

Auditory Phonemic Perception in Dyslexia: Categorical Identification and Discrimination of Stop Consonants

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The possibility that phonological confusions may underlie some difficulties in processing written language was investigated using four speech perception tasks. Twelve dyslexic and four normal-reading children identified and discriminated synthetic speech syllables which varied either in voice-onset time (signaling the feature of voicing) or direction of formant transitions (signaling place of articulation). Results indicate that, like normal-reading children and adults, dyslexic children perceive these sounds categorically. Discrimination of the stimuli was limited by their identifiability. It is suggested that linguistic disturbances at other stages of the grapheme to meaning transformation underlie misreading.

This report focuses on some speech perception capabilities of dyslexic children—children who, despite normal intelligence and motivation, lag behind their peers in ability to deal with written language. If the process of reading requires the transformation of the printed word into some phonological representation before meaning can be extracted (an admittedly contentious issue; see Marshall & Newcombe, 1973; Shallice &

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Warrington, 1975), it seems reasonable to raise the possibility that some reading-disabled children may have difficulty at the phonemic level of speech processing.

The question of phonological confusions in poor readers has been previously raised by Liberman, Shankweiler, Orlando, Harris, and Berti (1971). In their study of letter orientation errors in dyslexic children, they discovered that the four reversible lower-case letters (b,d,p,g) were not equally confused with each other. These errors, it should be noted, were relatively rare and occurred only in the poorest readers of their sample. However, of the orientation errors observed, "b" was often confused with both "p" and "d." "d" was often read as "b," but almost never as "p." To be sure, this finding can be explained on a purely visual basis ("d" requiring two 180° transformations to convert it to a "p," all other conversions requiring only one). Nonetheless, Shankweiler and Liberman (1972) opted for the following linguistic explanation: The phonemes /b/ and /p/ differ from each other only on the articulatory feature of voicing. /b/ is the voiced labial stop while /p/ is unvoiced. On the other hand, the phonemes /b/ and /d/ share the voice feature and differ on place of articulation. /b/ is a bilabial plosive while /d/ is alveolar. The phonemes /d/ and /p/, however, differ on both features of voicing and place (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). In order to confuse these phonemes, one would have to make two feature errors, despite the fact that Miller and Nicely (1955) have shown that when errors are made in consonant perception, the response typically differs from the target by a single feature.

The central question addressed in the present study is whether dyslexic children are deficient in their ability to extract from speech signals the information necessary to encode distinctive features phonetically. On most accounts, this information is considered to be only indirectly accessible from the acoustic properties of speech—i.e., no one-to-one relationship is thought to exist between sound waves and perceived phonemes. Rather, some phonemes are thought to be restructured into phonetically encoded features (Liberman et al., 1967).

Obviously, children with developmental dyslexia are not totally incapable of perceiving distinctive feature categories. The spoken words "bat" and "pat," for example, are not likely to be confused, especially if they are embedded in a semantic context. Even so, relatively subtle difficulties in perceiving speech segments may disrupt the ability of these children to establish graphemic-phonemic correspondences. One such difficulty might implicate the categorical nature of speech perception.

With auditory stimuli that are perceived continuously, such as pure tones, small changes in the physical aspects of the stimulus are perceived as gradual changes. This is also true of vowel perception (Stevens, Liberman, Studdert-Kennedy, & Öhman, 1969). In the perception of most consonants, however, continuous changes in the acoustic signal have no

significance until a sudden qualitative change in phonemic category is noticed. This "categorical perception" of speech also includes the inability to discriminate speech segments unless they are assigned to different phoneme classes (Lieberman et al., 1967). Thus, although one can usually discriminate many more stimuli than can be labeled with a continuously perceived continuum, discrimination of the distinctive features of speech consonants is limited by the listener's ability to provide different phoneme labels for the stimuli.¹

The study reported here examined the extent to which reading-disabled children perceive speech categorically. The first phase of the study used a series of synthetic speech stimuli which varied in voice-onset time (VOT). VOT refers to the time (in milliseconds) between the release of the burst of the stop consonant and the onset of laryngeal pulsing (Lisker & Abramson, 1964). Previous studies with normal adults (Lisker & Abramson, 1964; Liberman, Harris, Kinney, & Lane, 1961), young children (Wolf, 1973), and infants (Eimas et al., 1971) have indicated that variation in VOT is a sufficient cue to the voiced-unvoiced distinction (i.e., between the phonemes /b/ and /p/, /d/ and /t/, and /g/ and /k/).

