

Speech Perception in Dyslexic Children With and Without Language Impairments

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Developmental dyslexia refers to a group of children who fail to learn to read at the normal rate despite apparently normal vision and neurological functioning. Dyslexic children typically manifest problems in printed word recognition and spelling, and difficulties in phonological processing are quite common (Lyon, 1995; Rack, Snowling, & Olson, 1992; Stanovich, 1988; Wagner & Torgesen, 1987). The phonological processing problems include, but are not limited to, difficulties in pronouncing nonsense words, poor phonemic awareness, problems in representing phonological information in short-term memory, and difficulty in rapidly retrieving the names of familiar objects, digits, and letters (Stanovich, 1988; Wagner & Torgesen, 1987; Wolf & Bowers, 1999).

The underlying cause of phonological deficits in dyslexic children is not yet clear. One possible source is developmentally deviant perception of speech at the phoneme level. A number of studies has shown that dyslexics' categorizations of speech sounds are less sharp than normal readers (Chiappe, Chiappe, & Siegel, 2001; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Maassen, Groenen, Crul, Assman-Hulsmans, & Gabreëls, 2001; Reed, 1989; Serniclaes, Sprenger-Charolles, Carré, & Demonet, 2001; Werker & Tees, 1987). These group differences have appeared in tasks requiring the labeling of stimuli varying along a perceptual continuum (such as voicing or place of articulation), as well as on speech discrimination tasks. In two studies, there was evidence that dyslexics showed better discrimination of sounds differing phonetically within a category bound-

ary (Serniclaes et al., 2001; Werker & Tees, 1987), whereas in one study dyslexics were poorer at both within- and between-phoneme discrimination (Maassen et al., 2001). There is evidence that newborns and 6-month-olds with a familial risk for dyslexia have reduced sensitivity to speech and nonspeech sounds (Molfese, 2000; Pihko, Leppänen, Eklund, Cheour, Gutfom, & Lyytinen, 1999). If dyslexics are impaired from birth in auditory processing or, more specifically, in speech perception, this would affect the development and use of phonological representations on a wide variety of tasks, most intensively in phonological awareness and decoding.

Although differences in speech perception have been observed, it has also been noted that the effects are often weak, small in size, or shown by only some of the dyslexic subjects (Adlard & Hazan, 1998; Brady, Shankweiler, & Mann, 1983; Elliot, Scholl, Grant, & Hammer, 1990; Manis, McBride-Chang, Seidenberg, Keating, Doi, Munson, & Petersen, 1997; Nittrouer, 1999; Snowling, Goulandris, Bowlby, & Howell, 1986). One reason for small or variable effects might be that the dyslexic population is heterogeneous, and speech perception problems are more common among particular subgroups of dyslexics. A specific hypothesis is that speech perception problems are more concentrated among dyslexic children showing greater phonological deficits. McBride-Chang (1996) reported structural equation analyses indicating that speech perception was not directly related to word recognition among third graders. Instead phoneme awareness acted as a mediator for the relationship of speech perception and word reading. She proposed that poor perception of the phoneme might impede the development of phoneme awareness, which in turn interfered with early word decoding and word reading development.

Evidence in support of this view was provided by Manis et al. (1997). They tested older (ages 10–14 years) dyslexic children who had serious delays in word recognition, but who varied in the degree of deficit in phoneme awareness. About half of the sample of dyslexics fell within the normal range for chronological age on a measure of phoneme awareness. Manis et al. (1997) found that dyslexics with low phoneme awareness were more likely to have speech perception deficits on a task requiring them to identify /b/ versus /p/ on the basis of voice onset time (VOT). Five of the 13 cases with low phoneme awareness had abnormal categorical perception functions, as opposed to only 2 of the 12 cases with normal phoneme awareness. Only 1 of 25 cases in the chronological age (CA) matched group and 3 of 24 cases in the reading level (RL) matched group showed abnormal categorical perception, and these were minor deviations from normal compared with what was seen in the low phoneme awareness subgroup. It is possible that past studies finding a significant group difference in speech perception had a greater concentration of dys-

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1987), whereas in one study between-phoneme discrimination that newborns and 6-month-old infants showed reduced sensitivity to speech (Leppänen, Eklund, Cheour, & Ahonen, 1997). In children impaired from birth in auditory perception, this would affect phonological representations on a wide range of phonological awareness and decod-

have been observed, it has been found to be small in size, or shown by Hazan, 1998; Brady, Shanker, & Hammer, 1990; Manis, Vanunson, & Petersen, 1997; Yeh, & Howell, 1986). One reason that the dyslexic population is larger is that reading difficulties are more common among children with specific language impairment. A hypothesis is that speech perception deficits are more common among children with specific language impairment. McBride-Chang (1996) reported that speech perception was not different between 1st and 2nd graders. Instead phonological awareness of speech perception is related to reading development.

