to phonetic information then the reading disordered children should perform similarly to the children in the control group on the F1 continuum. If the deficit is temporal in nature then they should perform less well than the control group. That is, they should not be able to discriminate as well between the formants of differing duration.

A two interval AX procedure was used for the discrimination tasks. This paradigm was chosen as opposed to others (e.g. ABX) because it has been reported to be easier for children (Wolf, 1973) and appears to place fewer demands on memory (Pollack and Pisoni, 1971).

A test of time-compressed speech was included to further examine whether these children have difficulty processing rapidly occurring information. If the dyslexic children do have trouble processing information that occurs rapidly in time as Tallal suggests, then they should perform poorly, as compared to normal readers, on stimuli which are time compressed. To investigate this, phonetically balanced lists of time compressed monosyllabic words were used as stimuli. Two amounts of time compression were used, 30 and 60 percent.

Reading skill and strategy was assessed with tasks that required the reading of isolated words, rather than words in connected text. Single word tasks were chosen in order to minimize the meaningful contextual cues, inherent to connected text which would reveal the identity of a word.

In this way decoding skill was emphasized. In this regard, it is relevant to note that Shankweiler and Liberman (1972) found that children's skill at reading isolated words was highly correlated to success at reading connected text.

The children's reading strategies were analyzed using the Boder Test of Reading-Spelling Patterns (1982) to compare the performance of clinically identified dyslexic subgroups, i.e. a dysphonetic, dyseidetic and mixed dysphonetic-dyseidetic group. It was proposed that those children whose errors reflected phonetic confusions would have trouble on the speech tasks while those children whose errors reflected visual confusions would perform similarly to the normal readers. As noted above, the Boder test is designed to determine whether dyslexic children attempt to read and spell using a phonetic approach, thereby revealing skill in this domain (dyseidetic) or whether they lack phonetic skill and rely on a more visual approach (dysphonetic) or whether they lack both phonetic and visual skill (mixed dysphonetic-dyseidetic).[7] Boder defined the dysphonetic reader as a child who typically has a limited sight vocabulary of words and who reads words globally rather than analytically. In contrast, the dyseidetic reader reads by sounding out words and typically fails to read words that don't have grapheme-phoneme correspondence. In contrast to the dysphonetic reader who reads quickly, this type of reader reads slowly as if seeing each word for the first time. The mixed dysphonetic-dyseidetic reader has trouble reading globally and analytically and therefore is the most disabled of the three types of readers.

Footnotes

1 A distinctive feature system is a scheme for classifying speech sounds. Classically, the speech sounds are defined according to the way they are produced (i.e. articulated). For example, a consonant can be distinguished in part by whether, in production, the tongue is pressed against the alveolar ridge or the back of the palate. Theoretically, the articulatory processes correlate with the acoustic characteristics of the sound.

2 In speech perception, consonants are perceived categorically whereas vowels are less clearly categorized. Further, vowels are less stable than consonants, i.e. they are more subject to phonetic variation across individuals and dialects.

3 Short term memory, although not the focus of the present study, is clearly of primary importance for and intimately related to the phonological processing of both written and spoken language. The listener or reader must be able to hold on to bits of phonological information in order to comprehend messages.

4 Resonances of the vocal tract are referred to as formants, and their frequencies are referred to as the fomant frequencies. They are dependent on the shape of the vocal tract.

5 Categorical perception occurs with the perception of items which vary according to place of articulation, manner of articulation and voicing class. However, isolated steady state vowels (Pisoni, 1971), F2 transitions (Mattingly, Liberman, Syrdal, and Halwes, 1971) and nonspeech sounds tend to be perceived less categorically, or are instead perceived more continuously, similar to what is usually the case in psychophysical studies of nonspeech. Although some studies have shown that continuous and categorical types of responding can occur on the same stimulus patterns, what seems clear is that for some sounds, categorical perception is most likely to occur when the listener is interpreting the stimuli as speech, i.e. when he is responding in a "speech mode". For further discussion of these issues, the reader is referred to Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967; Pisoni, 1973).

6 Although VOT is a temporal cue (classically

described as the time from plosive release to glottal vibration), other cues serve to alert the listener as to the identity of the consonant. These cues commonly work in concert but have also been shown to be sufficient to distinguish the voicing contrast. They include: the presence of absence of aspiration during the VOT interval (Summerfield and Haggard, 1974), the onset frequency of the F1 transition (Stevens and Klatt, 1974) and the rise of the F1 transition (Cooper, Delattre, Liberman, Borst, and Gerstman, 1952).

7 The children are separated into groups on the basis of their reading and spelling patterns. Three items are relevant for deciding on group membership: 1) the percentage of words which are read correctly that are spelled correctly; 2) the percentage of words which are not read correctly which are spelled as good phonetic equivalents; 3) the Reading Quotient (RQ). The RQ is calculated as follows: (Boder reading grade level + 5/chronological age) x 100. If the following is true then the child is classified as dysphonetic: 1) the child is unable to spell at least 50 percent of the words which he is able to read; 2) the child is unable to spell words which he cannot read using a good phonetic equivalent; 3) the RQ is greater than or equal to 67. If (1) and (2) are true but the child has an RQ lower than 67 then the child is classified as mixed dysphonetic-dyseidetic. If the following is true then the child is classified as dyseidetic: 1) the child is unable to spell at least 50 percent of the words which he is able to read; 2) the child is able to spell at least 50 percent of the words which he cannot read using a good phonetic equivalent; 3) the RQ is less than or equal to 80.

METHOD

Subjects

The subjects were children from public and private schools in the New York City metropolitan area. Four reading specialists were asked to select good and poor readers, between the ages of seven and nine, from their respective school or private practice. (An attempt was made to keep the age range of the subjects to a minimum since there is evidence that speech perception skills change through early childhood (Goldman, Fristoe and Woodcock, 1970)). In some cases the normal readers were children of friends of the author. Nineteen children (eleven normal readers and eight poor readers), served as subjects in the study. The poor readers were at minimum five months delayed in reading as measured by the average of their scores on the Woodcock Reading Mastery - Word Attack and Word Recognition subtests (mean reading grade level=2.5). The normal group was at or above grade level in reading (mean grade level=6.4). The mean age for both groups was 8.7 years. The groups were equated on intellectual functioning with the Ravens Coloured Progressive Matrices. The mean Raven's score for the dyslexic group was at the 85th percentile and for the normal readers at the 89th percentile. There was no significant difference betweeen the groups on the Ravens test. (See Table 1 and 2 for the individual children's age, grade, IQ and reading level). Only children with normal peripheral hearing as measured by a standard audiometric battery were included in the study. All children came from at least upper middle class homes. In addition, any child with documented psychiatric difficulties was excluded from the study. Twelve children did not meet at least one of the criteria and were therefore excluded from the study. In addition, due to fatigue, one of the dyslexic and one of the normal children did not participate in the set of nonspeech tasks, two of the normal readers did not participate in the set of /ba/-/wa/ tasks.

Stimuli

The discrimination and identification test stimuli were recorded onto reel-to-reel tapes. They were generated on a parallel resonance synthesizer at Haskins Laboratories.

There were three identification continua each with eight syllables and three discrimination continua each with five pairs of syllables. Of these continua, there were two sets of speech and one set of nonspeech tasks. Each syllable in the speech series was 360 milliseconds in duration and composed of two formants. The utterances in the nonspeech set were composed of one formant. The syllables in one of the speech series ranged from a stop consonant /ba/ to a semivowel /wa/. The first formant of each syllable consisted of an initial formant transition which varied in duration from that appropriate for /b/ to that for /w/ and a subsequent period of steady-state appropriate for the vowel /a/. The duration of the transitions varied from 30 to 100 milliseconds in 10 millisecond steps. As the duration of the formant transitions increased, the duration of the steady state formants decreased in order to maintain the syllables' duration at 360 milliseconds. For all stimuli the second formant consisted of an initial formant transition appropriate for either /ba/ and /wa/ and a subsequent steady state appropriate for the vowel /a/. The duration of the second formant transition was 90 milliseconds.

The first and second formants started at 100 and 616 Hz. respectively and rose linearly to steady state values of 769 and 1232 Hz. respectively. The fundamental frequency rose linearly from 90 Hz. to 110 Hz. in 50 milliseconds and then gradually decreased across the syllable to 90 Hz.

The syllables in the second speech (VOT) series ranged from a /da/ to a /ta/. They consisted of formant transitions appropriate for an alveolar stop, and a steady state segment appropriate for the vowel /a/. The change in VOT was accomplished by cutting back the first formant transition and simultaneously exciting the second formant transition with noise rather than a periodic signal. The stimuli varied from a VOT of 0 to +70 in 10 millisecond steps.

The first formant of the first syllable started at 234 Hz. However, since F1 was cutback for each stimulus in the series there was a corresponding increase in F1 onset. All of the first formants rose linearly to a steady state value of 769 Hz. The second formant started at 1848 Hz. and fell to a steady state value of 1232 Hz.. The fundamental frequency contour was the same as for the /ba-wa/ continuum.

The nonspeech series was composed of the varying first formant transitions of the /ba/-/wa/ continuum. Subjects were asked to identify the stimuli as "short" or "long".

All of the stimuli were digitized at a 10 kHz sampling rate by the pulse code modulation (PCM) system at the Haskins Laboratory. An identification and discrimination task was created with the stimuli from each set. Each identification task consisted of eight tokens of each stimulus, totalling 64 items. The items were randomized and divided into eight equal blocks of eight stimuli. There was an inter-stimulus-interval of 3 seconds and an inter-block interval of 8 seconds. Each discrimination task consisted of twenty pairs of stimuli with eight repetitions of each pair totalling 160 pairs. The sets included five pairs of stimuli differing by 30 milliseconds along each continuum (i.e. 10-40, 20-50, 30-60, 40-70, 50-80) and each pair had four arrangements (e.g. 10-40, 40-10, 10-10, 40-40). The pairs were randomized and divided into ten blocks of sixteen pairs. There was a one second interval between the items in each pair and a three second interval between each pair.

In order to familiarize the subjects with the stimuli three tokens of each endpoint (i.e. stimulus 1 and stimulus 8) were presented prior to the identification task. In order to make sure the subjects understood each task a criterion test was given. The criterion series for the identification tasks consisted of twelve tokens of each endpoint stimulus (i.e. stimulus 1 and stimulus 8) totalling 24 items. The 24 tokens were randomized. The criterion test for the discrimination tasks consisted of four pairs of endpoint stimuli with four repetitions of each pair (i.e. stimulus 1 paired with stimulus 8; stimulus 8 paired with stimulus 1; stimulus 1 paired with stimulus 1; stimulus 8 paired with stimulus 8). The items were randomized.

The stimuli used for the time compressed speech conditions included tape recorded versions of two lists of the WIPI obtained from AUDITEC of St. Louis. The lists consisted of monosyllable words, suitable for young children. One list was time compressed to 30 percent and the other to 60 percent of original time. (The technique of time compression increases the rate of speech by eliminating small sections of the speech signal within words and combining the remaining acoustic energy. In this method rate is altered but the frequency components of the words are preserved (Rintelmann and Lynn, 1984)).

Procedure

The identification, discrimination and time compressed speech tests were presented on a Tandberg TC20A reel to reel tape recorder through TDH39 headphones in a quiet room.

At the first session the children received the Ravens Coloured Progressive Matrices, the Woodcock Reading subtests, the peripheral hearing exam, one set of identification and discrimination tasks and the WIPI Time Compression Speech Test. At the second session they received the Boder Test of Reading and the last two sets of identification and discrimination tasks. The Ravens, Woodcock and Boder tests were administered in the standard format. In the WIPI test the children were asked to repeat the words they heard. In the identification test the children were asked to label the items as either, for example, /da/ or /ta/. For the nonspeech set they were asked to label the items as "short ones" or "long ones". Their responses were recorded by the experimenter. The children were introduced to the perceptual tasks in the following way, following an instructional procedure designed by Wolf (1973).

> "Have you ever heard a robot talk? (Child's response) Well, I have some sounds that a robot made. This robot can only say two things: he says ba and wa. Can you say that? (Child's response) I want you to listen very hard to what the robot says, and then say the very same thing. When he says ba, you say ba; when he says wa, you say wa. Okay? You say exactly what the robot says.

In the discrimination test the children were asked to state whether the sounds they heard were "exactly the same" or "a little bit different". The responses were recorded by the experimenter.

In the nonspeech tasks the children were told that the robot would say long and short sounds, not "letters". It was emphasized that the sounds were not speech.

Twelve consecutive correct responses were required to "pass" the criterion tasks. None of the subjects failed to meet this criterion.

On all the tests, the children were asked to guess at the answer when unsure. Further, they were intermittently reinforced with stickers. The test tapes were stopped occasionally in order to give the children rests.

Results

The results of the identification task for the /da/-/ta/ continuum are displayed in Figure 5 for the normal reading and dyslexic group. The 8 stimulus values of the continuum are on the abscissa and the percentage of tokens of each stimulus labeled as /da/ is on the ordinate. As can be seen in the figure, the data indicate that subjects in both groups systematically classified stimuli with shorter VOT values as /da/ and those with longer VOT values as /ta/. Further, the slopes of the functions in the region of the category boundaries are characteristically sharp. These findings are consistent with previous research.

The results indicate that the groups did not differ in their ability to identify the stimuli, i.e. both groups were able to respond categorically. This was confirmed with a repeated measures analysis of variance with group as the between subjects factor, stimulus as the within subjects factor and the percent of times a stimulus was identified as /da/ as the dependent variable. The analysis indicated that there was no significant difference between the groups on percent of voiced judgements ($F < 1$), there was no significant interaction ($F < 1$), and the number of voiced responses changed abruptly across VOT value ($F(7, 119) = 631.65$, $p < .001$) (see Table 3 for means).

The results of the identification tasks for the /ba/-/wa/ continuum are displayed in Figure 6 for the normal reading and dyslexic group. The data indicate that subjects systematically classified stimuli with short duration first formant transitions as /ba/ and those with longer durations as /wa/. These results are consistent with previous research.

As was seen in the /da/-/ta/ tasks the groups did not differ in their ability to identify the /ba/-/wa/ stimuli. In fact, both groups were able to respond categorically. This was confirmed with a repeated measures analysis of variance with group as the between subjects factor, stimulus as the within subjects factor, and the percent of times a stimulus was labeled as /ba/ as the dependent variable. As was seen in the /da/-/ta/ tasks the analysis revealed that there was no significant difference between the groups on the percentage of /ba/ responding ($F < 1$), there was no significant interaction ($F < 1$), and the number of /ba/ responses changed significantly as the duration of the transition increased ($F(7, 105) = 131.60$, $p < .001$). (see

Table 3 for means).

The results of the identification task for the nonspeech continuum are displayed in Figure 7 for the normal reading and dyslexic group. The data revealed that the subjects were able to categorize nonspeech-like stimuli into groups. They systematically classified stimuli with short duration first formant transitions as short and those with longer durations as long.

As was seen in the speech tasks the groups did not differ in their ability to identify the nonspeech stimuli; both groups were able to respond categorically. This was confirmed with a repeated measures analysis of variance with group as the between subjects factor, stimulus as the within subjects factor and the percent of times a stimulus was labeled as short as the dependent variable. There was no significant difference between the groups on the percentage of short responses ($F < 1$), there was no significant interaction ($F < 1$), and the number of short responses changed abruptly as the duration of the transition increased ($F(7, 105) = 77.35$, $p < .001$). (see Table 3 for means).

The identification functions of the /da/-/ta/,

/ba/-/wa/ and nonspeech continua were further analyzed by deriving a slope, locus of category boundary (50 percent crossover point) and uncertainty range (range of stimulus values that fell between the 25 and 75 percent marks) using linear regression techniques. Separate T-tests were performed, with each of these measures as the dependent variable (i.e. slope, locus of category boundary and uncertainty range), on each continuum (i.e. speech and nonspeech), to test for group differences. Results, which can be seen in Table 4, indicate that (1) there were no significant differences between the groups on these measures for any of the continua. The mean category boundary for the groups was at almost exactly the same value for the /da/-/ta/ task: 26.39 compared to 26.41; for the /ba/-/wa/ task: 60.81 compared to 56.94; and for the nonspeech task: 63.26 compared to 62.86 (2) the groups were roughly equivalent at classifying stimuli near their category boundaries as measured by the range of stimulus values that fell between the 25 and 75 percent marks and by the slopes of the identification functions. The groups evidenced similiar ranges of uncertainty and similar slopes on all the continua.

Three, the groups did not differ in their ability to identify endpoint stimuli, presumably good exemplars of the stimulus categories. This was revealed on each continuum using repeated measures analysis of variance, with group as the between subjects factor, endpoint stimulus as the within subjects factor, and the percentage of correctly labeled endpoints as the dependent measure. There were no significant differences between the groups ($F < 1$), and there were no significant interactions ($F < 1$). The only significant stimulus effect was on the nonspeech continuum, i.e. it was found that the groups were more consistent at labeling the short duration endpoint stimuli as short than they were at labeling the long duration stimuli as long ($F(2,30) = 9.11$, $p < .01$). (see Table 5 for means).

Discrimination Tasks

The discrimination results for all of the continua were analyzed using repeated measures analysis of variance with group as the between measures factor, stimulus pair as the within measures factor and percent correct difference response per pair as the dependent variable.

The functions from the discrimination task for the /da/-/ta/ continuum are displayed in Figure 8 for the normal reading and the dyslexic group. The five three-step pairs of stimuli used to test discrimination are on the abscissa, and the percentage of different pairs which were correctly called "different" are on the ordinate. As can be seen in Figure 8, both the normal and disordered readers evidenced discrimination peaks which coincided closely with their established category boundary of 26 milliseconds (see also Figure 9). These peaks indicate greater sensitivity in discriminating stimuli from different phonetic categories than from the same phonetic category. This was supported by the main effect for Pair which suggested that not all pairs were discriminated equally well ($F(4,68) = 263.76$, $p < .001$). The main effect for group indicated that in contrast to the findings on the identification tasks, the dyslexic children were inferior to the normal readers in their ability to perceive differences among the stimuli ($F(1,17) = 3.35$, $p < .05$, one tailed). Due to the poorer between category discrimination of the dyslexics on pair 3-6, the group difference appeared as a significant Group X Pair interaction ($F(4,68) = 2.73$, $p < .05$). (see Table 6 for means.) The individual subject data for the /da/-/ta/ continuum can be seen in Figures 10 and 11 for the dyslexic group and Figures 12 and 13 for the normal reading group. An examination of the data showed that the reduced performance of the dsylexic group on the continuum was contributed by only some of the dyslexic children. The significant main group effect was mainly due to the lower performance of three or four of the eight dyslexic children (i.e. subjects 7, 8, 1, perhaps 2). This can also be seen in Table 7 and 8. Table 7 displays the children's performance on pair 3-6. Table 8 shows a rank order of their performance on this pair. (This stimulus pair was found to be most representative of the children's performance on all the discrimination tasks and was used as a quick way to characterize performance in general).