The second phase of this study made use of stimuli which varied along the dimension of place of articulation. This distinction between the bilabial, alveolar, and velar stop consonants has been shown to correspond to the extent and direction of the second and third formant transitions of the stimuli (Delattre, Liberman, & Cooper, 1955; Liberman, Harris, Hoffman, & Griffith, 1957). Place of articulation is considered a more highly encoded articulatory feature than is voicing as it is less closely tied to invariance in the acoustic waveform (Lieberman et al., 1967). Therefore, considerable restructuring of the speech signal is required to extract linguistic information from the place series. If poor readers do have difficulty constructing phonemic categories, it is probably more likely to be manifest on the place of articulation tasks.

METHOD

Subjects

Twelve reading-disabled and four normal-reading boys served as subjects. They were all prescreened for normal audiometric thresholds.

The dyslexic children were students at The Landmark School, Prides Crossing, Massachu-

¹ Studies of the speech perception abilities of infants (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) and non-human mammals (Kuhl & Miller, 1975; Waters & Wilson, 1976) have produced results contrary to this assumption. These subjects evidence discrete discrimination boundaries between sounds perceived by adult humans as different phonemes while obviously not themselves able to provide phoneme labels. In addition, a study of aphasic adults (Blumstein, Cooper, Zurif, & Caramazza, 1977) has demonstrated that Wernicke's aphasics are often able to discriminate speech syllables categorically while unable to label them consistent with the discrimination. In spite of these data, the formal theory of categorical perception assumes that the discriminability of speech sounds depends on the listener's ability to assign them to different linguistic categories.

setts, a school specializing in the remediation of learning disabilities. They were all at least 2 years behind their age mates in reading level, as determined by the Gray Oral Reading Test and the Slosson Oral Reading Test. None of the children had obvious neurological or behavioral problems. Their average age was 10.5 years (range 8.4 to 12.4) at the start of the study.

Due to the linguistic nature of the tasks employed, level of verbal ability was considered a factor in the selection of reading-disabled subjects. The 12 dyslexic boys were therefore assigned to one of three groups on the basis of their verbal and performance subscales of the revised Wechsler Intelligence Scale for Children (Wechsler, 1974). Four subjects were selected whose verbal IQs exceeded their performance IQs by 15 points or more (higher VIQ group). Similarly, there were four subjects with verbal IQs 15 points or more lower than their performance IQs (lower VIQ group). A third group was composed of four children with verbal-performance IQ discrepancies of 10 points or less (even VIQ-PIQ group).

The mean full-scale IQ for the 12 dyslexic subjects was 105 (range 94 to 126). The three groups differed, however, in their mean full-scale IQs: higher VIQ = 98, lower VIQ = 115, even VIQ-PIQ = 101 ($F(2, 9) = 5.75, p < .025$). These differences, while statistically significant, are not seen as theoretically meaningful since all the subjects obviously had the general cognitive capacity to comply with the instructions and participate fully in the experiment.

The four normal-reading boys were all relatives or neighbors of the authors' colleagues. All were reported by their parents to be at or above grade level in reading ability and free of learning or behavioral problems. Their mean age was also 10.5 years (range 9.3 to 12.1). Additional data from nondyslexic children on similar speech perception tasks may be found in Bennett and Ling (1973, their control group) and Wolf (1973).

Each reading-disabled subject participated in two experimental sessions. The first session was devoted to the study of voice-onset time. In the second session, conducted approximately 3 months after the first, perception of place of articulation was studied. The normal-reading subjects performed both sets of tasks on the same day.

Stimuli

Voice-onset time. The speech stimuli consisted of 11 synthetic consonant-vowel syllables produced by a computer-controlled parallel resonance synthesizer at Haskins Laboratories, New Haven, Connecticut. These three-formant stimuli were 350 msec in duration and differed from each other only on the dimension of voice-onset time. For each stimulus, the first formant (F1) transition started at 200 Hz and rose to a steady-state frequency of 800 Hz. F2 started at 1800 Hz and dropped to 1250 Hz, while F3 began at 3200 Hz and increased in frequency to a steady-state level of 3500 Hz. VOT values ranged from -20 msec (F1 preceding onset of F2 and F3 by 20 msec) to +80 msec (F1 onset lagging 80 msec behind onset of F2 and F3). The VOT continuum was in 10-msec steps. Previous studies with adult listeners (e.g., Liberman et al., 1961) and children (Wolf, 1973) indicated that these stimuli are perceived either as the voiced plosive /d/ or the unvoiced /t/ followed, in each case, by the vowel /a/.