As noted by Manis et al. (1997), children who had serious reading difficulties had the degree of deficit in phonological awareness that fell within the normal range of phoneme awareness. Children with low phoneme awareness had deficits on a task requiring identification of voice onset time (VOT). In 12 of the 12 cases with normal reading level (RL) matched group, these were minor deviations seen in the low phoneme awareness studies finding a significant concentration of dys-

lexic children with problems in phonological awareness. However, findings inconsistent with this viewpoint have been reported. Nitttrouer (1999) studied a sample of poor readers with considerable phonological difficulties, but failed to observe deficits in auditory processing or speech perception.

Another possibility is that speech perception difficulties might be more common among dyslexics with broader impairments in language. The selection criteria used in past studies of dyslexia (e.g., typically scores within the normal range on a full-scale IQ test or on a short-form of the IQ test) allow for the possibility that some dyslexics have mild to moderate language delays. There is strong evidence that speech perception problems are implicated in children categorized as specific language impaired (SLI; Elliot & Hammer, 1988; Stark & Heinz, 1996; Tallal & Stark, 1982; Thibodeau & Sussman, 1979). Many, but not all, SLI children tend to be dyslexic (Catts, Fey, Tomblin, & Zhang, 2002; Kamhi & Catts, 1986; Goulandris, Snowling, & Walker, 2000).

The purpose of the studies described in this chapter was to investigate the relationships among reading difficulties, phonological processing, language impairments, and speech perception. We first present data from Joanisse, Manis, Keating, and Seidenberg (2000), including re-analyses of the data, as well as data from a follow-up study on the same subjects administered 1 year later.

DYSLEXIA AND SPECIFIC LANGUAGE IMPAIRMENT

The specific question we address in this chapter is why speech perception difficulties are not consistently found in a majority of dyslexic children. One possibility is that they are associated more with phonological deficits, as hypothesized by a number of investigators (Adlard & Hazan, 1998; Manis et al., 1997; McBride-Chang, 1996). Still another is that speech perception problems are part of broader language deficits found in some dyslexic children, as hypothesized by investigators exploring the correlates and sequelae of SLI (Elliot & Hammer, 1988; Leonard, 1998; Tallal & Stark, 1982). A third view is that the varying results of speech perception tasks in the dyslexic population might be due to lack of sensitivity in the tasks. With a sufficiently sensitive task, it might be found that all or nearly all dyslexics have a speech perception deficit (Serniclaes et al., 2001).

Phonological dyslexia is prominent in studies exploring heterogeneity within the dyslexic population. Investigations by Castles and Coltheart (1993) and others (Boder, 1973; Stanovich, Siegel, & Gottardo, 1997) as well as in our lab (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Manis et al., 1999) have identified children, termed *phonological dyslexics*,

who exhibit specific phonological impairments relative to word reading ability. This subsample of dyslexics, who make up a sizeable proportion of cases in a typical dyslexic sample, fit the profile of phonological impairments that is often associated more generally with dyslexia (Rack, Snowling, & Olson, 1992; Stanovich, 1988; Wagner & Torgesen, 1987). Surface or delay dyslexics have phonological skills that are on par with their word reading skills. These children read as far below grade level as children typically included in dyslexia samples, but their profile of reading and phoneme awareness skills resembles that of younger normal readers.

Although phonological processing problems are found in a majority of dyslexic children, it is also the case that a number of children with dyslexia have a history of language impairments. Research on SLI has often been carried out somewhat independently of studies of dyslexia, although 50% or more of a sample of children manifesting language delays in early childhood eventually meet the criteria for dyslexia in middle childhood (Catts et al., 1994; Goulandris et al., 2000). Specific language-impaired children typically exhibit normal nonverbal intelligence, but have delayed or deficient development of inflectional morphology and other aspects of grammar, as well as difficulties with phonological processing and aspects of speech perception (Catts et al., 2002; Dollaghan & Campbell, 1998; Elliot & Hammer, 1988; Leonard, 1998; Stark & Heinz, 1996; Tallal & Stark, 1982; Thibodeau & Sussman, 1979). Evidence of deficits in phonological processing and speech perception raise the issue of the similarity of dyslexia and SLI.

Despite relatively independent development of the two lines of research on SLI and dyslexia, there is evidence that dyslexia and SLI share some characteristics or SLI may be a part of one developmental pathway to dyslexia. Scarborough (1990) found that nearly 60% of a sample of children who were deemed at risk for dyslexia because of a dyslexic family member qualified as dyslexic at age 8. Data collected at ages 2½, 4, and 5 years of age indicated that children who later became dyslexic had delays in the development of expressive morphology, articulation, word retrieval, and phonological awareness compared with at-risk children who did not qualify as dyslexics as well as children without a familial risk. Moreover, the syntactic problems predicted unique variance in later word recognition scores, partialing out the contribution of phonological awareness and other language variables. These data indicate that language delays are a common predecessor of reading difficulties, suggesting a common cause for both dyslexia and the language difficulties. Whether the cause could be localized in phonological processing or more specifically in speech perception remains to be seen.