The discrimination functions from the /ba/-/wa/ continuum can be seen in Figure 14. As can be seen in the figure, both the normal and disordered readers evidenced discrimination peaks which coincided closely with their established category boundary of 56-60 milliseconds (see also Figure 15). As was the case for the /da/-/ta/ task, these peaks indicate greater sensitivity in discriminating stimuli from different phonetic categories than from the same phonetic category. This was supported by the main effect for Pair which suggested that not all pairs were discriminated equally well ($F(4,60) = 13.28$, $p < .001$). The main effect for group indicated that, as expected, and as was seen in the /da/-/ta/ tasks, the dyslexic children were inferior to the normal readers in their ability to perceive differences among the stimuli ($F(1,15) = 3.97$, $p < .05$, one tailed). There were no significant interactions ($F < 1$) (see Table 9 for means.) The individual subject data can be seen in Figures 16 and 17 for the dyslexic group and in Figures 18 and 19 for the normal readers. An examination of the data showed that the reduced performance of the dyslexic group on the continuum was contributed to by most (six out of eight) of the dyslexic children (subjects 1, 4, 7, 6, 8, 2). As in the /da/-/ta/ task pair 3-6 appears to best represent the children's overall performance. Their performance on pair 3-6 is displayed in Table 7 and rank ordered in Table 8.

The results of the discrimination task for the nonspeech continuum are displayed in Figure 20 for the normal readers and dyslexic group. As can be seen in the figure, both groups were able to discriminate between the stimuli in the first 4 pairs with a relatively high degree of accuracy. Both groups responded less categorically than they had in the speech tasks, i.e. the groups were better able to discriminate between pairs from the same category than had been seen in the /da/-/ta/ and /ba/-/wa/ speech tasks. For example, although stimulus 3 was generally labeled as short and stimulus 6 was generally labeled as long in the identification task, the subjects were able to discriminate between them with a relatively high degree of accuracy in the discrimination task. These results are consistent with previous research using nonspeech.

In contrast to the findings on the /da/-/ta/ and /ba/-/wa/ speech tasks, the main effect for group was not significant in the nonspeech task ($F(1, 15) = .856$, $p = .37$). In general the groups did not differ in their ability to perceive differences between the pairs. The individual subject data can be seen in Figures 21 and 22 for the dyslexic group and Figures 23 and 24 for the normal group. All but one subject (S1) in the dyslexic group appeared to perform similarly to the normal group. Although there was a significant interaction of Group X Pair ($F(4,60) = 3.44$, $p < .05$) in the group data, an exploratory post hoc analysis using Least significance difference (LSD) revealed that the groups could only be told apart at pair 2-5 ($< .05$). This appears to be due to subject 1 as can be seen in Figure 21. (A Scheffe test was performed but did not show any significant difference between the means. An LSD was used as an exploratory technique to further investigate the issue with higher power (Kirk, 1968)). (see Table 10 for means.)

Brief temporal measures

Although the data revealed that in general the dyslexic group had trouble discriminating phonetic information, the data did not lend support to the notion that reading disordered children have particular difficulty with "brief" temporal information as had been suggested by Tallal et. al.. This was demonstrated by a number of results. The reading disordered group did not need a longer first formant transition in order to identify stimuli as /wa/ or as /long/ as indicated by the lack of difference between the groups on locus of category boundary on the /ba/-/wa/ and nonspeech tasks and by the lack of significant difference between the groups on percentage of /wa/ responses on the /ba/-/wa/ identification task and /long/ on the nonspeech task (noted above). Further they were as capable of perceiving stimuli with brief formant transitions as they were of perceiving stimuli with longer formant transitions as revealed by the lack of difference in correct responding to the endpoints of the /ba/-/wa/ continuum. That is, the dyslexic group performed equally well at perceiving stimuli at the /ba/ end of the /ba/-/wa/ continuum as at the /wa/ end. In fact, the poor readers were more consistent at labeling the short duration formant transition stimuli as "short" than they were at labeling the long duration formant transition stimuli as long, as noted above.

The results of the time compressed speech tasks are displayed in Figures 25-29. The two time compression conditions - 30 and 60 percent - are on the abscissa and percent correct is on the ordinate. The group data is displayed in Figure 25; the individual data for the dyslexic group is displayed in Figures 26 and 27; the individual data for the normal reading group is displayed in Figures 28 and 29. As can be seen in Figure 25 the dyslexic children performed slightly better than the normal readers when the stimuli were compressed 30 percent; however they performed worse when the stimuli were compressed 60 percent. These differences, while not significant, led to a significant group X test interaction, i.e. there was a greater difference in performance between the 30 and 60 percent conditions for the dyslexic children than for the normal readers ($F(1,17) = 5.76$, $p < .05$). As expected, the analysis revealed a main effect for test suggesting that both groups performed significantly worse when speech was compressed 60 percent as compared to 30 percent ($F(1,17) =$

41.39, $p < .001$) (see Table 11 for means).

Boder Analysis

Of the 8 dyslexic children, 5 fit the criteria for the dysphonetic and 3 fit the criteria for the mixed group. None of the children were found to fit the criteria for the dyseidetic group. All the normal reading children fit the criteria for the normal group as defined by Boder. The children's grade level scores and their group membership are displayed in Table 12. The subjects who were found to be members of the mixed group (i.e. subject 2 (D2), 5 (D5) and 7 (D7) are underlined in Table 8. As can be seen in Table 8 some of the children in this group performed poorly on the tasks in each continuum and others performed similarly to the normal reading children: In the /ba/-/wa/ task subject D5 performed better than all the dyslexic children and similarly to the normal reading children, while subject D7 performed worse than most of the dyslexic children. Subject D2 fell somewhere in between. In the /da/-/ta/ task subject D5 performed similiarly to the normal reading children while subject D2 and subject D7 performed worse than most of the dyslexic and normal reading children. This was also evident on the time compressed speech tasks. This pattern was also true for the children in the dysphonetic group. Thus, it appeared that the Boder test did not differentiate the children's performance.

In order to determine the degree of relation between the children's reading scores on the Woodcock and Boder Reading tests, a Spearman Rank-Difference Correlation was prformed. The correlation coefficient was found to be highly significant (,(17) = +.93, $p < .001$).

Discussion

A discussion of the findings will be presented in the following manner. First, the findings of each task will be discussed individually, i.e. the findings of the identification task for each continuum, the findings of the discrimination task for each continuum, the findings of the time compressed speech tasks. Second, the findings on all the tasks will be summarized with respect to the hypotheses advanced in the introduction. Third, suggestions will be made for future research.

Identification Tasks

The results of the identification tasks for the /da/-/ta/ and /ba/-/wa/ continuum are consistent with previous findings from adults and infants with respect to the general slopes of the functions and loci of category boundary (Lisker, 1975; Miller and Eimas, 1983; Liberman, Delattre, Gerstman and Cooper, 1956). In the /da/-/ta/ identification tasks the children evidenced sharp perceptual categories while in the /ba/-/wa/ tasks they showed a more gradual, but still significant, perceptual change. In the nonspeech task the children appeared to categorize the sounds into two categories, similarly to the way they had done so in the speech continua.

In the identification tasks the reading disordered children were able to label the stimuli appropriately thereby revealing skill at perceiving phonetic information and utilizing that information for categorization. In this regard they did not appear to have difficulty with the temporal cues of voicing and duration of first formant transition. These findings were not consistent with those of Godfrey, et. al. (1981) who performed similiar analyses on identification functions of /ba/-/da/ and /da/-/ga/ continua obtained from dyslexic and normal readers. They found that although there were no group differences in the phoneme boundaries, there were group differences in the slopes of the functions. Further, they obtained a significant Stimulus X Group interaction suggesting that the dyslexic children were less certain in their identification of the speech sounds.

Discrimination Tasks

In contrast to the equality of performance on the identification tasks, the performance of the reading disordered children was inferior to that of the normal reading group on both the /da/-/ta/ and /ba/-/wa/ discrimination tasks. On both of these tasks the reading disordered group was less accurate in their ability to discriminate stimuli from different phonetic categories. These results were consistent with those of Godfrey et. al. who found that dyslexic children performed less well than normal readers on /ba/-/da/ and /da/-/ga/ discrimination tasks. The dyslexic children in their study were also less sensitive in their ability to discriminate between stimuli from different phonetic categories.

The results of this study and those of Godfrey et. al. are not necessarily in conflict with the results of experiments by Brandt and Rosen (1980) who concluded that poor readers do not differ from normal readers on discrimination tasks. Brandt and Rosen did not perform statistical group comparisons of the difference scores (i.e. percent of time a pair was labeled different when the stimuli in the pair were actually different). However in their study the /ba/-/da/ discrimination peak was at approximately 85 percent for the normal group and 70 percent for the dyslexic group. Likewise the /da/-/ga/ discrimination peak was at approximately 75 percent for the normal group and 65 percent for the dyslexic group. As observed by Godfrey et. al. these findings might have been significant were they analyzed. In addition, it is perhaps noteworthy that Brandt and Rosen reported that they found three dyslexic children who initially demonstrated deviant identification and discrimination task performance. They noted that their identification functions did not show a sharp boundary between the /da/ and /ga/ stimuli and that the /ba/-/da/ and /da/-/ga/ discrimination functions did not have distinct peaks. However rather than displaying the functions and discussing the performance of these children as possibly noteworthy, they dismissed the finding and retested the children three months later. On retesting, their performance was found to be less deviant than it had been at the first session; performance on this retest was included in the analyses.

In general, the /ba/-/wa/ task was more difficult for the children than the /da/-/ta/ task. The peaks of the discrimination functions were considerably lower on the /ba/-/wa/ as compared to the /da/-/ta/ tasks (see Figures 8 and 14). This was especially true for the dyslexic group. Further most of the dyslexic children had trouble with this continuum; fewer had difficulty with the /da/-/ta/

continuum. That is, whereas six out of eight dyslexic children performed less well than the normal reading children on the /ba/-/wa/ discrimination task, only three or four dyslexic children performed less well than the normal reading children on the /da/-/ta/ discrimination task. Thus, it appeared that this continuum was more difficult, requiring a more efficient perceptual system. This might have been because the /da/-/ta/ stimuli were closer to the acoustic characteristics of natural speech as noted above. This type of finding was also reported by Godfrey, et. al. who found that dyslexic children were better able to perform with a /ba/-/da/ as opposed to a /da/-/ga/ continuum. The authors suggested that the extra cue (two rather than one formant change) in the /ba/- /da/ series may have made the perceptual differences easier to detect.

Despite the fact that the dyslexic children were less effective at disciminating between the stimuli on the /da/-/ta/ task, their performance was not grossly abnormal as compared to the normal readers. As can be seen in figure 9 they evidenced discrimination peaks which coincided closely with their established category boundary. Similar to the normal readers they were generally more sensitive in discriminating stimuli from different phonetic categories than stimuli from the same phonetic category. This was also the case, though less so, for the /ba/-/wa/ task (see Figure 15). Godfrey et. al. also noted this and found that although dyslexics differed in their ability to identify and discriminate phonetic information, their performance was not of an extremely poor nature. Since dyslexic children do not display obvious perceptual deficits, it is not surprising that their weak performance on these tasks was not as extreme as those reported in subjects who have significant auditory deficits. For example, grossly abnormal performance on synthetic speech tasks was seen in studies with hearing-impaired adults (see Godfrey and Millay, 1978, 1980).

Although overall performance on the nonspeech continuum was slightly higher for the normal readers than for the dyslexic group, this difference did not reach significance. This finding suggested a number of things. One, it revealed that the dyslexic children could perform a discrimination task. Thus, their difficulty with the /ba/-/wa/ and /da/-/ta/ tasks was not simply task-specific. Two, it gave further support to the notion that the deficit in dyslexic readers is specific to phonetic rather than auditory information. Three, it gave some support, although inconclusive, to the hypothesis that the deficit in poor readers was not specific to temporal information. This was not conclusive due to the nature of the nonspeech stimuli. Recall that the nonspeech stimuli were each composed of the isolated first formant transition of the stimuli in the /ba/-/wa/ continuum. This acoustic configuration was used in order to obtain a stimulus that was nonspeech-like in quality, temporally dependent on and analagous to the speech stimuli. Since the transitions varied in duration, the effect of eliminating the steady state was to create syllables which differed in duration and therefore in intensity. Although naive adult listeners, when asked, stated that the difference between the stimuli was of a durational nature, the intensity difference, when noted, could be perceived. One cannot rule out the possibility that the listeners might have perceived the intensity difference, rather than, or in addition to, the temporal difference. On the other hand, one might argue that the listeners subconsciously used an intensity difference in order to discriminate between the /ba/-/wa/ stimuli, since the significant cue in the /ba/-/wa/ continuum was durational.

Time Compressed Speech Tasks

In contrast to what would be expected by Tallal, the dyslexic readers were able to perceive speech that was compressed 30 percent as well as the normals. In fact the dyslexic children were found to perform better than the normal readers, although not significantly so. Similarly, there was no significant difference between the groups on the 60 percent condition. However, there was a greater difference between the dyslexic children's performance on the 30 percent and 60 percent tasks than was the case for the normal readers as revealed by the significant interaction (see Figure 25). Thus it appeared that the dyslexic children were more affected by the 60 percent time compressed condition. This finding might have been due to the dyslexic children's greater difficulty with degraded stimuli. Given that the dyslexic children performed slightly better than the normal readers on the 30 percent condition, one wonders whether the difference in performance in the 60 percent condition would have reached significance were the groups equated in performance on the 30 percent condition. That is, if the dyslexic children had performed slightly worse on the 30 percent condition (which can be seen as a baseline) they might also have performed slightly worse on the 60 percent condition and thereby shifted the lack of significance into a significant level. In addition, it is interesting to note that the two children who performed the worst on the 30 percent condition also performed the worst on the 60 percent condition, ie. subject 4 and subject 8 as can be seen in Figures 26 and 27.

Brief Temporal Processing

Despite the fact the dyslexic children had trouble processing temporal speech cues there was no evidence to support the view that poor readers have a deficit processing "brief" temporal information in general as suggested by Tallal. Although the dyslexic children were less efficient at discriminating the phonetic information, as compared to the normal readers, this result alone was not conclusive. The dyslexic children were able to perceive brief temporal information, i.e. stimuli with short transitional durations (the /ba/-/wa/ identification task) and stimuli in which there was a brief voice onset time (the /da/-/ta/ identification task). There were no differences between the groups in the slopes of the identification task functions. In addition no stimulus had to have a longer transition to be labeled as /ba/ or to have a longer voice onset time to be labeled as /ta/ by the dyslexics as compared to the normals. In addition, in contrast to what would be expected by the argument offered by Tallal, the groups did not differ on a task in which speech was compressed in time by 30 percent. If anything, the poor readers were somewhat more accurate on this task.

Phonetic Perception

The dyslexic children appeared to have some difficulty processing phonetic information. This was demonstrated by the findings on the /ba/-/wa/ and /da/-/ta/ discrimination tasks and was suggested by the results of the 60 percent time compressed speech task condition. In addition, support was given to the notion that the deficit was specific to phonetic information. This was shown by the fact that the dyslexic children performed equivalently to the normal readers on the nonspeech discrimination task.

In reflecting upon the reason for the disparity between the performance of the dyslexic children on the identification and on the discrimination tasks two possibilities come to mind. 1) The discrimination task is more perceptually demanding than the identification task. On the discrimination task the perception of the information must be more "exact" since a subtle comparative judgement is necessary. 2) In the discrimination task, there is a greater load on memory. Rather than immediately responding to one item, the listener has to hold two items in memory long enough to compare the information. Both of these possibilities are congruent with notions presented in the introduction. These children do not display clinically obvious linguistic deficits. Therefore, any perceptual task designed to reveal deficits must stress their processing skills. It might be that the identification task, the less demanding of the two types of tasks, was not sufficiently stressful.

It is difficult to separate the perceptual and memory demands of the discrimination task. As a result one might argue that it is impossible to know whether the dyslexic children's difficulty with the discrimination tasks was of a perceptual nature or the result of a deficit in short term memory for phonetic information. The argument that the deficit was specific to memory processes would seem to be compelling in light of the fact that the children did not have trouble with the identification task. However it seems reasonable to propose that the limitation was in part perceptual, i.e. that the children were less effective at registering the phonetic information and this in turn had an effect on memory processes. The reasoning is as follows.

It is clearly the case that dyslexic children can hold a sequence of two syllables in memory long enough to decide whether the syllables are the same or different, e.g. "cat" and "hat". In this respect the memory demand made by the discrimination task was of a minor nature. On the other hand, there were only subtle differences between the stimuli in each pair on the discrimination task, and the listener was required to make this perceptually subtle discrimination judgement. Given, the task demands of the A X paradigm it would seem that on the surface, the memory demand was relatively minor as compared to the perceptual demand and therefore that the perceptual demand created the difficulty. It is possible however, that a perceptual impairment might have affected memory processing. The following study ought make this last point clear.

Rabbitt (1968) demonstrated that the efficiency with which an input is perceived can have consequences for memory. He found that normal adults had greater difficulty recalling sequences of digits presented in white noise than sequences of digits presented with no-noise, despite the fact that they were able to accurately repeat the digits in noise when they were presented individually. Thus, memory processes were found to suffer because of the increase in the perceptual demand of the stimuli. Rabbitt argued that the resources required to perceive the more demanding information load (i.e. the noisy sequence) reduced the resources which were required for memory processing. Thus although memory processes were affected the source of the difficulty was perceptual in nature.

One additional possibility is that the poorer performance of the dyslexic children on the discrimination task (as compared to the identification task) was due to attentional factors since the discrimination task was the longer of the two tasks. However, while attentional factors may have played a role in their poor performance, it is unlikely that this factor alone created the effect since the dyslexic children performed equivalently to the normal readers on the nonspeech discrimination task.

The dyslexic children in this study appeared to have the most difficulty with the more difficult tasks. For example, they did not have trouble with the identification but they did have trouble with the discrimination tasks.

Further, they had more difficulty discriminating the /ba/-/wa/ stimuli than the /da/-/ta/ stimuli. They had a tendency to perform worse on the 60 percent than the 30 percent condition. It might not be that that dyslexic children have trouble with particular acoustic cues but rather that their difficulty arises when their perceptual system is stressed. The findings of Brady et. al. (1985) are consistent with this notion. As noted earlier, in their study, poor readers were found to have difficulty perceiving phonetically demanding stimuli. Good and poor third grade readers were compared on repetition tasks which varied in difficulty (monosyllable, multisyllable, and pseudoword stimuli). While the groups were found to perform comparably on the easier monosyllable word list, the poor readers performed significantly worse than the normal readers on the multisyllable and pseudoword lists.

This notion is also consistent with earlier studies of speech perception and reading. As mentioned in the introduction, Brady et. al. (1983) found that although good and poor readers performed similarly on a speech perception task in quiet, the poor readers performed worse when noise was added. Thus, when their perceptual capabilities were stressed (the speech signal was degraded) they performed less effectively. The authors concluded that their speech perception skills were less effective than the good readers'.

Since the dyslexic children did not have trouble with the identication tasks and their phoneme boundaries were comparable to those of the normal readers it would seem that their difficulty on the discrimination tasks did not stem from a deficit in categorical perception. That is, consonant with the performance of the normal readers, the dyslexic children were able to label the stimuli appropriately and categorize them into linguistic groups. The difficulty appeared to be specific to discrimination and the phenomenon is perhaps similar to that found in other studies of speech perception and reading, e.g. that reported by Brady et. al. noted above.