Test stimuli for the identification task consisted of 10 random presentations of each of the 11 syllables. The interstimulus interval was 4 sec.

For the discrimination of VOT, the stimuli were recorded in pairs. The members of each pair were either identical stimuli, or differed from each other by 20 msec VOT. The interstimulus interval was 1 sec and the intertrial interval was 3.5 sec.

Of the 141 discrimination trials, there were 108 "different" trials and 33 "same" trials (identical stimuli). Not all the possible "different" pairs appeared with equal frequency. Since the stimulus pairs with VOTs of +10 and +30, +20 and +40, and +30 and +50 were assumed to comprise critical trials (based on work with normal subjects), these pairs appeared 24 times each. The remaining "different" pairs appeared 6 times each and the "same" pairs appeared 3 times each.

Place of articulation. Fourteen five-formant stimuli were used in this phase of the study. The sounds differed from each other only in the direction and extent of the F2 and F3 transitions. All the stimuli were 250 msec in duration.

The first three formants of each sound began with linear transitions and terminated in steady-state positions corresponding to the vowel /a/. The duration of the F2 and F3 transitions was 40 msec, while the F1 transition varied in duration. For all 14 stimuli, the first formant began at 200 Hz and rose in frequency to a fixed-formant position of 720 Hz. The second and third formants began at variable frequencies and leveled off at 1170 and 2600 Hz, respectively. (See Blumstein, Stevens, & Nigro, 1977, for a more detailed description of the stimuli.) Previous studies with normal adult listeners (e.g., Delattre et al., 1955) have revealed that these variations in the F2 and F3 transitions correspond to the bilabial (/ba/), alveolar (/da/), and velar (/ga/) places of articulation.

The identification task consisted of 15 practice trials followed by 10 random presentations of each of the 14 stimuli. The interstimulus interval was 4 sec. The discrimination task consisted of 120 stimulus pairs. On half of these trials (the "same" trials) the same stimulus appeared in both halves of each trial. Of the 60 "different" trials there were an equal number of each of the 12 different stimulus combinations. A sound was always paired with one two stimulus numbers away. Thus, five trials paired stimulus 1 with stimulus 3, five paired stimulus 2 with stimulus 4, five paired stimulus 3 with stimulus 5, and so on. The order of presentation of the pairs was randomized. The interstimulus interval was 2 sec and the intertrial interval was 4 sec.

Procedure

The subjects were tested individually in a quiet room. The test tapes were played on a Teac 2340 tape recorder and the stimuli were delivered binaurally to the subjects at 70 db (A scale) via Koss Pro-40 headphones.

Voice-onset time. For the identification task, the subjects first labeled six syllables produced orally by the experimenter. Since the dyslexic children are known to have difficulty with written language, all subjects were asked to clearly speak their responses, rather than write them or point to printed "da"s and "ta"s. The subjects were then presented with six practice syllables selected from the identification tape. The stimuli selected were unambiguously /da/ or /ta/; i.e., they occupied the extremes of the VOT continuum. If the subject responded correctly to four of the six trials, he was included in the study. None of the subjects failed to meet this criterion. The entire identification tape was then played and the subject verbally labeled each stimulus "da" or "ta" as it was presented. No feedback was provided by the experimenter.

For the phoneme discrimination task, a two-interval AX procedure was used (as by Wolf, 1973). The subjects were presented with a pair of stimuli and their task was to decide whether or not the sounds were identical. They said "same" or "different" depending on their judgment about the pair. As in the identification task, subjects first made judgments about six experimenter-produced stimulus pairs. They then practiced on six unambiguous synthetic speech pairs before proceeding with the 141 test trials.

It should be noted that the ABX procedure, in which the final member of a triad is judged to be more similar to either the first or second stimulus, is more usually employed in discrimination studies of this kind. However, that procedure may have the disadvantage of placing a heavy load on memory, requiring the listener to first label the sounds and then make the discrimination (Pollack & Pisoni, 1971). That is, the ABX procedure may, in effect, induce categorization (Pollack & Pisoni, 1971; Wood, 1977). The AX same-different paradigm used in this study is probably more appropriate, as well as being easier for most children (Wolf, 1973).