Goulandris et al. (2000) followed a sample of children identified at age 4 as SLI. They compared children with resolved SLI ($n = 19$), those with

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IDENTIFICATION FUNCTIONS IN DYSLEXICS AND NORMAL READERS: JOANNISSE ET AL. (2000)

We report the results of a study by our group (Joanisse et al., 2000) in some detail. This was an initial study exploring the role of phonological impairments and broader language impairments in speech perception. We divided dyslexics into three subgroups: a group with delayed nonword reading or phoneme awareness (as measured by experimental tests of nonword pronunciation and phoneme deletion) relative to a reading-level comparison group (phonological dyslexic [PD] group, $n = 16$); a group with delays in both phonological skill and oral language as measured by tests from the CELF-III (Semel, Wiig, & Secord, 1995) and the WISC-III (Wechsler, 1992) of morphology and vocabulary, respectively (language impaired [LI] group, $n = 9$); and a group whose language scores were normal for chronological age and whose phonological skill was within the range of the reading-level group (delayed group, $n = 23$). The three dyslexic subgroups were equally impaired in word reading (scoring on the 8th, 6th, and 9th percentiles, respectively). The PD and LI groups were quite impaired in nonword reading and phoneme awareness, with the PD group tending to have more severe impairment. Groups of 52 chronological age-matched normal readers (CA group) and 37 reading level-matched normal readers (RL group) were also tested. The RL group allowed us, to some extent, to balance effects of reading achievement on phonological or language variables. If dyslexics perform more poorly than the RL group on a given measure, it can be argued that the dyslexics' difficulties are not simply a byproduct of low reading achievement. Subjects had to score at the 40th percentile or higher on the Woodcock Reading Mastery Test, Word Identification subtest (Woodcock, 1989) to qualify for the CA and RL groups. In addition, the RL group was matched to the dys-

lexic group as a whole for mean and range of Word Identification grade-equivalent scores. The mean age for the dyslexic group was 8;7 (range 7;10-9;4), for the CA group it was 8;5 (range 7;11-9;3), and for the RL group it was 6;11 (range 6;1-8;1). Descriptive data for the groups are shown in Table 5.1.

Joanisse et al. (2000) explored categorical perception along a VOT (/d/-/t/) continuum (*dug-tug*) and a place of articulation (POA) (/p/-/k/) continuum (*spy-sky*). Perception of VOT and POA contrasts has been found to be categorical in nature in past studies of speech perception in both normal listeners and dyslexics (e.g., Godfrey et al., 1981; Liberman, 1996; Maassen et al., 2001; Werker & Tees, 1987). For the /d/-/t/ contrast, *dug-tug* stimuli were constructed by cross-splicing progressively more components of *tug* into *dug* from natural speech. The result was a continuum of eight different VOT values ranging from 10-ms to 80-ms voicing lag in roughly 10-ms increments. The subjects heard six practice items at the endpoints, with feedback, and simply pointed to a picture representing the correct word (a cartoon figure digging or tugging on a rope). There were 40 experimental trials, with each point on the continuum represented by five tokens administered in random order. The /p/-/k/ contrast was presented as a contrast between the words *spy* and *sky*. The POA contrast was created by varying the onset frequency of the second formant (F2) transition sweep in the second consonant of the target word. This produced a continuum from the labial /p/ to the dorsal /k/ phoneme. F2 onsets varied from 1,100 to 1,800 Hz in 100-ms steps. Formant transition duration was close to that of natural speech—45 ms. A closure duration of 30 ms was chosen to be long enough to produce a clear stop consonant percept, but short enough to present problems if listeners had difficulty responding to stimuli presented at short intervals (Reed, 1989; Tallal, 1980). These stimuli were produced synthetically using the Klatt hybrid synthesizer on a PC (Klatt, 1990) and recorded as 16-bit, 22.05 kHz digital sound files. There were 6 practice trials with endpoint stimuli and 32 experimental trials, four at each of eight F2 onset frequencies.

Stimuli were presented using a Macintosh Powerbook with 16-bit audio and an active matrix screen. The responses were expected to conform to the S-shaped identification curves typical of categorical perception tasks. To quantify the data, each child's categorization responses were fitted to a logistic function using the Logistic Curve Fit function in SPSS. This yielded a logistic slope coefficient. Valid coefficients tend to be between 0 and 1.0, with higher values representing shallower slopes. To control for positive skew, which can invalidate logistic functions, we excluded coefficients of 1.2 or more.