Individual differences

There was a good deal of variability in the performance of the individual dyslexic children both within and across the speech tasks. This is best seen in Table 8 where the performance of the children on the discrimination task (pair 3-6) is rank ordered. On each task, a few of the dyslexic children performed within the normal limits of the normal reading group. For example, in the /ba/-/wa/ task subject 5 (D5) and subject 3 (D3) performed similarly to the normals. The same pattern can be seen for some of the other dyslexic children and on the other tasks. However, poor performance on one task was not a perfect predictor of poor performance on another. For example, although subject 4 (D4) performed poorly on the /ba/-/wa/ task and the 60 percent time compressed speech task, he performed like the normal reading children on the /da/-/ta/ task. Again, this can be seen for some of the other children. The diversity of the performance of the dyslexic group is not unlike that found in other studies in the literature (see Vellutino, 1979). That is, it is not uncommon to find that some dyslexic children perform like normal reading children on a task which other dyslexic children selected from the same group fail. Nor is it uncommon to find that some dyslexic children will fail one task and succeed on another that appears to assess the same or similar functions. For example, in a study by Bradley and Bryant (1978) 91 percent of the backward readers made errors on one task assessing phonetic sophistication (i.e. where they had to pick which was the odd word out of a group of 4 words (e.g. nod, red, fed, bed)) and 38 percent of the backward readers failed a different task also assessing phonetic sophistication (i.e. where they had to produce rhymes for words). Further, what is often seen in clinical practice is that these children vary in performance from day to day.

The difficulties in researching the dyslexic population are perhaps best shown in the subtype literature where repeated attempts have been made to subcategorize homogeneous groups of children. Categories have been defined by various researchers. However it is not uncommon to find that large numbers of children do not fit any category because of their mixed or overlapping deficits. For example Denckla (1973) using a subtype scheme similar to that of Mattis, French and Rapin's (1975) found that 70 percent of the children had either mixed deficits or did not fit any a priori category (Taylor, Fletcher and Satz (1982).

Reading Skill

To recall, on the basis of the Boder test two groups of dyslexic readers were formed: a dysphonetic and a mixed dysphonetic-dyseidetic reading group. However no differences in performance on the discrimination or time compressed speech tasks were found between these two groups. This was not a surprising finding since one of the defining features of the group identified as "mixed" was that their reading and spelling errors suggest, like those of the dysphonetic group, that they have difficulty in the phonological domain. On the other hand, given Boder's description of the children in the mixed group (i.e. that they are the most disabled of the reading disordered children), one might expect that they would not do as well on the speech tasks as the children in the dysphonetic group. In light of this, one cannot help but entertain the possibility that the Boder test is not valid for purposes of subtyping. Relevant to this is the finding of Godfrey et. al. (1981) who did not find performance differences between dysphonetic and dyseidetic readers.

Future studies

It appears that dyslexic children are less efficient at processing temporal cues in speech signals. However it may be the case that their difficulty is not specific to temporal information but exists for other speech cues as well. To test this one could employ the same paradigm as that used in this study with stimuli in which the speech cue is spectral in nature, e.g. /sa/-/fa/. In this regard it is interesting to note a recent study by Tallal and Stark (1981). They found that language disordered children performed significantly worse on a /sa/ versus /fa/ contrast. (The experimental paradigm was exactly the same as that used in their earlier studies, noted earlier.) The syllables used in the study differed spectrally throughout 130 milliseconds of frication. Tallal expected that the children would not have difficulty since her temporal theory suggests that 130 milliseconds is of sufficient duration for discrimination. Tallal concluded from these findings that the perceptual deficit in language impaired children may not be limited to discriminating specific types of temporal cues, but may also include spectral cues.

In order to lend further support to the notion that dyslexic children have a perceptual deficit that is specific to phonetic (as opposed to auditory) information one ought use speech and nonspeech stimuli that are perfectly comparable. Possible candidates are /da/-/ga/ stimuli similar to those used in a study by Mann and Liberman (1983). The speech stimuli in their study were each composed of three formant syllables in which the third formant varied from a transition appropriate for /da/ to one appropriate for /ga/. The nonspeech stimuli were the isolated third formant transitions of the /da/-/ga/ set and they sounded like chirps. By using these stimuli rather than those used in the present study one eliminates any possible confounding of intensity.

Since there was a greater spread between the performance of the dyslexic children on the 30 and 60 percent time compressed task, than was the case for the normal readers, it would be interesting to see whether the spread would widen if the demands of the task were increased. To the aim, it would be useful to include a task that is time compressed 70 percent. That a deficit for the poor readers would be apparent is suggested by the falling slope of the function for the dyslexic group in Figure 25. In addition, it would be interesting to see whether dyslexic children have a perceptual deficit for specific acoustic cues, or one that is more general and would arise with any phonetically demanding task. To this aim it would be useful to include, in the same study, a variety of phonetically demanding tasks, e.g. a filtered speech task, a time compressed task and a task in which speech is placed in noise.

Final Remarks

Although we do not completely understand exactly why it is that some children have trouble learning to read, there is strong evidence that the syndrome stems from some deficit in language ability, and in particular phonological processing. The present research lends further support to this notion. In particular, it has been shown that some dyslexic children have trouble discriminating phonetic information and in perceiving speech cues that are temporal in nature, i.e. voice onset time and transition duration. Although some of the dyslexic children were found to have trouble processing temporal speech cues there was no evidence to support the view that poor readers have a deficit processing "brief" temporal information in general as suggested by Tallal. The results of this study provide additional evidence that poor readers have difficulties in the phonological domain.

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Table 1

Age, Grade, Reading Level, IQ of Subjects in
Dyslexic Reading Group

Subject	Age	Grade	Reading Level[a]	IQ (%ile)[b]
1	9.5	4.7	4.20	50
2	8.7	3.7	2.05	75
3	9.4	3.8	2.40	95
4	8.6	3.8	3.30	99
5	9.2	3.8	1.95	82.5
6	9.2	3.9	3.30	92.5
7	8.11	3.9	1.35	92.5
8	7.3	2.0	1.50	99

a From the average of the reading grade scores obtained on the Word Attack and Word Recognition subtests of the Woodcock Reading Mastery Tests, Form A

b Ravens Coloured Progressive Matrices

Table 2

Age, Grade, Reading Level, IQ of Subjects in Normal Reading Group

Subject	Age	Grade	Reading Level[a]	IQ (%ile)[b]
1	8.9	3.2	3.40	99
2	8.10	3.2	4.65	99
3	9.2	3.2	6.45	99
4	8.6	3.3	4.35	99
5	8.9	3.2	4.85	50
6	8.7	3.6	8.60	90
7	9.0	3.6	6.20	92.5
8	8.7	3.7	8.40	95
9	8.11	3.7	10.00	82.5
10	8.11	3.8	4.60	75
11	9.5	3.9	9.05	99

a From the average of the reading grade scores obtained on the Word Attack and Word Recognition subtests of the Woodcock Reading Mastery Tests, Form A

b Ravens Coloured Progressive Matrices

Table 3

Mean Identification Scores on Each Continuum for
Normal (N) and Dyslexic (D) Children

	Da-Ta			Ba-Wa			Short-Long		
	N	D	Mean	N	D	Mean	N	D	Mean
Stimulus									
1	99	99	99	99	97	98	97	96	97
2	98	98	98	87	75	81	87	87	87
3	81	77	79	79	75	77	77	75	76
4	2	5	4	54	42	48	61	52	57
5	2	5	4	17	12	15	23	20	21
6	0	0	0	6	9	7	28	23	25
7	0	2	1	3	2	2	9	11	10
8	1	0	0	1	2	1	16	14	15
Group Mean	36	36		43	39		49	47	

Table 4

Characterization of the Identification Functions for /da/-/ta/, /ba/-/wa/, short-long: Mean Slope, Category Boundary and Range of Uncertainty for Normal and Dyslexic Groups

	Da-Ta		Ba-Wa		Short-Long	
	Normal	Dyslexic	Normal	Dyslexic	Normal	Dyslexic
Slope	-1.69	-1.68	-1.63	-1.50	-1.36	-1.36
Category Boundary	26.39	26.41	60.81	56.94	63.26	62.86
Uncertainty Range	29.59	29.81	30.92	34.15	39.06	39.52

Table 5

Mean Percent of Endpoints Correctly Identified
for Normal Reading and Dyslexic Groups

	Ba	Wa	Da	Ta	Short	Long
Normal	100	98.6	100	98.9	97.5	83.8
Dyslexic	96.9	98.4	100	100	96.4	85.7

Table 6

Mean Discrimination Scores on Da-Ta Continuum for
Normal and Dyslexic Groups

	Normal	Dyslexic	Mean
Pair			
1-4	98	90	94
2-5	99	92	96
3-6	91	75	83
4-7	11	15	13
5-8	7	13	10
Group Mean	61	57	
	(N=11)	(N=8)	

Table 7

Performance of Normal and Dyslexic Children
on Pair 3-6 of Discrimination Task:
% Correct Discrimination

	Subjects	Ba-Wa	Da-Ta	Short-Long
Normal				
	1	75	93.75	68.75
	2	75	100	100
	3	87.50	93.75	75
	4	50	75	87.50
	5	87.50	100	75
	6	81.25	93.75	81.25
	7		75	87.50
	8	81.25	100	100
	9	56.25	75	87.50
	10	75	100	81.25
	11		93.75	
Dyslexic				
	1	25	81.25	68.75
	2	56.25	56.25	100
	3	87.50	81.25	81.25
	4	31.25	100	81.25
	5	100	93.75	75
	6	50	75	81.25
	7	50	43.75	
	8	56.25	68.75	93.75

Table 8

Rank Ordered Performance of Normal (N) and Dyslexic (D) Children on Pair 3-6 of Discrimination Tasks and on 30 and 60% Time Compressed Speech Tasks

Ba-Wa	Da-Ta	Short-Long	30%	60%
D5	N2	N2	D5	N9
N3	N5	N8	D6	D2
N5	N8	D2	N2	D3
D3	N10	D8	N11	N2
N6	D4	N4	D3	N3
N8	N1	N7	D7	N11
N1	N3	N9	N3	D6
N2	N6	N6	N6	N6
N10	N11	N10	N9	N10
N9	D5	D3	N10	D7
D2	D3	D4	D1	N5
D8	D1	D6	D2	N1
N4	N4	N3	D8	N7
D6	N7	N5	N1	D1
D7	N9	D5	N4	N4
D4	D6	N1	N5	N8
D1	D2	D1	D4	D5
	D8		N8	D8
	D7		N7	D4

Table 9

Mean Discrimination Scores on Ba-Wa Continuum for Normal and Dyslexic Groups

	Normal	Dyslexic	Mean
Pair			
1-4	42	41	41
2-5	72	55	63
3-6	74	57	66
4-7	52	39	46
5-8	22	19	21
Group Mean	53	42	
	(N=9)	(N=8)	

Table 10

Mean Discrimination Scores on Short-Long Continuum for Normal and Dyslexic Groups

	Normal	Dyslexic	Mean
Pair			
1-4	93	79	86
2-5	96	77	87
3-6	84	83	83
4-7	73	74	73
5-8	19	31	25
Group Mean	72	69	
	(N=10)	(N=7)	

Table 11

Mean Time Compressed Speech Scores for
Normal and Dyslexic Groups

	30%	60%	Mean
Normal	92.00	87.00	89.50
Dyslexic	94.25	83.50	88.75
Group Mean	93.12	85.25	

Table 12

Reading Level and Group Membership on Boder Test for Normal and Dyslexic Children

	Subject	Reading Level	Membership
Dyslexic			
	1	5	Dysphonetic
	2	Preprimer	Mixed
	3	3	Dysphonetic
	4	1	Dysphonetic
	5	Preprimer	Mixed
	6	3	Dysphonetic
	7	Preprimer	Mixed
	8	1	Dysphonetic
Normal			
	1	5	Normal
	2	8	Normal
	3	8	Normal
	4	6	Normal
	5	7	Normal
	6	8	Normal
	7	9	Normal
	8	7	Normal
	9	8	Normal
	10	5	Normal
	11	8	Normal