Place of articulation. The procedure in this phase of the study was essentially the same as in the VOT phase. To begin the identification task, subjects were asked to verbally respond

“ba,” “da,” or “ga” to six syllables clearly spoken by the experimenter. They then practiced for 15 trials on unambiguous stimuli taken from the series of test stimuli before commencing with the actual 140-trial identification test.

For the AX discrimination task, subjects said “same” or “different” to six pairs of syllables produced by the experimenter and then to 12 practice trials of synthetic syllables. This was followed by the actual 120-trial discrimination test.

RESULTS

Voice-Onset Time

The distribution of /d/ and /t/ responses to the 11 stimuli was determined for each subject. Inspection of the identification distributions revealed that all 12 dyslexic subjects labeled the stimuli similarly. Sounds with VOTs less than +30 msec were consistently labeled /d/ while those with VOTs greater than +40 msec were consistently labeled /t/. In all cases, the identification functions were marked by a steep curve, indicating a sharp phoneme boundary.

For each subject, a discrimination function was constructed by plotting the percentage correct responses for the nine “different” pairs of stimuli. Each subject’s function was marked by a single peak at the locus of his labeling boundary. This indicates poor discrimination at the extremes of the VOT continuum but good discrimination between stimuli given different phoneme labels.

The mean identification and discrimination functions for the three groups of dyslexic subjects are presented in Figs. 1a–c. The functions for the four normal readers appear in Fig. 1d.

The percentage of correct “same” responses was also calculated for each subject. This measure of the subject’s response bias is needed since saying “different” on every trial of the discrimination test would yield 100% correct discrimination. The mean percentage of correct “same” responses for the higher VIQ group was 92.5% ($SD = 5.20$), 87.25% for the even VIQ–PIQ group ($SD = 5.12$), 91.0% for the lower VIQ group ($SD = 10.10$), and 91.75% ($SD = 8.60$) for the normal readers. These values do not differ significantly ($F(3, 12) = 0.61$).

Since the three dyslexic groups produced very similar identification and discrimination functions, the data from all 12 reading-disabled subjects were pooled. The resulting labeling function is presented in Fig. 2a. The mean of this curve (corresponding to the phoneme boundary) and its slope ($1/SD$) were estimated by the unweighted least-squares method (Guilford, 1954). A least-squares fit was made to the data points for +20, +30, +40, and +50 msec VOT.² The phoneme boundary was found to be at 37.33

² Since the stimuli at the ends of the VOT continuum were labeled so consistently, the curve-fitting procedure was restricted to the transition region of the identification function (Lindblom & Studdert-Kennedy, 1967; Wolf, 1973). As is common practice, we included only one data point below 10% and one above 90% identification, with the additional requirement that there be an equal number of data points above and below 50% identification.