Figure 1

Schematic representations of /ba/-/wa/ patterns

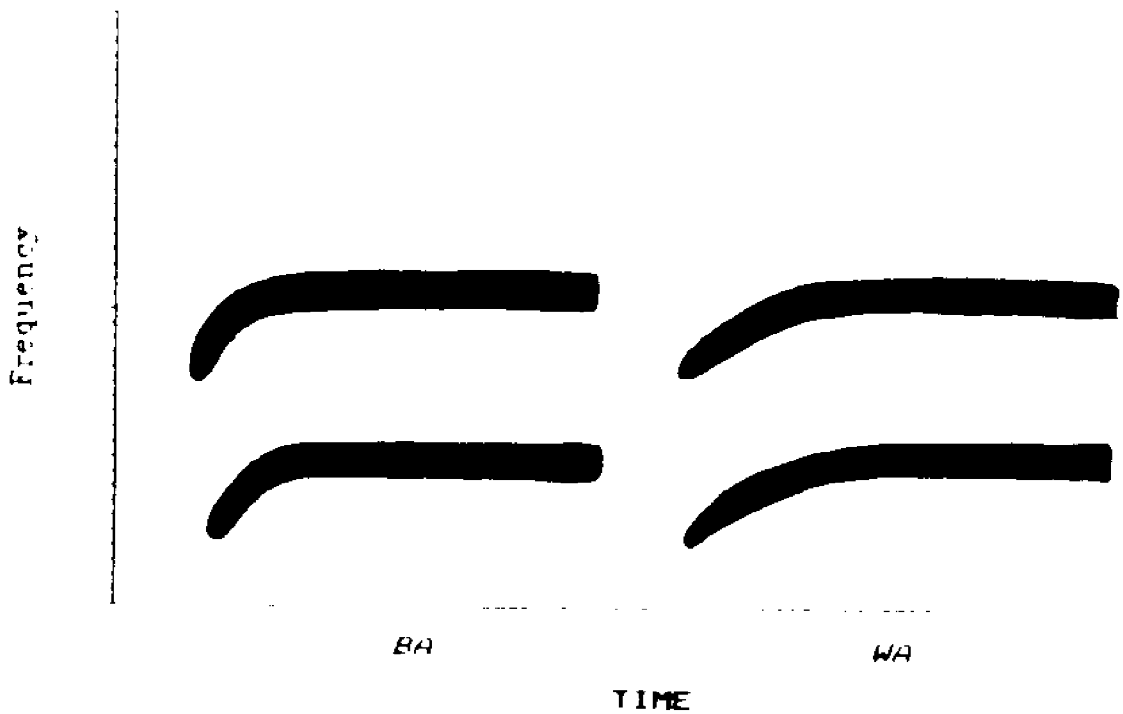

Figure 2

Schematic representations of /da/-/ta/ patterns

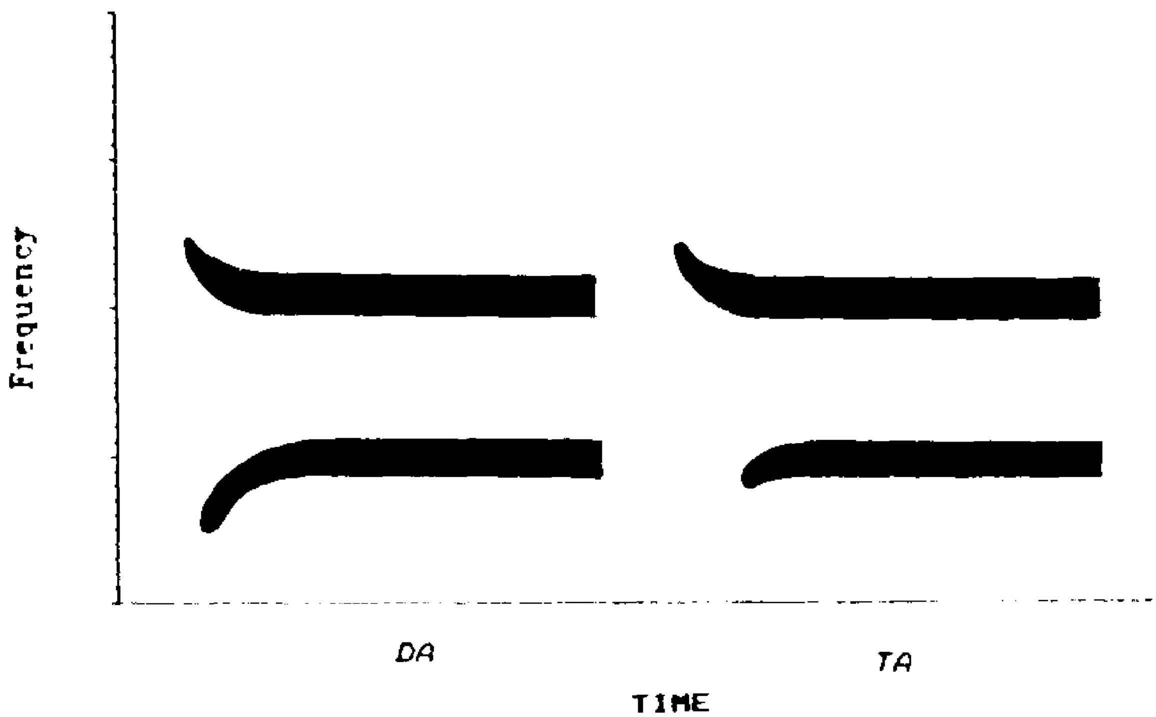

Figure 3

Schematic representations of /ba/-/da/-/ga/ patterns

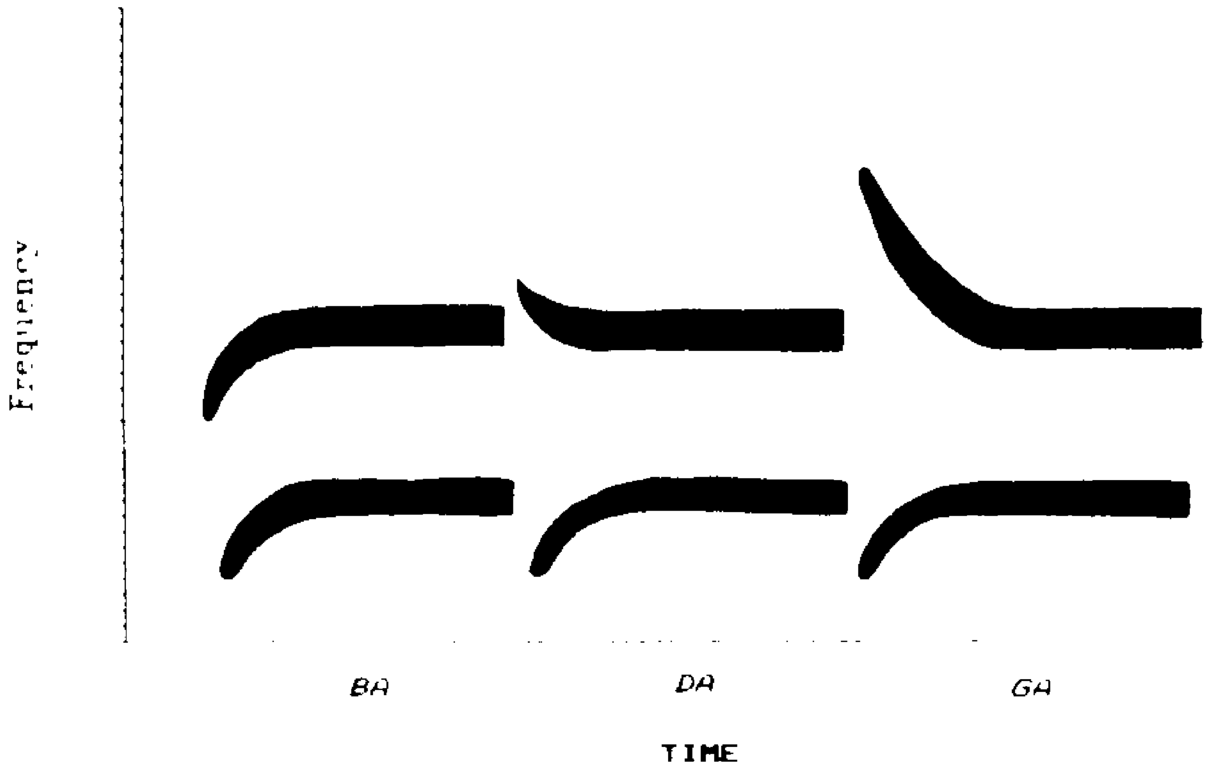

Figure 4

Schematic representation of /bæg/ pattern

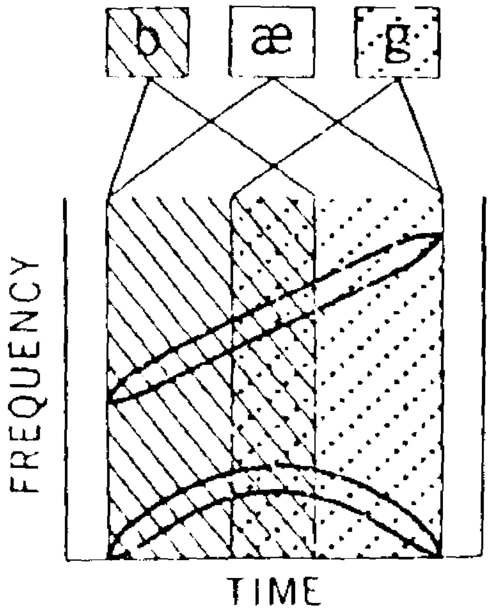

Figure 5

Performance of normal and dyslexic children on /da/-/ta/ identification task

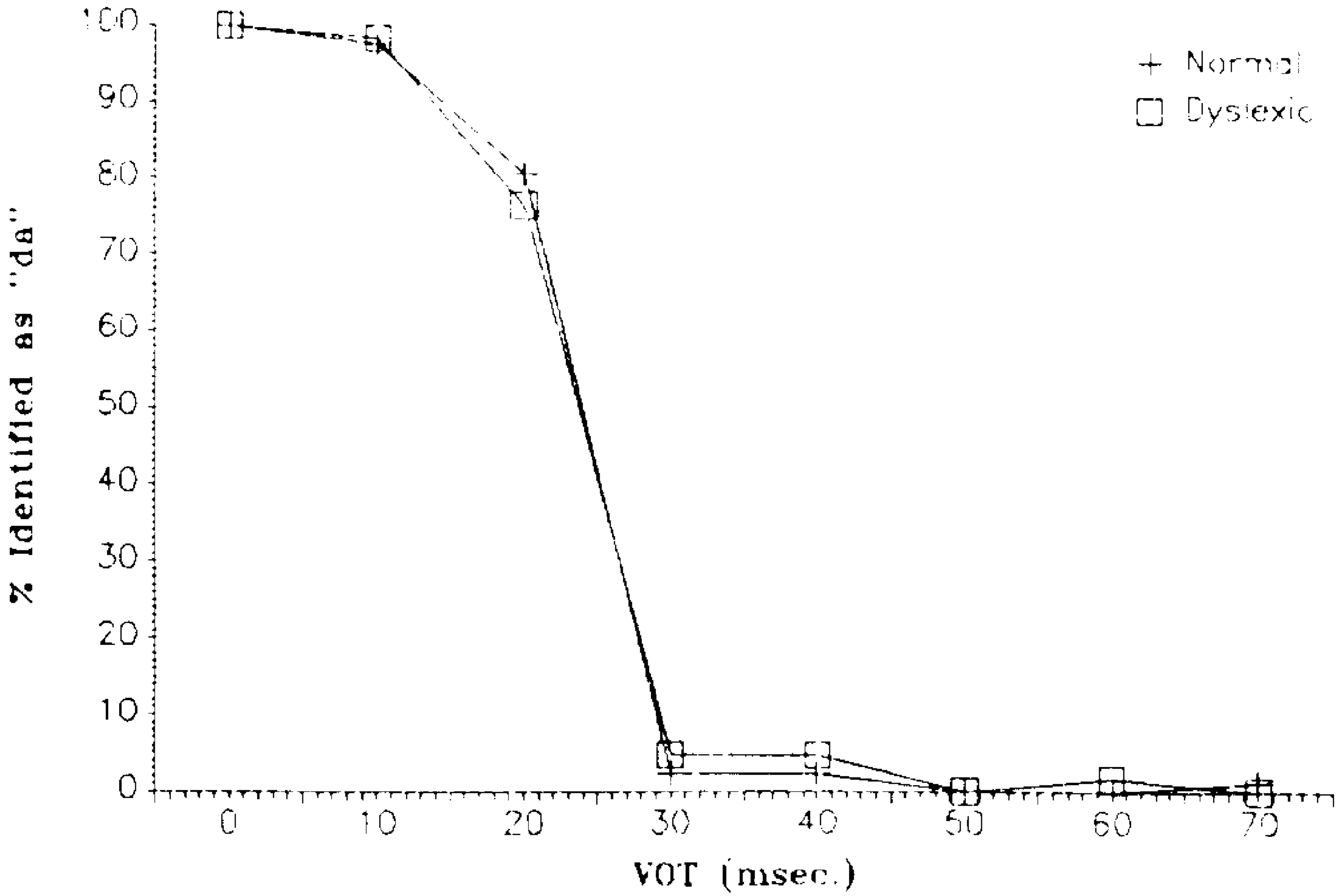

Figure 6

Performance of normal and dyslexic children on /ba/-/wa/ identification task

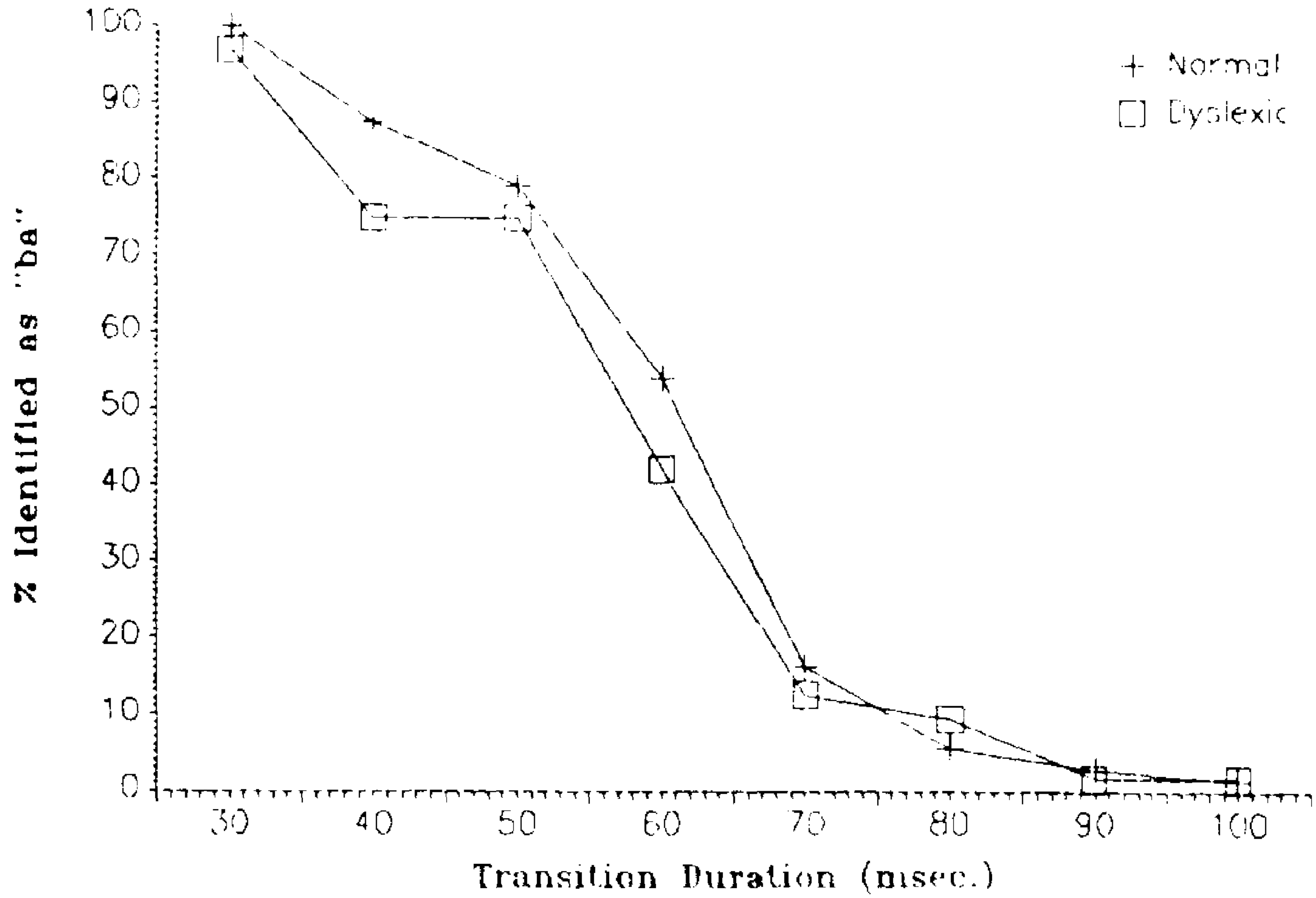

Figure 7

Performance of normal and dyslexic children on nonspeech identification task

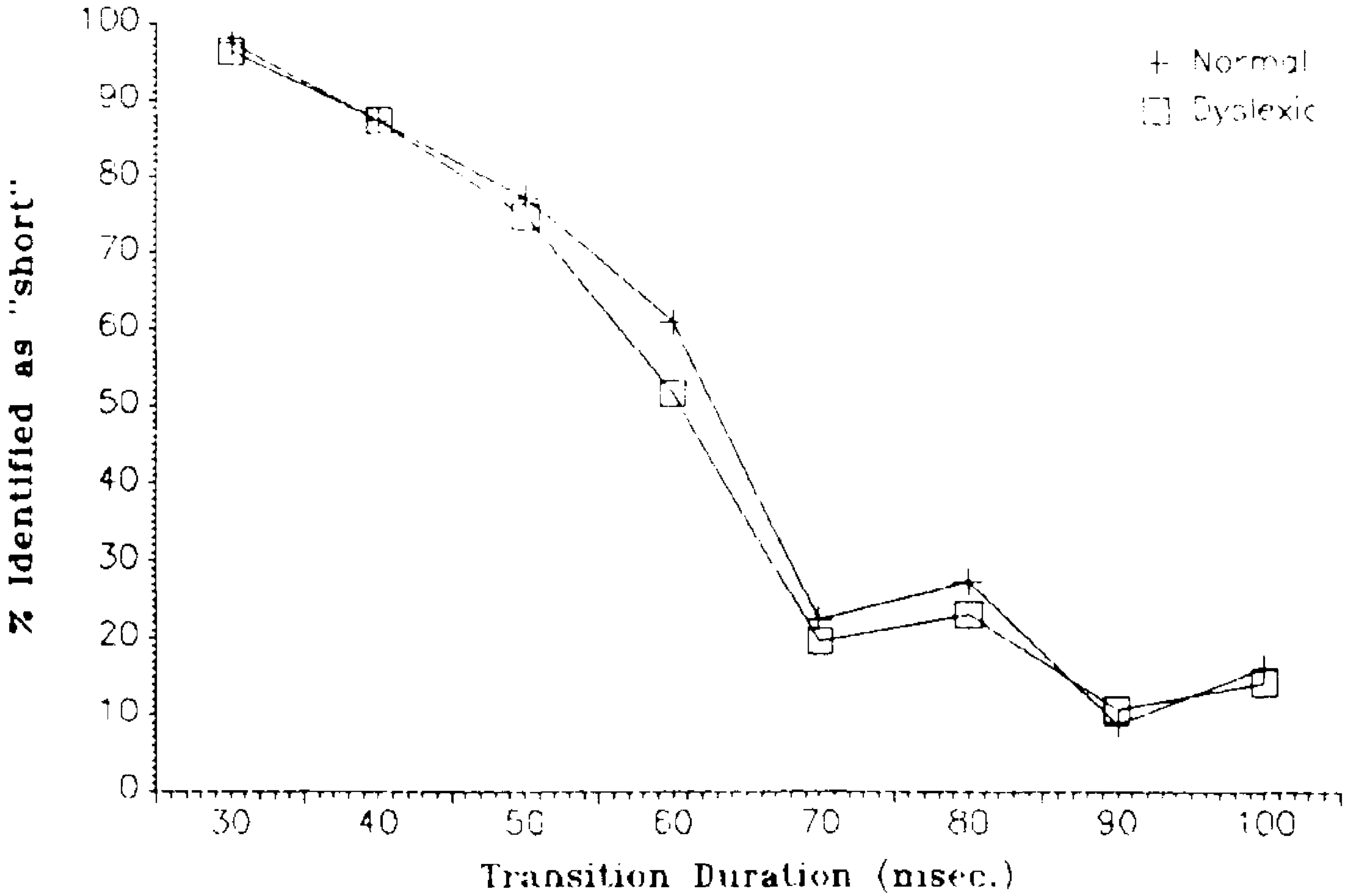

Figure 8

Performance of normal and dyslexic children on /da/-/ta/ discrimination task

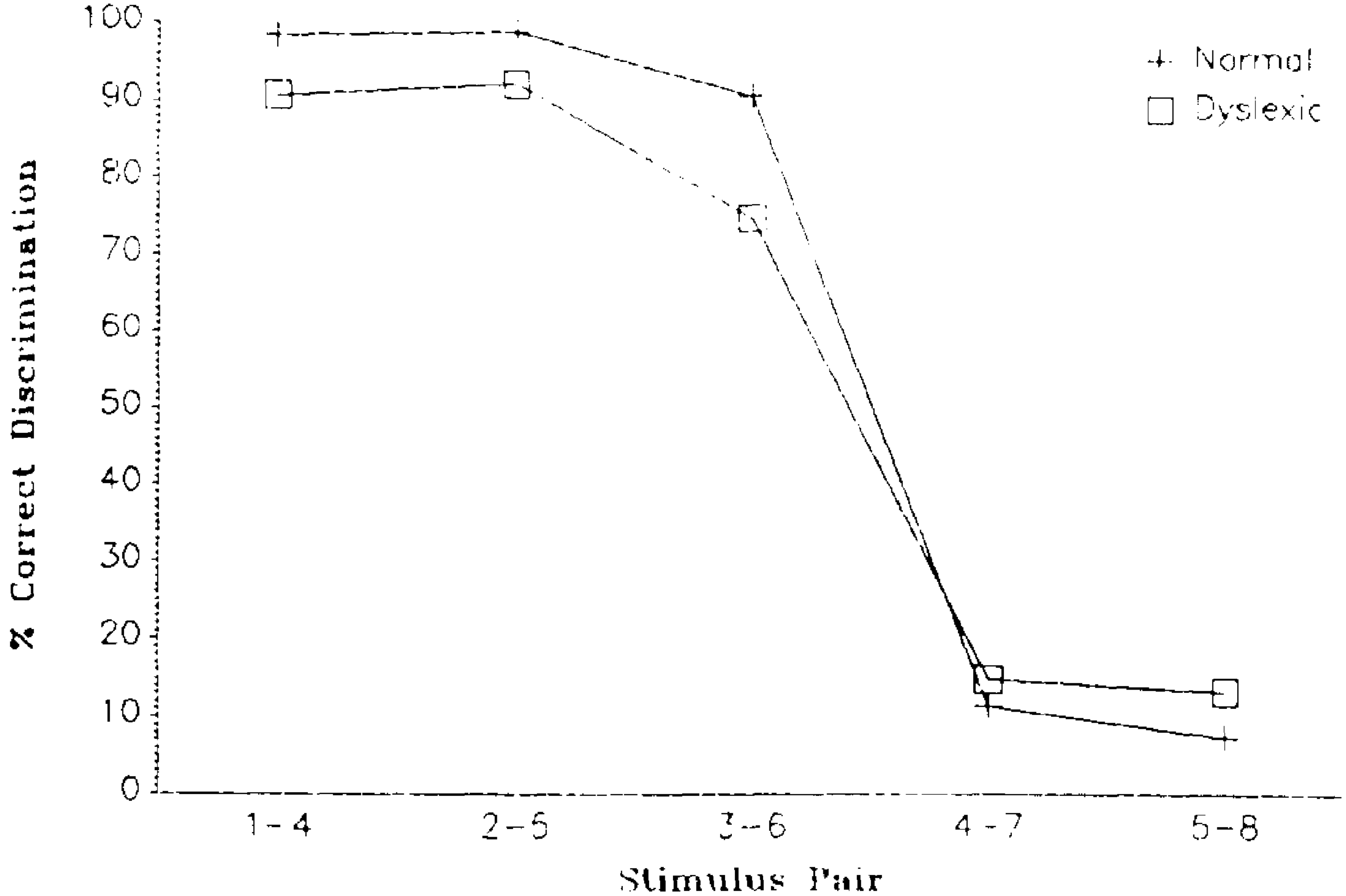

Figure 9

Performance of normal and dyslexic children on /da/-/ta/ identification and discrimination task