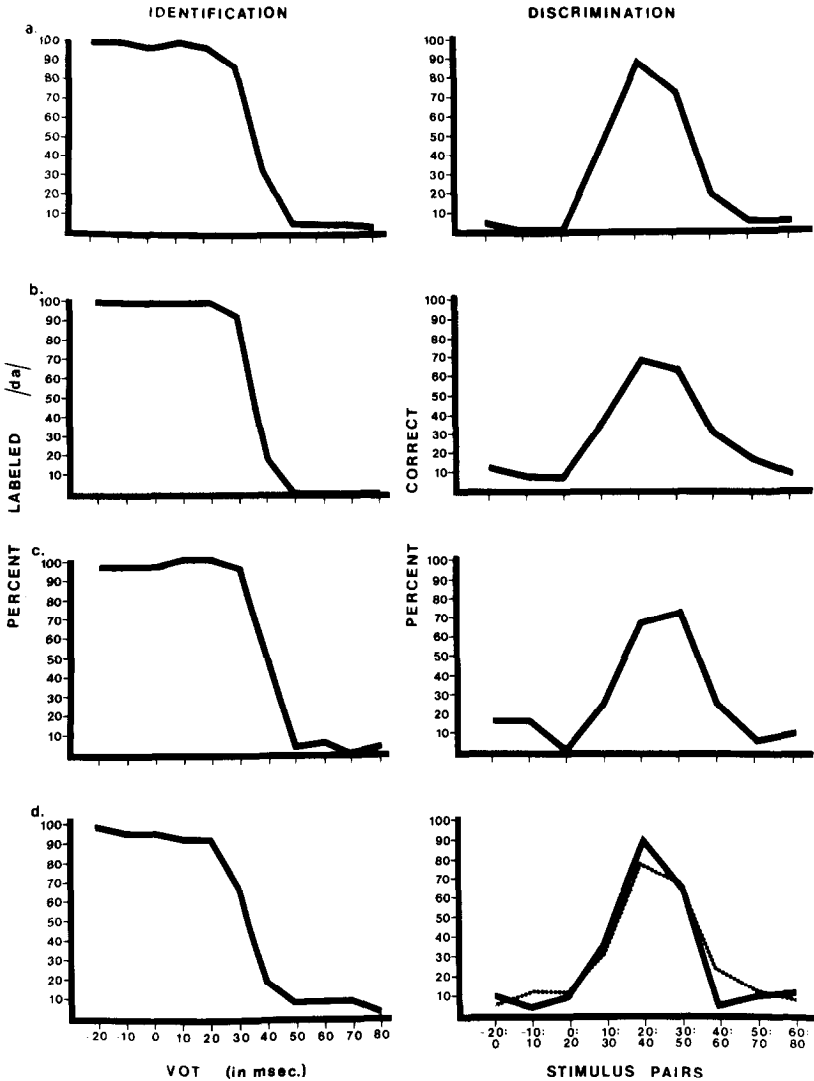


FIG. 1. VOT identification and discrimination functions for four groups of subjects: (a) higher VIQ group, (b) even VIQ-PIQ group, (c) lower VIQ group, and (d) normal-reading controls. Each graph represents data averaged from four subjects. For the identification functions, the percentage of /da/ responses to each of the 11 stimuli is plotted. In the discrimination functions, the percentage of trials on which the stimulus pair was judged "different" is plotted as a function of the VOT of the stimuli. Broken line in (d) is discrimination function predicted from identification data.

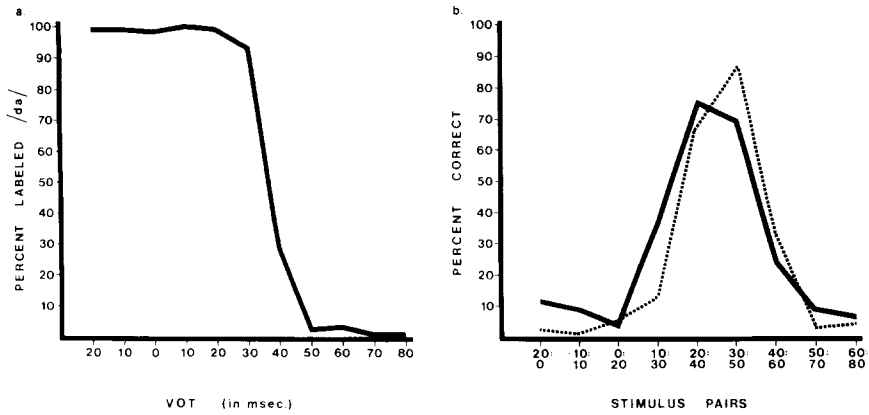


FIG. 2. (a) Average VOT identification function for 12 dyslexic subjects. (b) Average VOT discrimination function for 12 dyslexic subjects. Solid line represents obtained discrimination. Broken line is function predicted from identification data.

msec VOT, and the *SD* to be 6.65 msec. A χ^2 test revealed that the line fit by this method approximated the obtained data points well ($\chi^2(1) = .46, p > .30$).

For the normal-reading group (see Fig. 1d), the phoneme boundary was at 35.02 msec VOT (*SD* = 9.97). Goodness-of-fit was established at $p > .50$ ($\chi^2(1) = .035$).

The average discrimination function for the 12 dyslexic subjects is presented in Fig. 2b. It can readily be seen that the two stimulus pairs which were most often correctly discriminated (+20: +40 and +30: +50) were those which bridged the phoneme boundary. Also presented in Fig. 2b is the discrimination function that would be predicted from the identification data on the basis of absolute categorical perception; that is, if the subjects could discriminate two stimuli only if they labeled them as different phonemes. The method used to generate the predicted discrimination function was Wolf's modification (1973) of the procedure used by Liberman et al. (1957). Given the AX procedure and the two phonemic categories, a pair of stimuli could be judged "different" (assuming the strict view of categorical perception) only if the first stimulus was labeled as one phoneme and the second was labeled as the other phoneme. Thus, predicted discrimination was calculated as the probability that the first stimulus was labeled /da/ and the second /ta/, plus the probability that the first was labeled /ta/ and the second /da/. These probabilities were derived from the percentage of trials of the discrimination task that a given stimulus was labeled either /da/ or /ta/.

The expected discrimination function fits the actual data well. A measure of relationship between the obtained and expected percent-

ages, Kendall's rank-order correlation, yields a τ value of .44 ($p = .06$). However, the obtained function is slightly flatter (i.e., has a lower peak and higher troughs) than the expected function. This indicates that discrimination within phoneme classes is somewhat better than absolute categorical perception would predict and discrimination across classes is slightly poorer.

The obtained and expected mean discrimination functions for the four normal readers are seen in Fig. 1d. Kendall's τ between the two sets of ranked percentages is .38 ($p = .07$). Unlike in Fig. 2b, there is no indication that the obtained function is flatter than predicted. If anything, these subjects are even more accurate in their interphonemic discriminations than their labeling performance would predict.

Place of Articulation

Identification and discrimination functions were constructed for all subjects. Three reading-disabled children (two in the lower VIQ group and one in the even VIQ-PIQ group) did not generate data of the form expected on the basis of studies with normal-reading adults (e.g., Liberman et al., 1957). In general, their identification functions did not show a sharp boundary between stimuli labeled /d/ and /g/, and their discrimination functions did not have two distinct peaks. These subjects were retested approximately 3 months later on the two place tasks. In all three cases, the results of this second session were less deviant than the first and they will be included in the analyses reported here.³

The mean identification and discrimination functions for the three dyslexic groups are presented in Fig. 3a-c. The performance of the normal-reading group on the place tasks is illustrated in Fig. 3d. In general, the labeling functions have steep slopes, indicating sudden transitions between /ba/ and /da/, and /da/ and /ga/. The even VIQ-PIQ group is somewhat aberrant in that the stimuli at the high end of the series, which are usually consistently labeled /ga/, were labeled as such on less than 70% of the trials. This is largely due to one of the four subjects in this group who persisted in identifying these sounds as /da/.

The discrimination functions are also of the expected form. They all have two peaks, indicating better discrimination when the two sounds are

³ The authors consider this retesting of subjects legitimate in view of the fact that several researchers (e.g., Basso, Casati, & Vignolo, 1977; Liberman et al., 1961; Wolf, 1973) discard data from subjects who fail to label the stimuli as expected. Since one of the goals of this study was to determine whether learning-disabled children are deficient in their ability to hear these sounds as speech and respond to them as normal-reading children do, none of the subjects in this study was eliminated. The initial failure of three subjects to demonstrate clear categorical perception for place might be attributed to the nature of the acoustic cues for this linguistic feature or the greater difficulty inherent in three-alternative tasks compared to two-alternative tasks like identification of voicing.