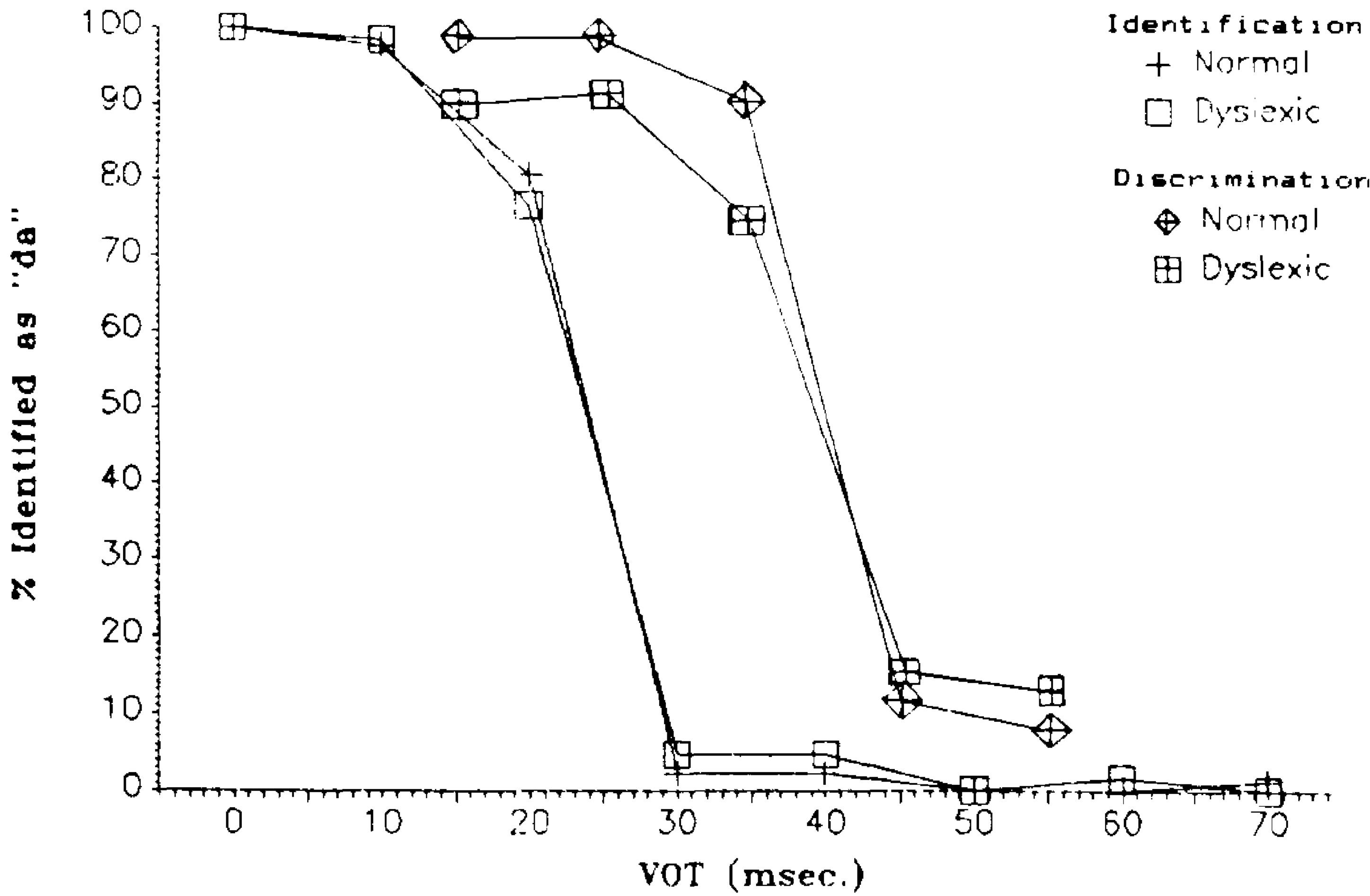

Figure 1D

Performance of dyslexic subjects 1-4 on /da/-/ta/ discrimination task

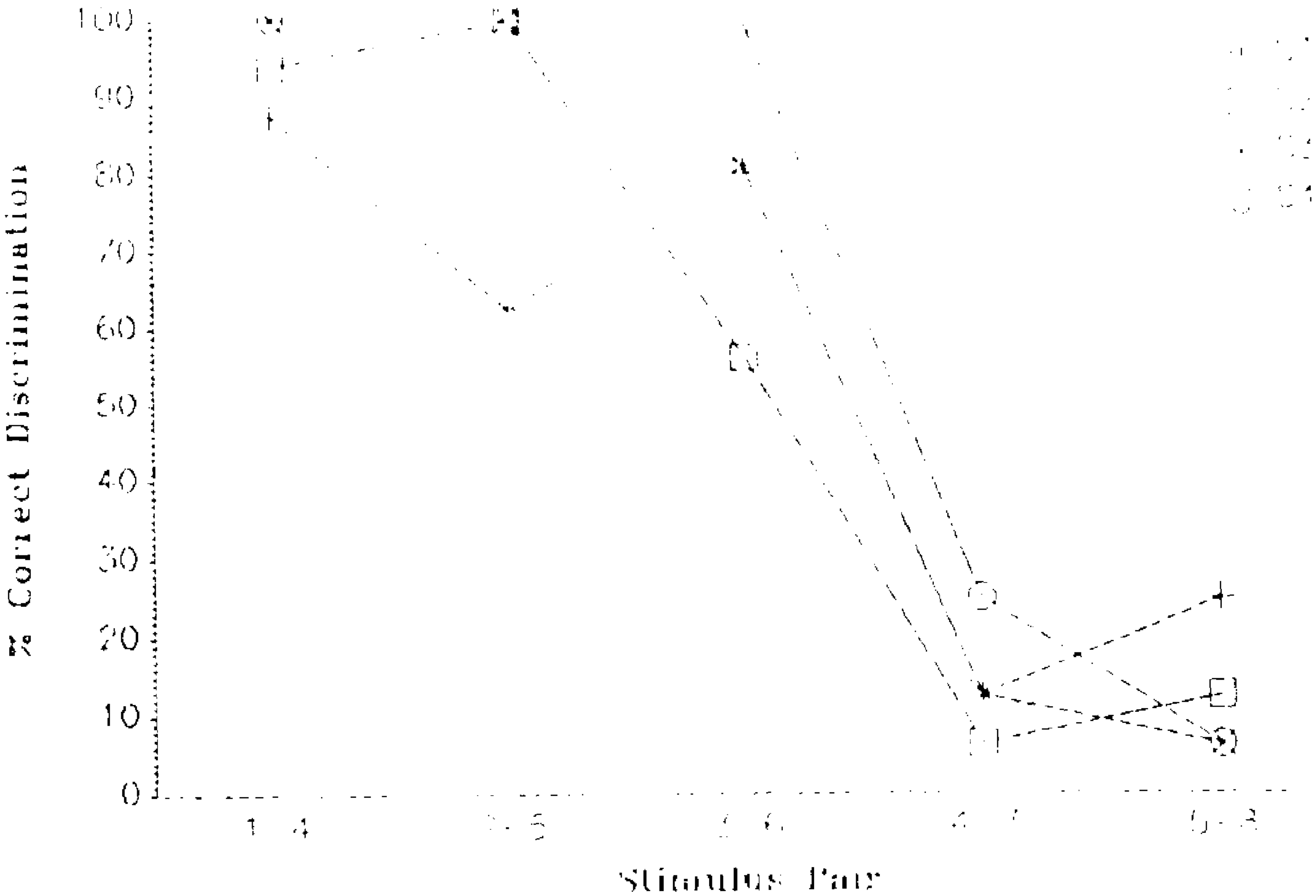

Figure 11

Performance of dyslexic subjects 5-8
on /da/-/ta/ discrimination task

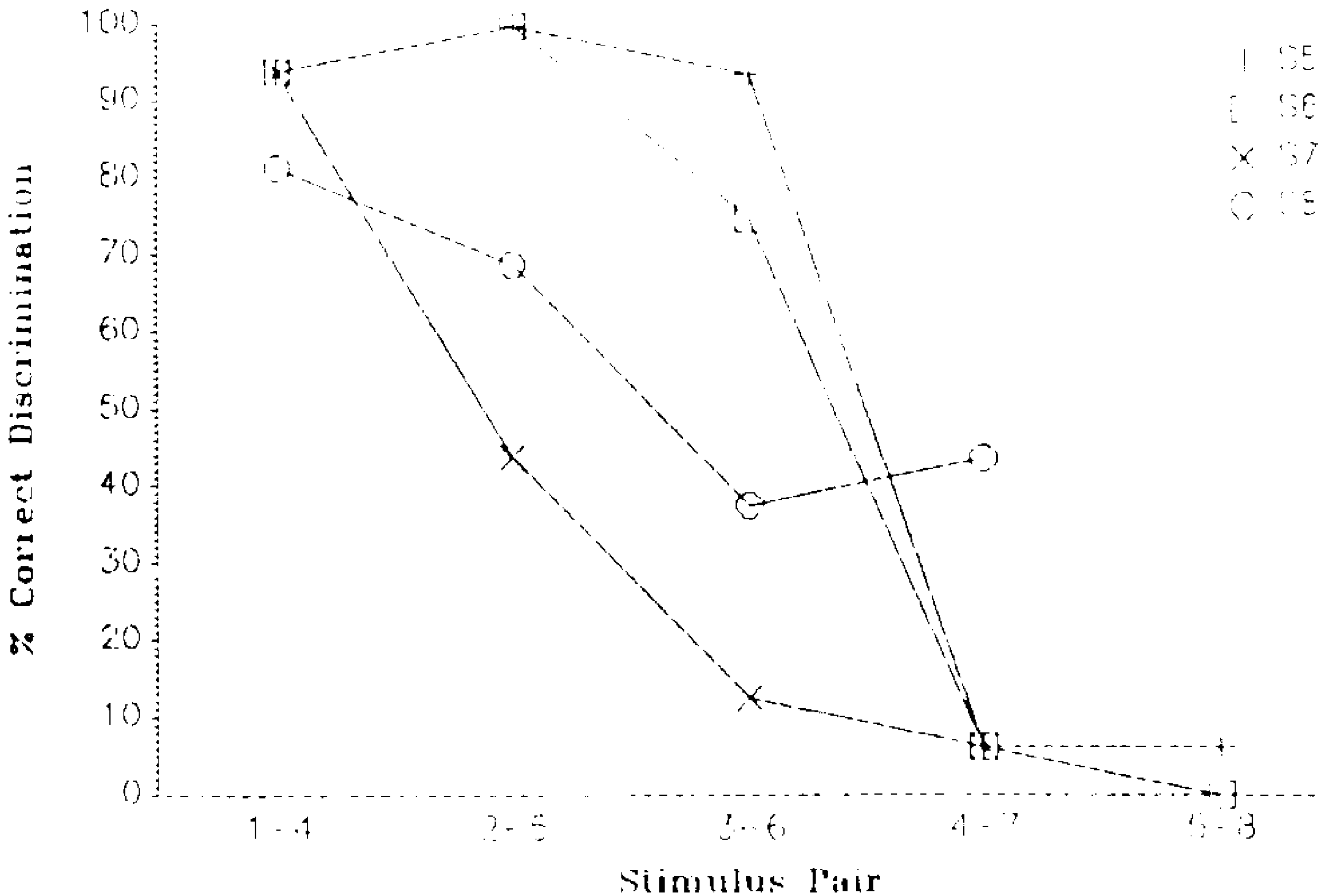

Figure 12

Performance of normal reading subjects 1-5 on /da/-/ta/ discrimination task

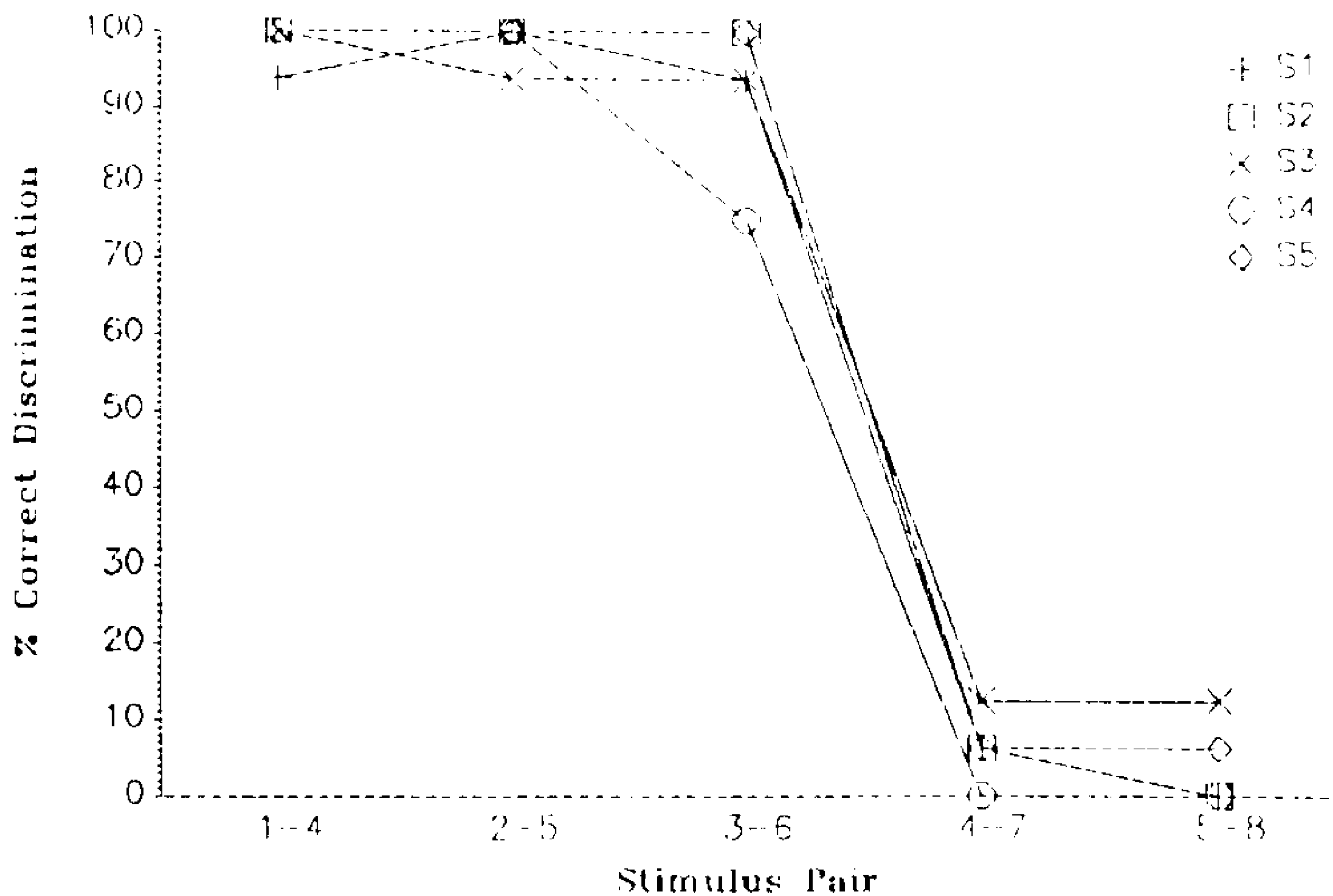

Figure 13

Performance of normal reading subjects 6-11
on /da/-/ta/ discrimination task

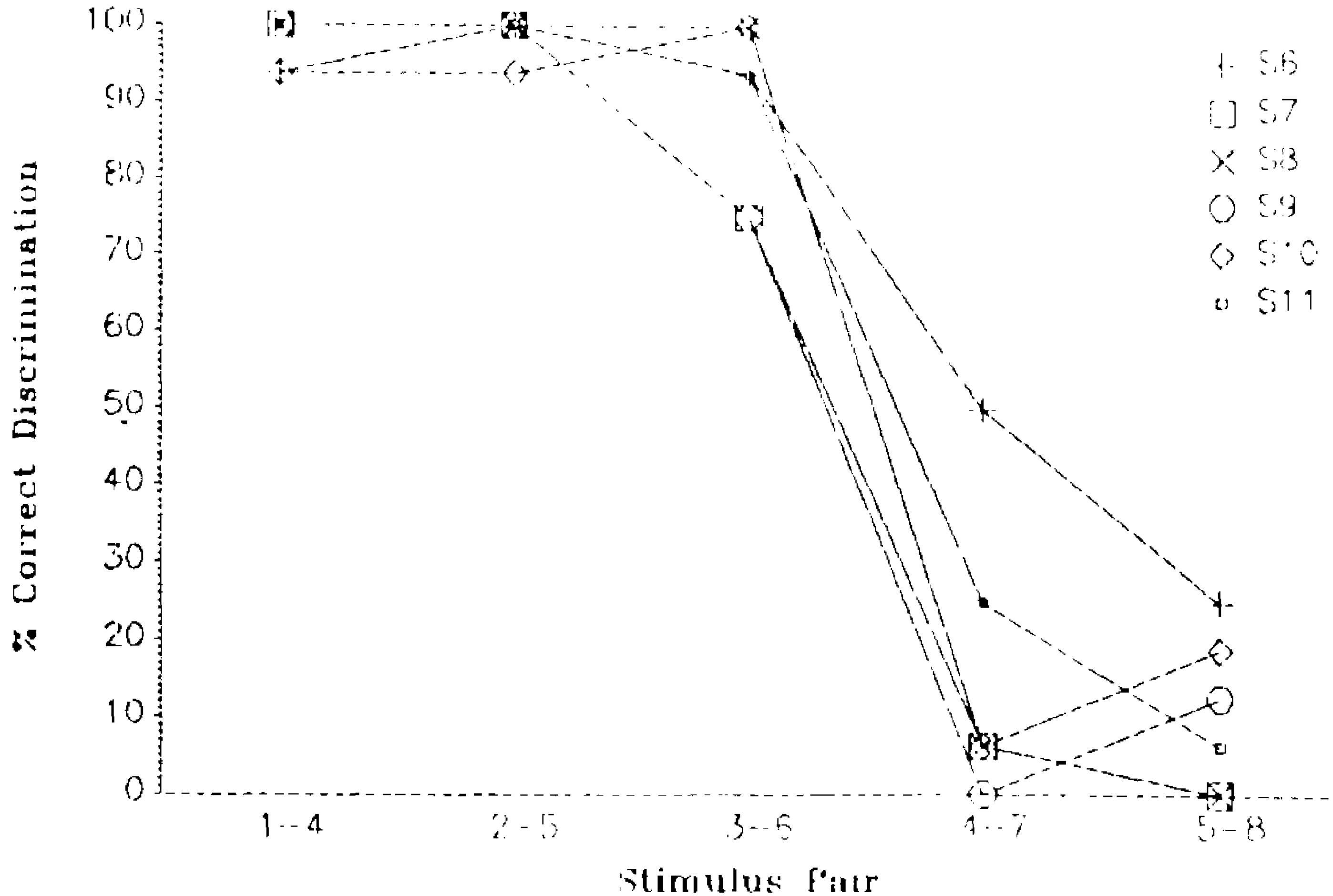

Figure 14

Performance of normal and dyslexic children on /ba/-/wa/ discrimination task

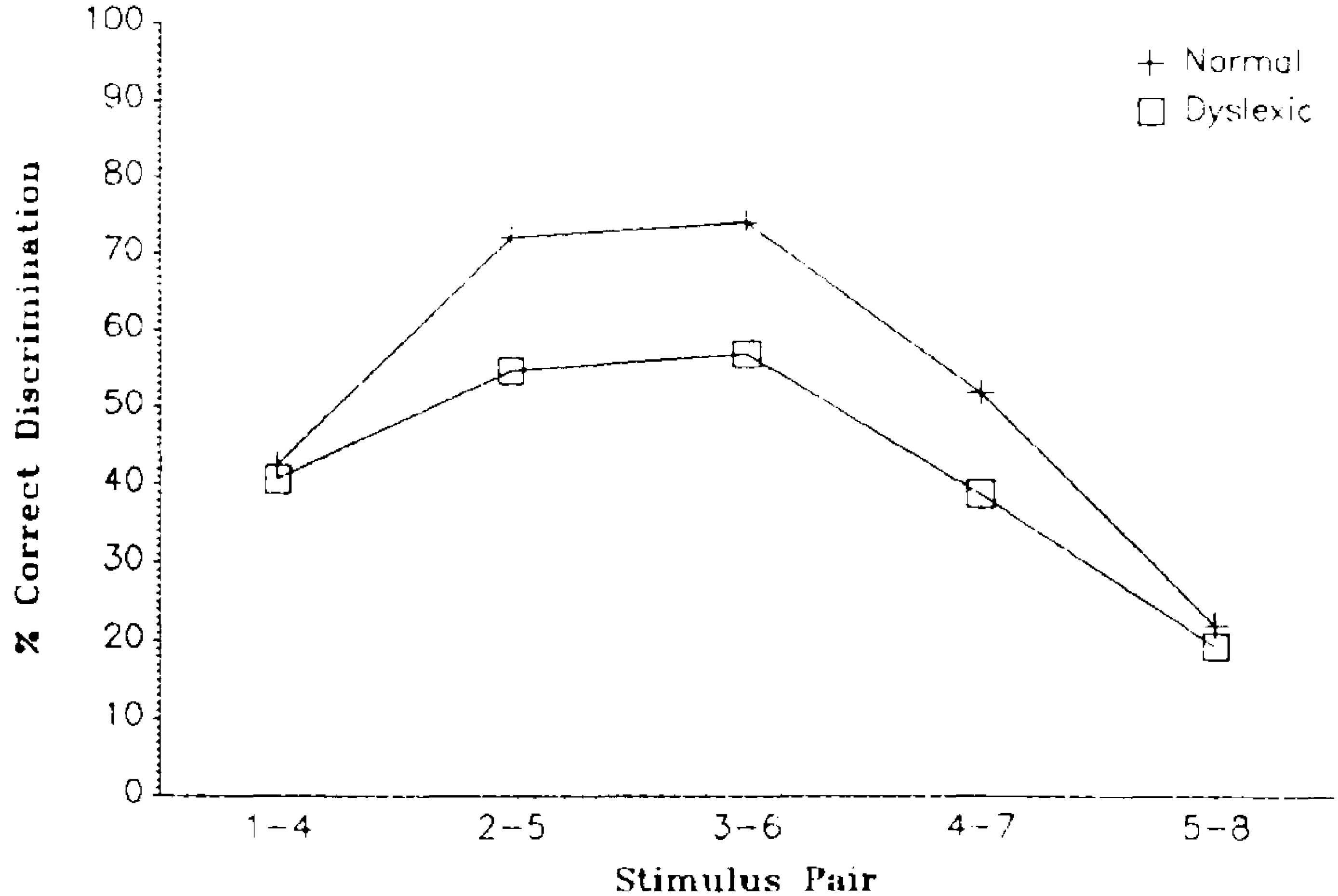

Figure 15

Performance of normal and dyslexic children on /ba/-/wa/ identification and discrimination task