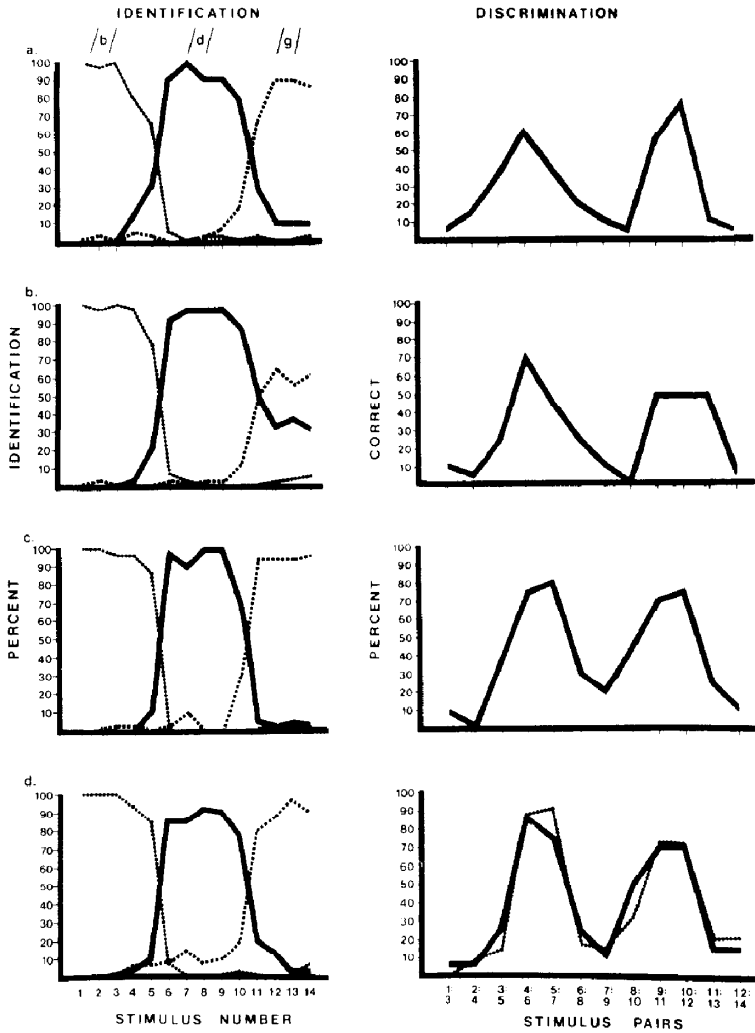


FIG. 3. Place of articulation identification and discrimination functions for four groups of subjects (a) higher VIQ group, (b) even VIQ-PIQ group, (c) lower VIQ group, and (d) normal-reading controls. Each graph represents data averaged from four subjects. In the identification functions, the left-most curve represents percentage labeled /ba/, the center curve /da/, and the right-most /ga/. Percentage correct "different" responses for the stimulus pairs is shown in the discrimination functions. Broken line in (d) is discrimination function predicted from identification data.

labeled as different phonemes. The function for the even VIQ-PIQ group has one flattened peak, corresponding to the ambiguity in the /da/-/ga/ boundary evident in the identification function.

The percentage of correct "same" trials was calculated for each subject. The mean response bias for the higher VIQ group was 85.0% (SD =

7.70), 83.25% for the even VIQ-PIQ group ($SD = 9.07$), 84.75% for the lower VIQ group ($SD = 15.61$), and 83.75% ($SD = 10.24$) for the normal readers. These differences between groups are not statistically significant ($F(3, 12) = .02$).

The data from all 12 dyslexic subjects were pooled and the resulting labeling function is presented in Fig. 4a. The two phoneme boundaries and their standard deviations were calculated by the least-squares method described earlier. For the /b/-/d/ boundary, a straight line was fit to the data points for stimuli 4, 5, 6, and 7. The phoneme boundary is at 5.30 ($SD = 0.82$). A χ^2 test establishes the goodness-of-fit at $p > .10$ ($\chi^2(1) = 2.67$).

In determining the /d/-/g/ boundary, the data points for stimuli 7 through 14 were included. The mean of the function is 11.26 and the SD is 2.32. Again, the goodness-of-fit is established at $p > .10$ ($\chi^2(5) = 8.52$).

For the normal readers (Fig. 3d), the /b/-/d/ boundary is at 5.82 ($SD = 1.12$; goodness-of-fit $\chi^2(3) = 2.19$, $p > .50$), while the /d/-/g/ boundary is at 10.39 ($SD = 1.35$; $\chi^2(3) = .96$, $p > .80$).

The obtained phoneme boundaries for both groups of children approximate those obtained by Blumstein et al. (1977) using the same stimuli. The normal adults in their study had a /b/-/d/ boundary at 5.4 ($SD = 0.21$) and a /d/-/g/ boundary at 10.2 ($SD = 0.36$). It is also interesting to note that in both Blumstein's study and the present one, the /d/-/g/ boundary is less steep than the /b/-/d/ boundary. The transition between the syllables /da/ and /ga/ is somewhat less categorically perceived than the transition between /ba/ and /da/, especially for the dyslexic subjects. In general, the children in this study were slightly less categorical in the description of

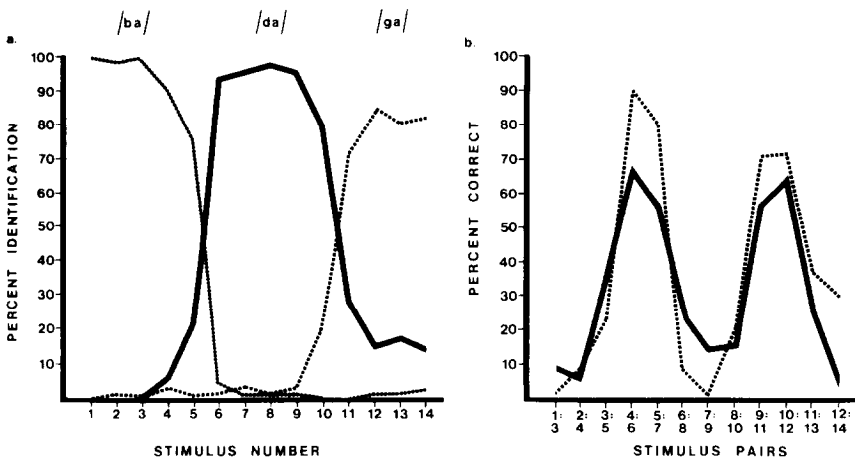


FIG. 4. (a) Average place identification function for 12 dyslexic subjects. (b) Average place discrimination function for 12 dyslexic subjects. Solid line represents obtained discrimination. Broken line is function predicted from identification data.

these stimuli (as indicated by the higher standard deviations of their labeling functions) than normal adults.

Figure 4b shows the observed and predicted mean discrimination functions for the dyslexic group for the place of articulation series. The expected percentage correct for each pair, assuming that these stimuli can only be perceived categorically, was calculated using the following formula:

$$\text{predicted percentage correct} = p(B1)p(D2) + p(D1)p(B2) + p(B1)p(G2) + p(G1)p(B2) + p(D1)p(G2) + p(G1)p(D2).$$

$p(B1)$ refers to the percentage of trials of the identification task in which the first stimulus of the pair was labeled /b/, while $p(D2)$ refers to the percentage of trials on which the second stimulus was labeled /d/. The probabilities of the other five combinations were calculated in a similar way. Since these six pairs of phoneme labels exhaust the possible ways for the stimuli to be perceived as "different," their joint probability yields the predicted percentage discrimination.

The obtained discrimination function for place of articulation corresponds closely to expected discrimination. The Kendall rank-order correlation between the two sets of ranked percentages is .49 ($p = .01$). As with the VOT series, discrimination at the phoneme boundaries is slightly poorer than expected.

For the normal readers as well, the obtained discrimination function approximates the expected function (see Fig. 3d). Kendall's rank-order correlation yields a τ of .81 ($p < .001$).

DISCUSSION

The major finding of this study is that children with significant reading impairments are not markedly impaired in their ability to extract and encode phonetic information from speech syllables. On both the VOT continuum and the more highly abstracted place of articulation series, these children labeled and discriminated the speech sounds very much like normal-reading children and adults (cf. Liberman et al., 1961; Wolf, 1973).

In comparing the data presented here to previous reports, it is noteworthy that for both VOT and place of articulation the dyslexic children's discrimination between phoneme categories is slightly poorer than expected on the basis of identification. Wolf (1973) reported a similar finding in her study of normal kindergarten and second-grade children. Studies with normal adults, however, typically find level of discrimination at the peaks to be somewhat better than predicted (Liberman et al., 1961). This would be impossible for a *strictly* categorical system, since the height of the expected discrimination function reflects the identifiability of the stimuli. The normal readers in the present study seem to lie somewhere

between these two levels of performance; their discrimination at the phoneme boundaries is more or less as expected. These data hint at a developmental sequence in speech perception, a sequence in which dyslexic children appear to be at an earlier developmental level than their age-matched, normal-reading peers. Whereas more mature communicators may be able to utilize purely acoustic as well as linguistic information in making interphonemic discriminations, dyslexic and normal younger children may rely more heavily on phonemic labels in discriminating speech sounds. In this respect, they may better exemplify the model of categorical perception than normal adults.

While we find this explanation appealing, an alternative interpretation of our data is certainly possible. The fact that the dyslexic group produced somewhat flatter discrimination functions than expected may, in fact, reflect a *less* categorical (i.e., less phonemically based) perceptual system than in the normal-reading group. The lower the peaks of the discrimination functions, the less of an advantage accrues to stimuli at the phoneme boundary. With a perfectly flat function, all stimuli would be equally discriminable.

While the data presented here do not provide a meaningful basis for selecting between these two alternatives, it is worth emphasizing the speculative nature of these hypotheses and reiterating our major finding of no significant impairment in the ability of reading-disabled children to extract and encode phonemic information from speech in the auditory mode. Our inability to demonstrate clear phonological deficits in these children forces us to look at other perceptual and linguistic levels for a breakdown in the written word to meaning transformation.

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