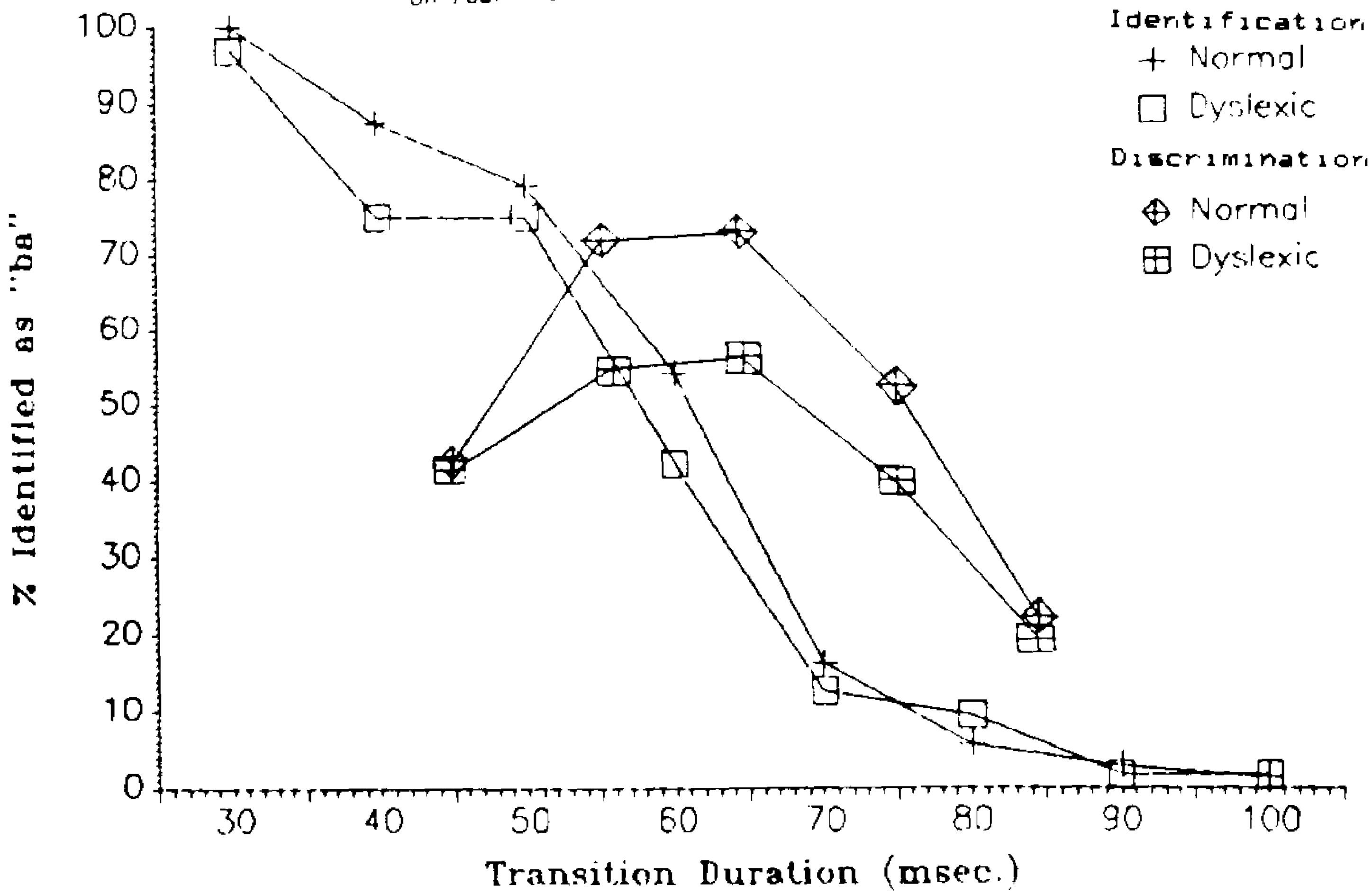

Figure 16

Performance of dyslexic subjects 1-4 on /ba/-/wa/ discrimination task

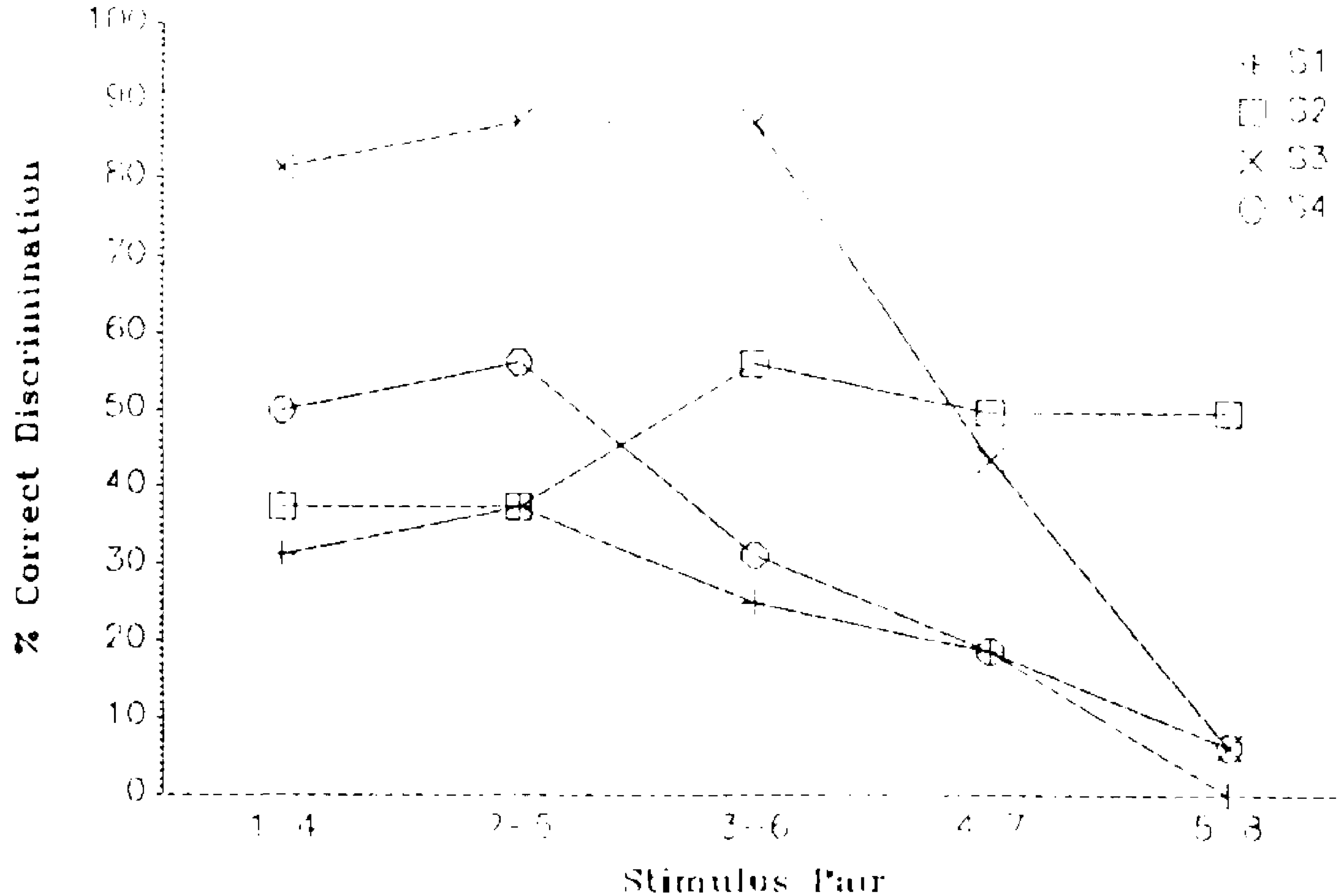

Figure 17

Performance of dyslexic subjects 5-8
on /ba/-/wa/ discrimination task

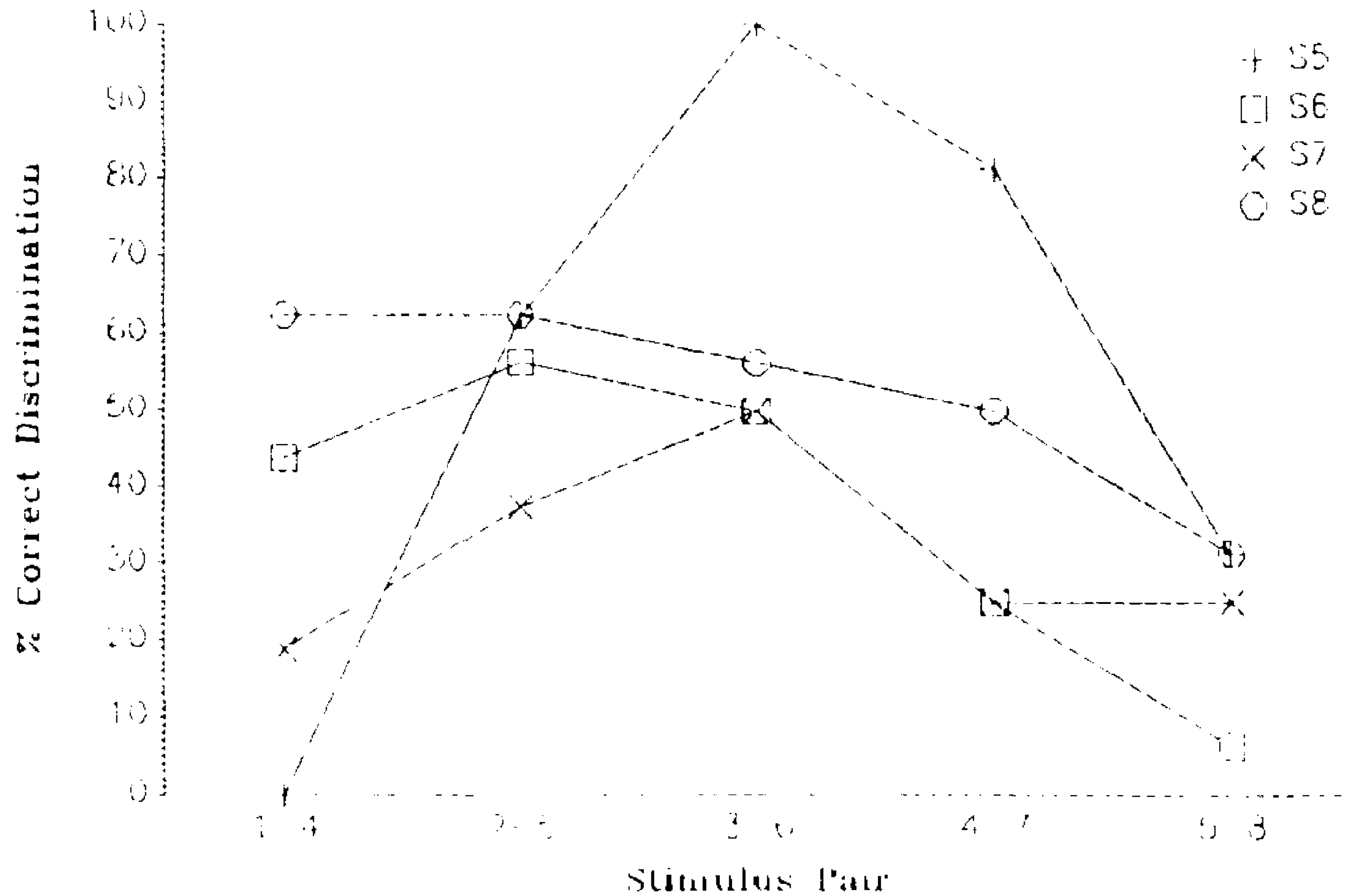

Figure 18

Performance of normal reading subjects 1-5
on /ba/-/wa/ discrimination task

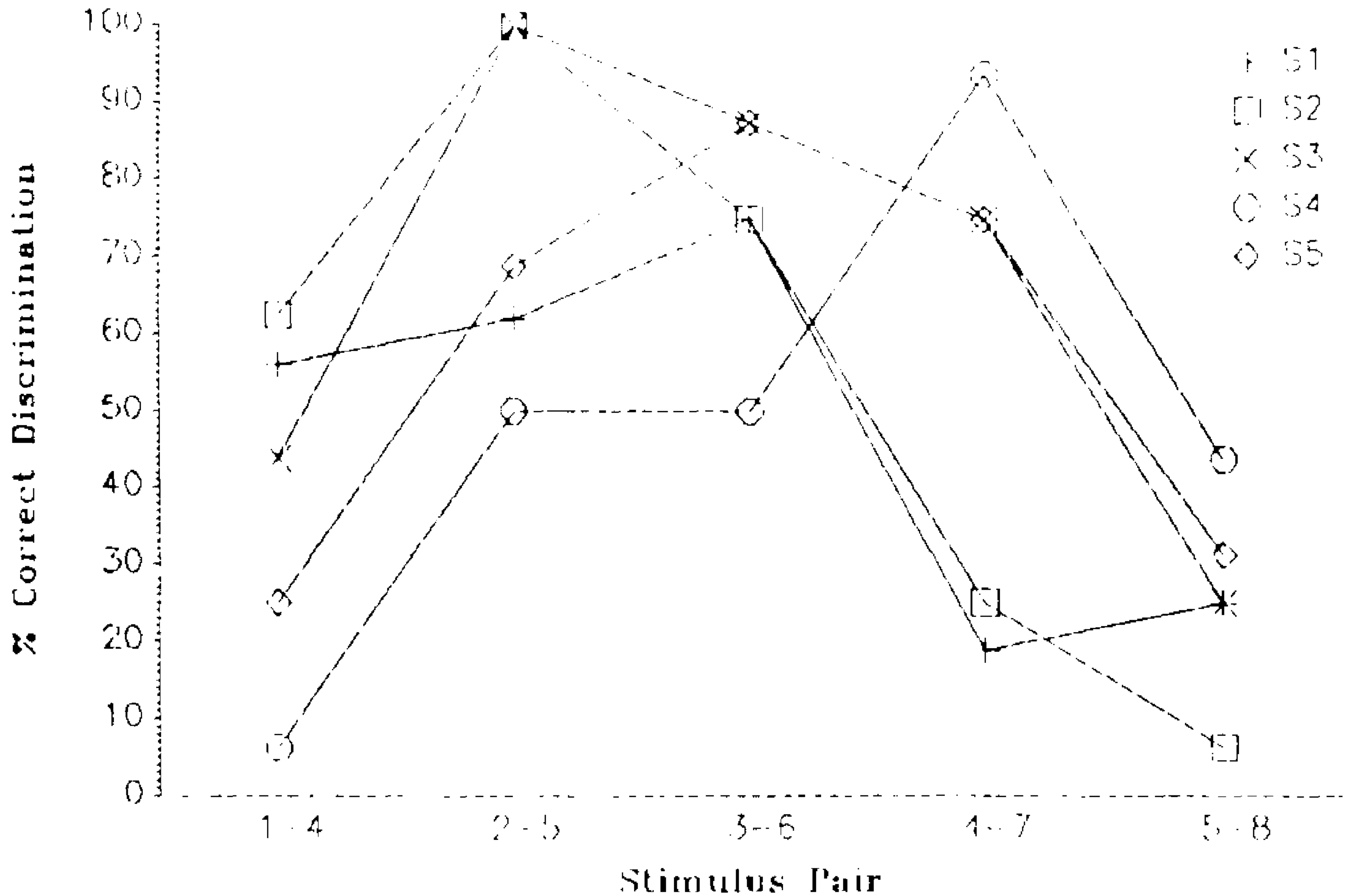

Figure 19

Performance of normal reading subjects 6-10
on /ba/-/wa/ discrimination task

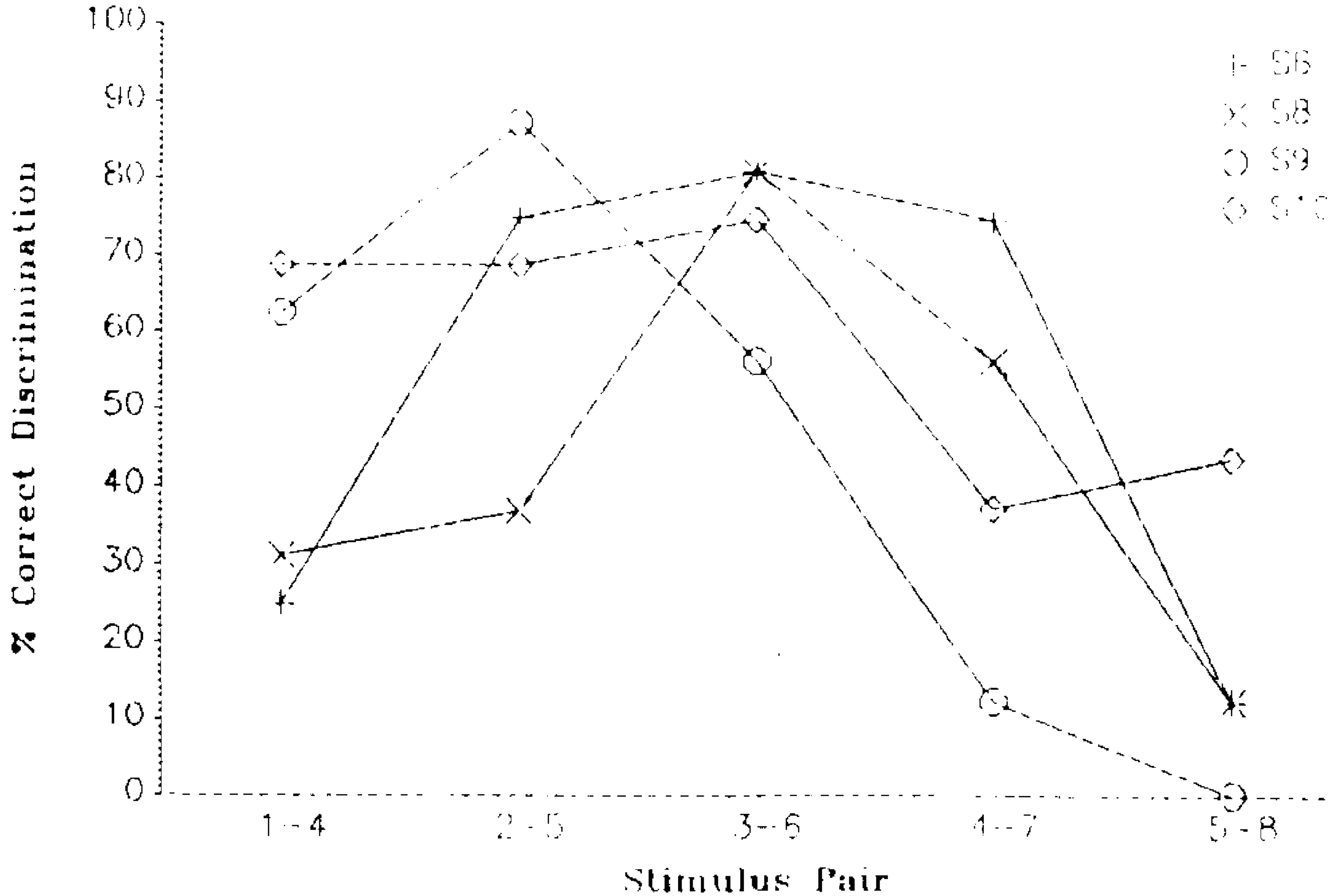

Figure 20

Performance of normal and dyslexic children on nonspeech discrimination task

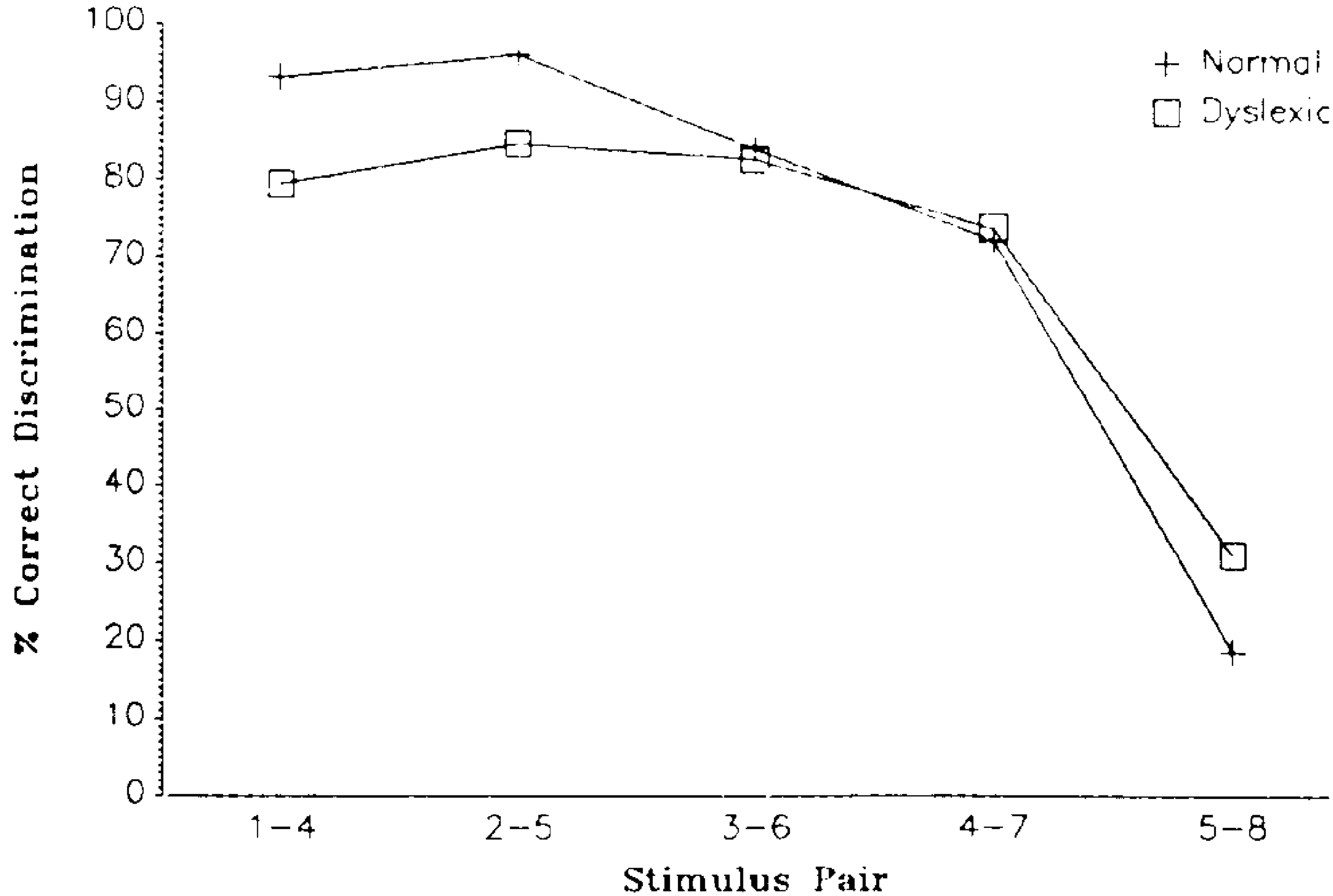

Figure 21

Performance of dyslexic subjects 1-4 on nonspeech discrimination task

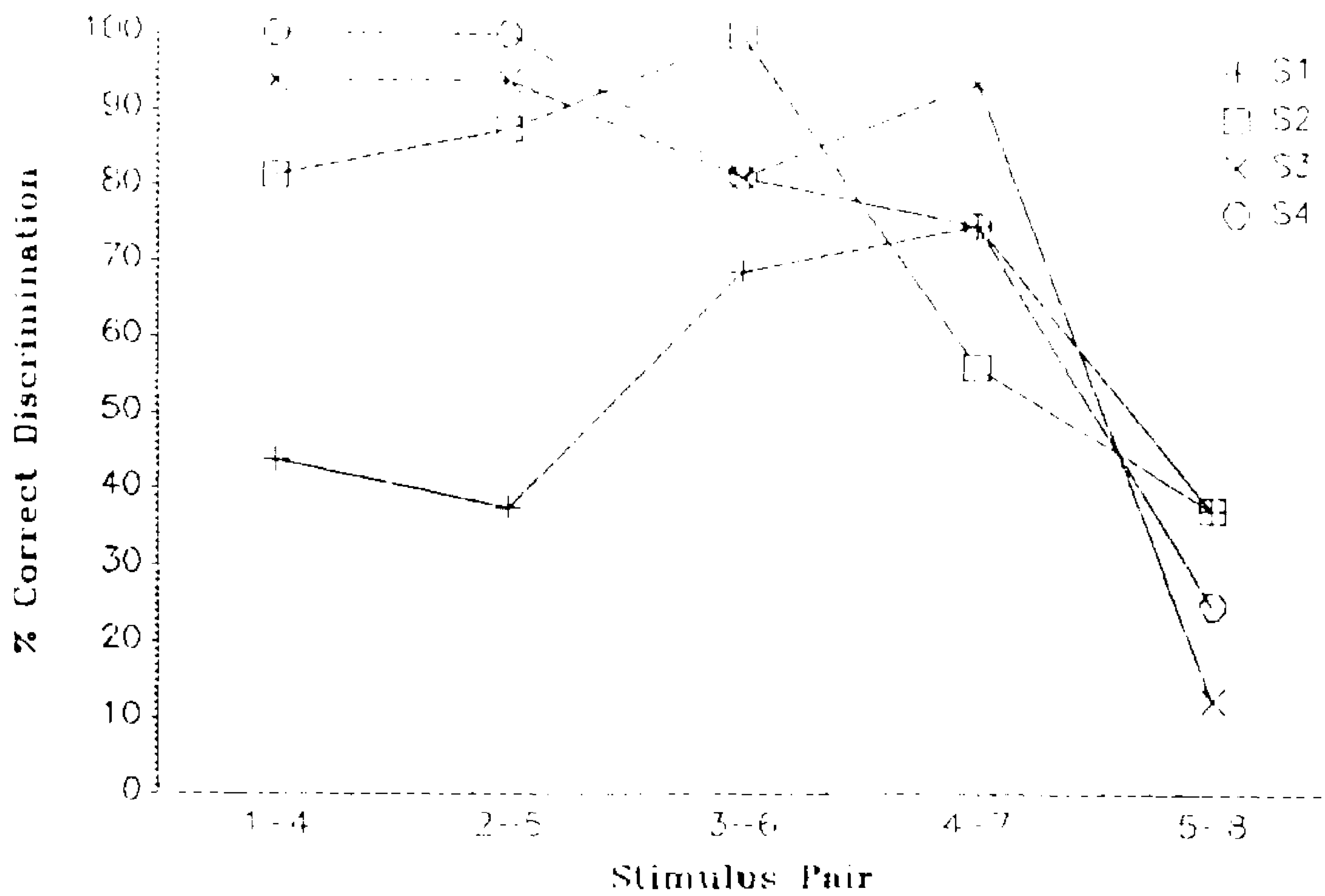

Figure 22

Performance of dyslexic subjects 5-6 and 8 on nonspeech discrimination task

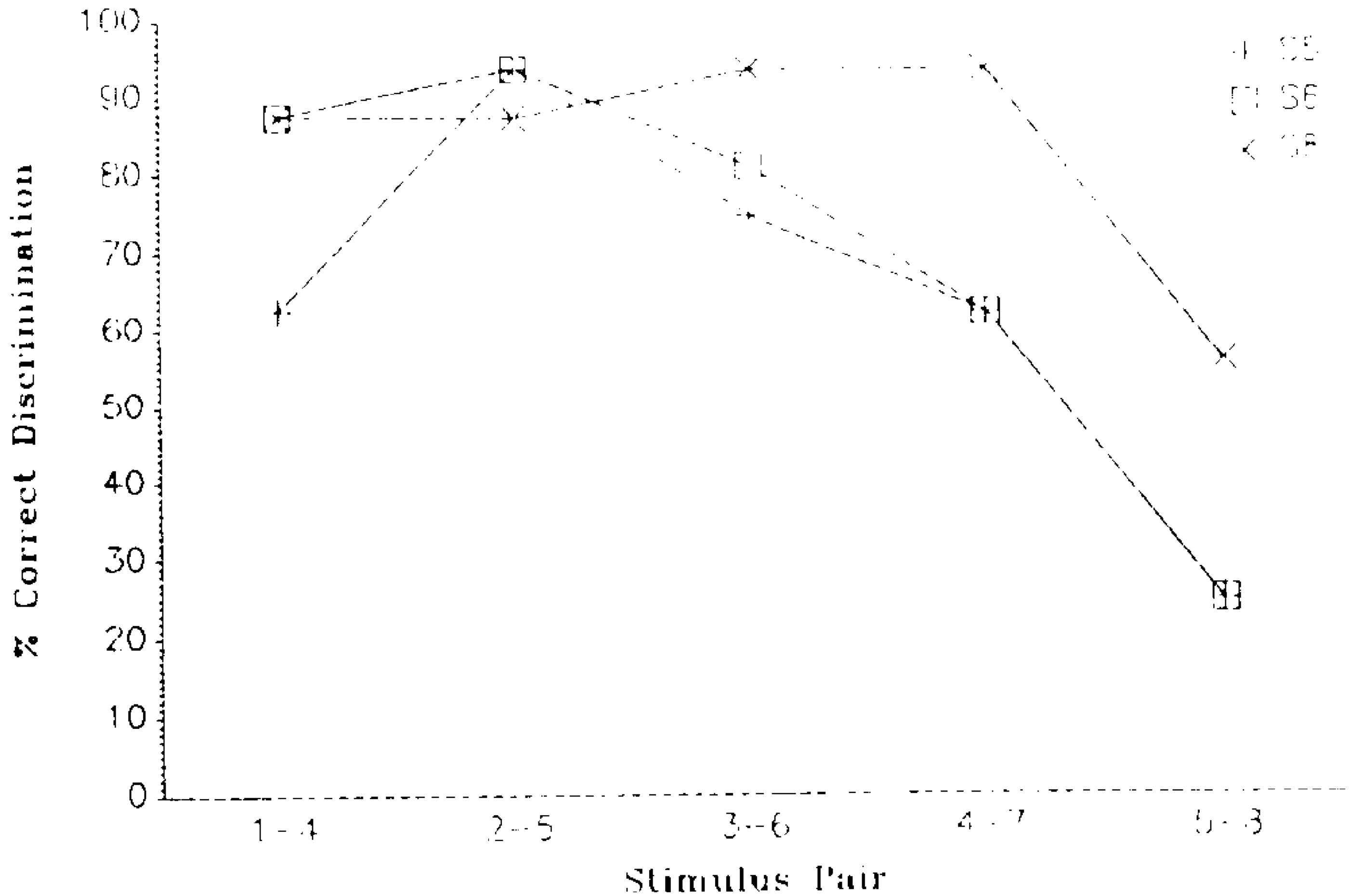

Figure 23

Performance of normal reading subjects 1-5 on nonspeech discrimination task

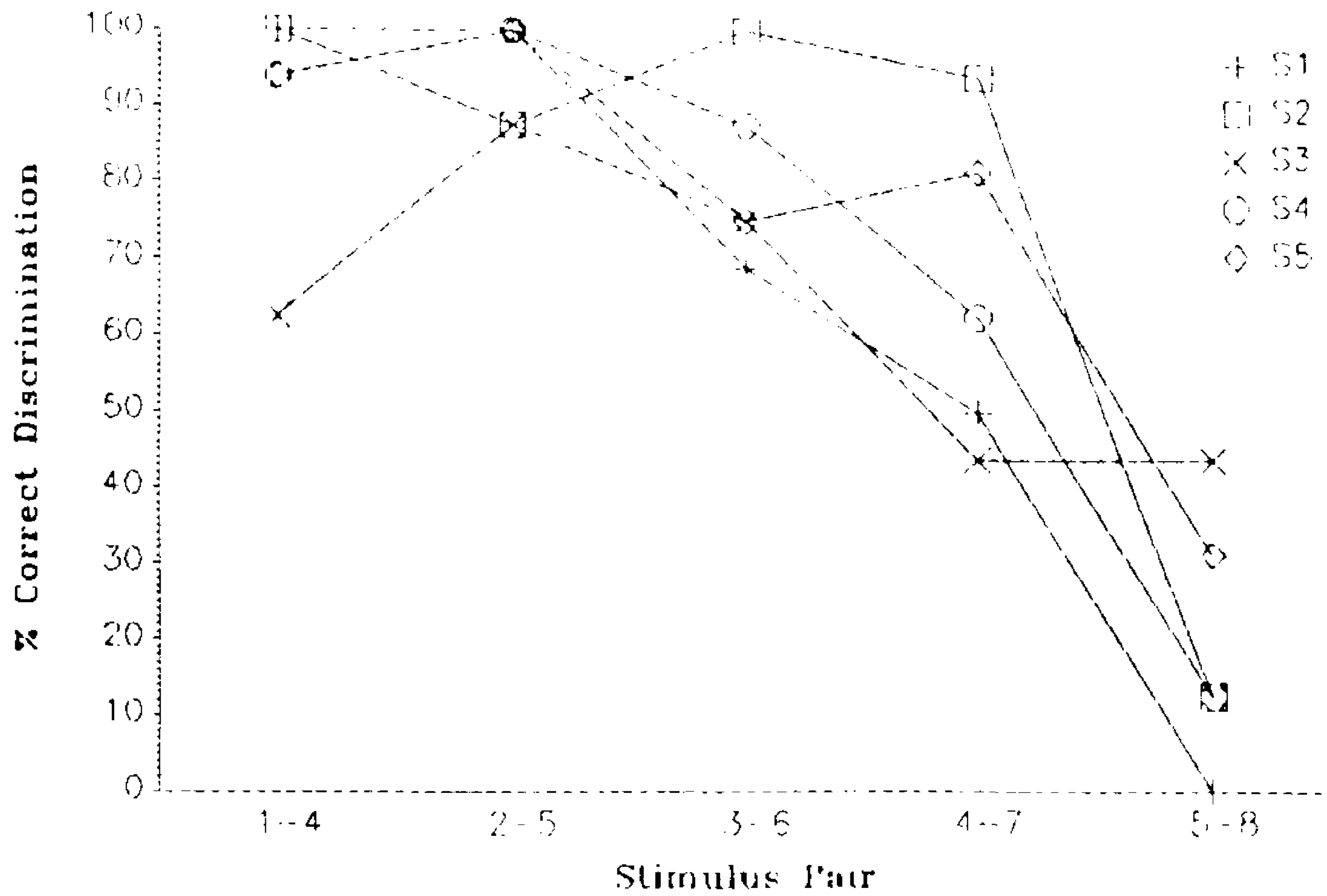

Figure 24

Performance of normal reading subjects 6-10
on nonspeech discrimination task

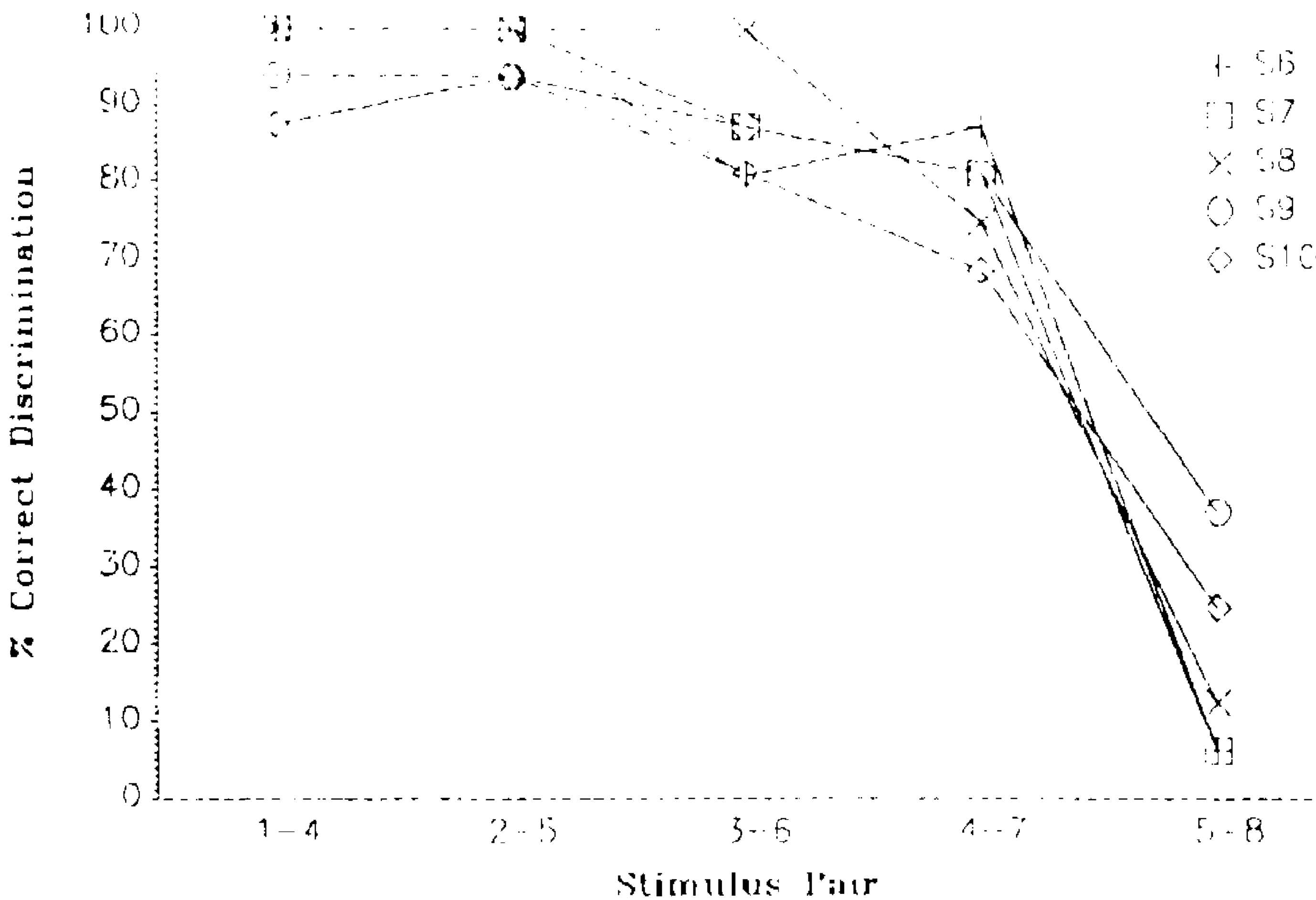

Figure 23

Performance of normal and dyslexic children
on time compressed speech task

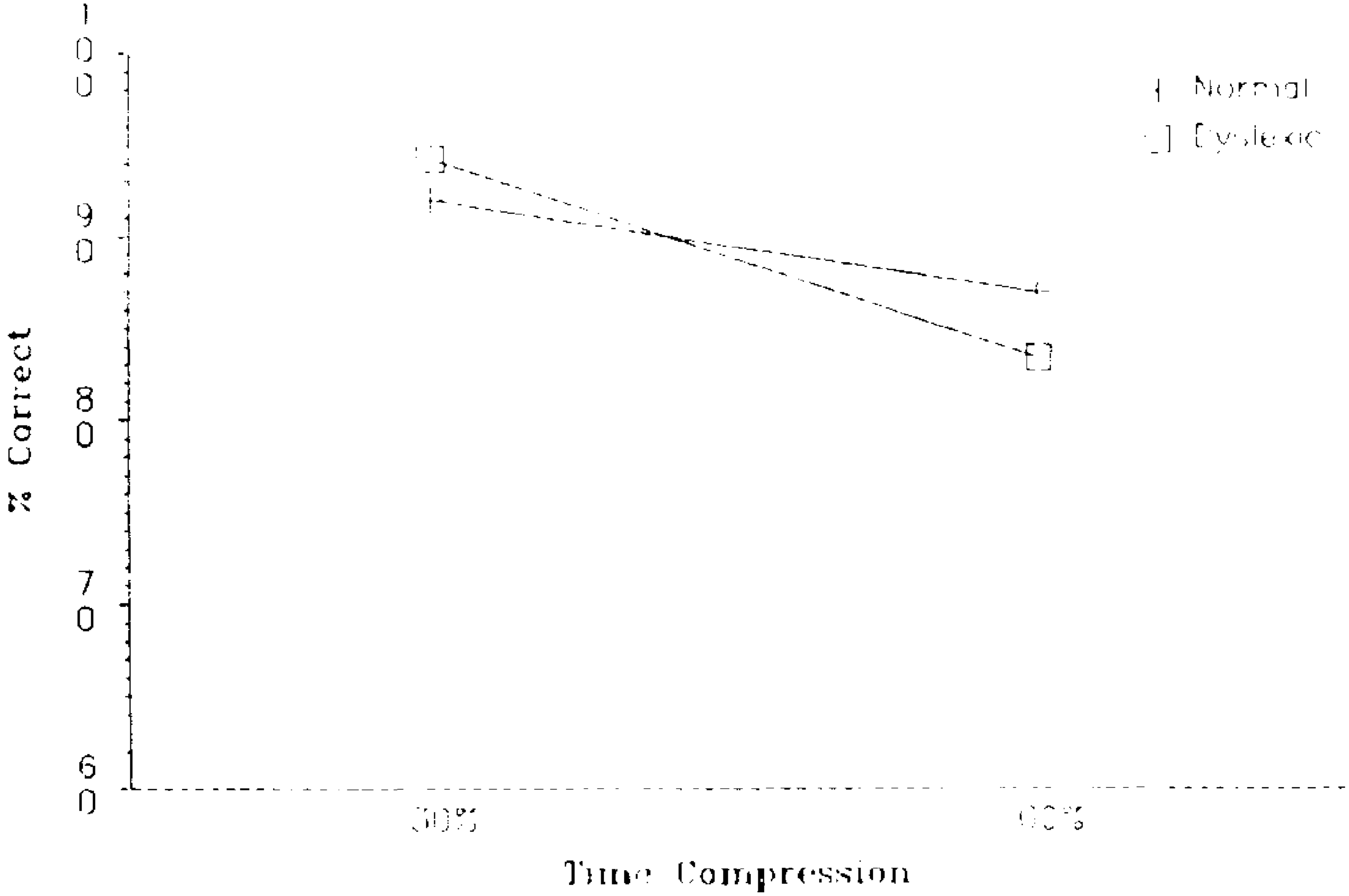

Figure 26

Performance of dyslexic subjects 1-4 on time compressed speech task

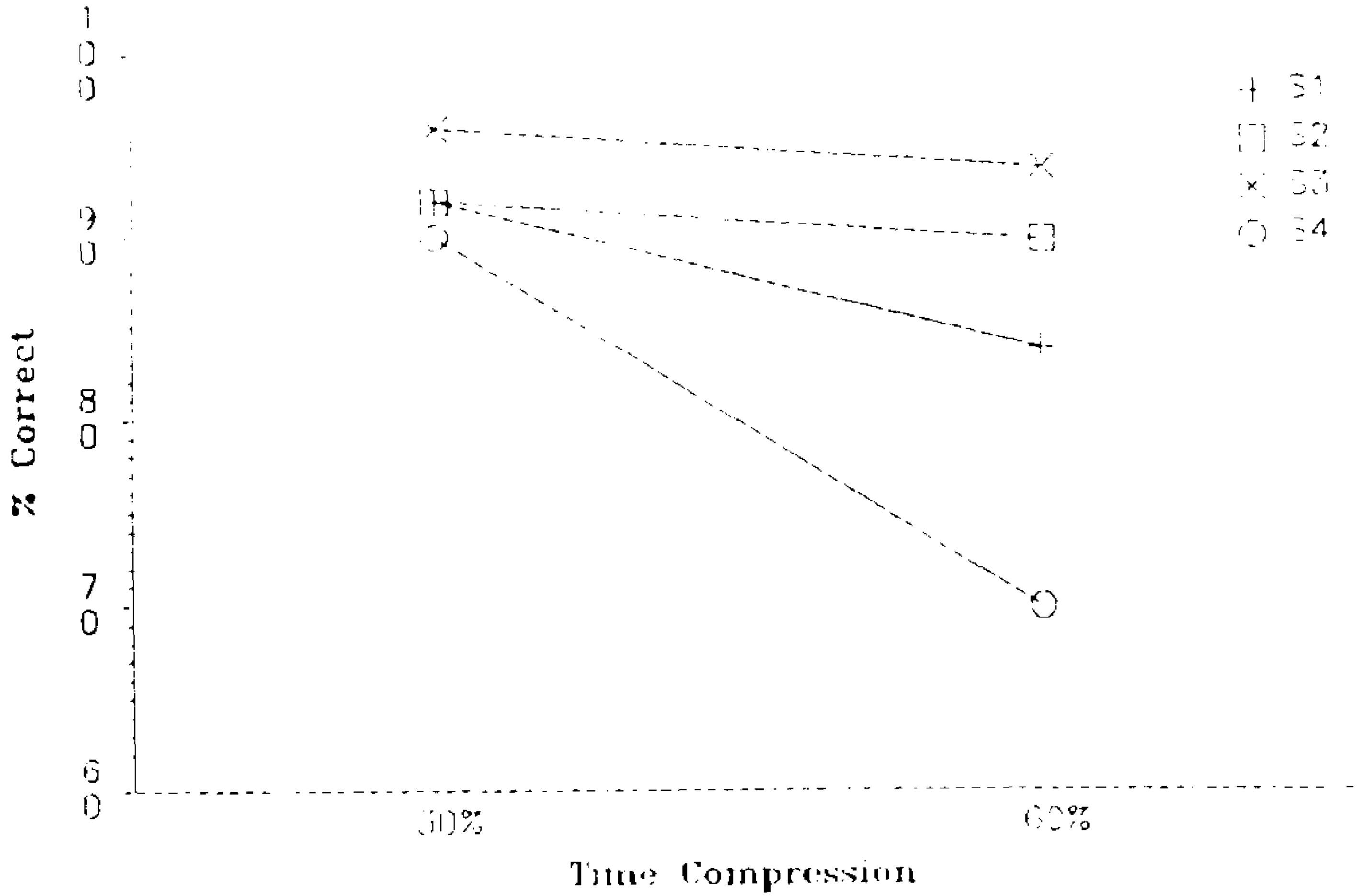

Figure 27

Performance of dyslexic subjects 5-8 on time compressed speech task

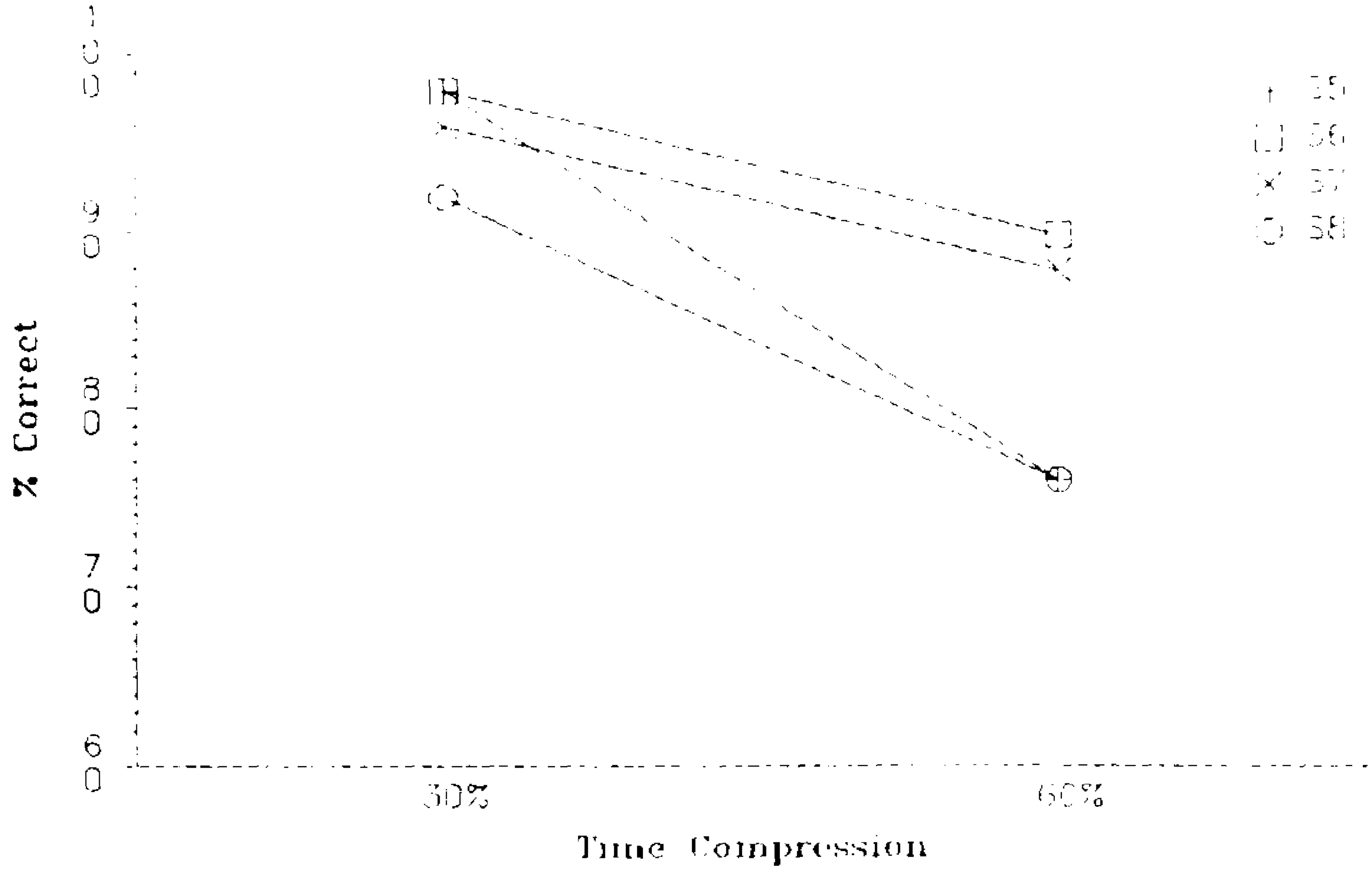

Figure 28

Performance of normal reading subjects 1-5
on time compressed speech task

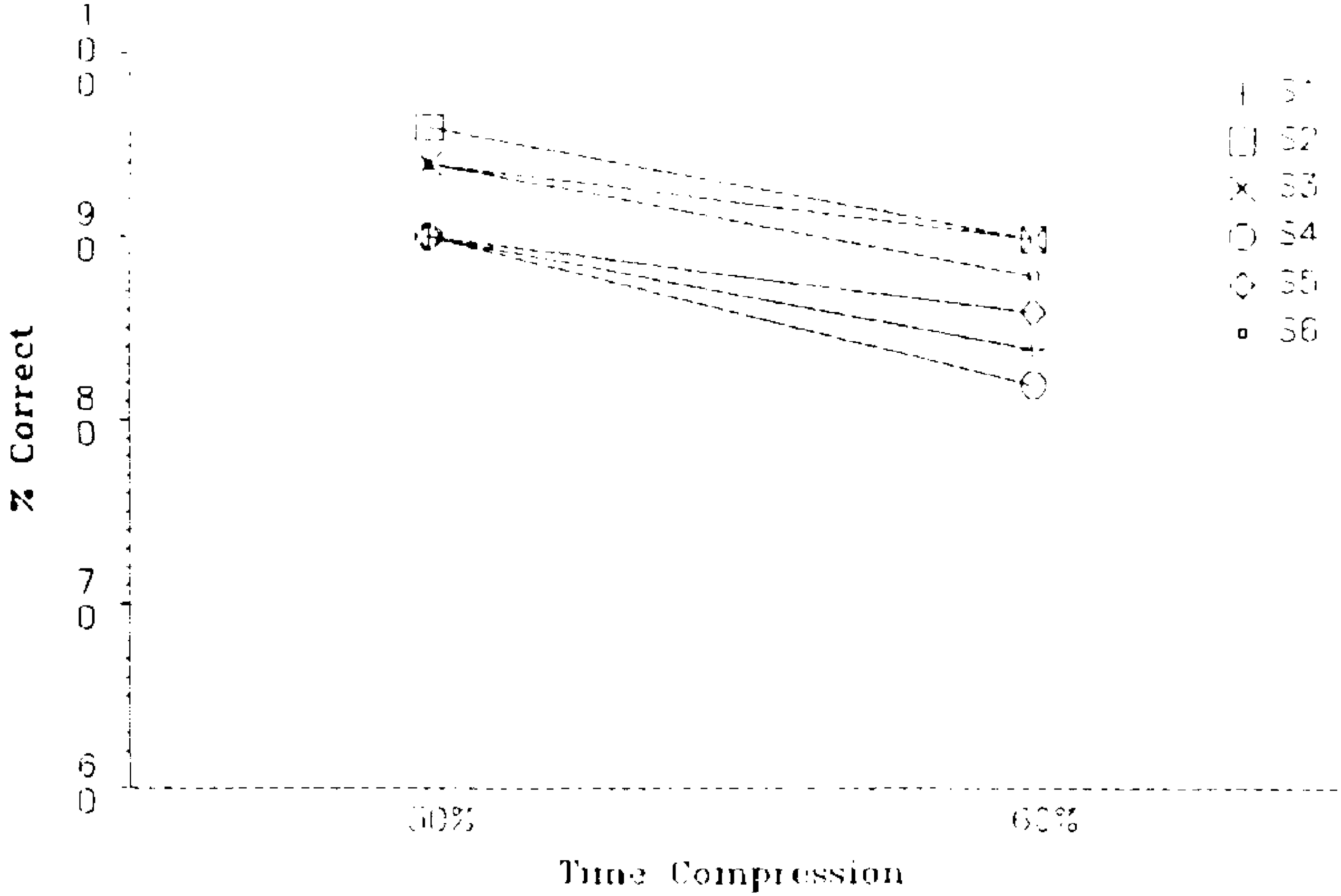

Figure 29

Performance of normal reading subjects 6-11 on time compressed speech task