We found speech perception deficits only in the LI subgroup. This group had an identification function with a shallower slope than that of

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TABLE 5.1
Means and Standard Deviations for the Identifying Tasks in the Joannisse et al. (2000) Study

Test	Group				
	LI (n = 9)	PD (n = 16)	Delay (n = 23)	CA (n = 52)	RL (n = 37)
Woodcock Word Iden.					
Grade Equivalent	2.1 (0.3)	2.1 (0.3)	2.1 (0.2)	4.0 (0.6)	2.2 (0.4)
Percentile	6.3 (5.9)	8.3 (6.2)	9.3 (4.4)	68.2 (16.4)	79.7 (15.5)
Nonword z score	-0.9 (0.7)	-1.1 (0.3)	-0.1 (0.7)	2.1 (1.2)	0 (1.0)
Phon. Del. z score	-0.9 (1.0)	-1.5 (0.6)	-0.02 (0.4)	0.7 (1.0)	0 (1.0)
WISC Vocabulary Standard Score	5.1 (0.9)	8.1 (3.2)	9.1 (2.7)	10.2 (2.9)	11.8 (3.8)
CELF Word Structure Standard Score	5.2 (1.0)	7.7 (1.9)	10.3 (2.9)	11.7 (2.9)	12.6 (2.3)

normal readers on both the VOT and POA dimension (see Figs. 5.1 and 5.2, which were not printed in the original article). The critical comparison is between each of the dyslexic subgroups and the RL group. The only significant difference for *dug-tug* involved the LI and RL group, where the LI group showed higher mean slopes, indicating a shallower slope. Likewise, the only significant difference for *spy-sky* resulted from the LI group having a higher slope than the RL group.

Inspecting the identification functions in Figs. 5.1 and 5.2, the crossover point appeared to be similar in the LI group and the other groups, but the LI group was more likely to label clear instances of /d/ as /t/ and vice versa and likewise for /p/ and /k/. The findings are consistent with broader or less distinct categories for phonemes.

However, an alternative possibility is that LI children experience generalized auditory processing problems that affect attentiveness to subtle auditory distinctions. According to this line of argument, the deficit is not as noticeable at intermediate values on the continuum because all of the children have difficulty categorizing those stimuli, but it becomes apparent at the ends of the continuum. This possibility can be addressed by administering a discrimination task using stimuli along the same continuum. In addition, the discrimination task provides a method of validating the subgroup distinctions in speech perception obtained for the identification task.

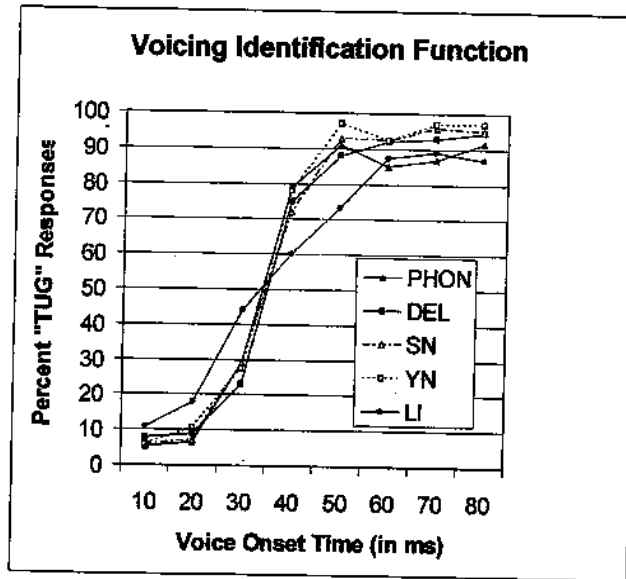


FIG. 5.1. Voicing (*dug-tug*) identification functions for the five groups in the study.

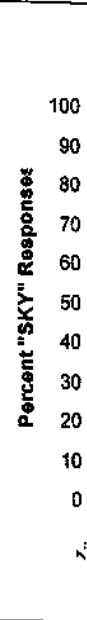


FIG. 5.2. Play study.

SPEECH DISCRIMINATION AND NORMAL

Previous studies with normal readers have yielded results that are typically given to judge word pairs that are difficult (e.g., two different vowels). Discrimination is much better between dyslexic children and normal readers on discrimination tasks like /ga/ or VOT. However, and discriminability (1981) reported for /ba/-/da/ as well. In addition, dyslexia for within-categc

dimension (see Figs. 5.1 and 5.2). The critical comparison is between the LI and the RL group. The only significant difference was found in the LI and RL group, where the LI group showed a shallower slope. Like the LI group, the RL group's performance on the *spy-sky* task resulted from the LI group.

In Figs. 5.1 and 5.2, the cross-group and the other groups, the LI group shows instances of /d/ as /t/ and the LI group's findings are consistent with the LI group's findings.

The LI children experience general difficulties in attending to subtle differences in the continuum because all of the stimuli are addressed by the LI group, but it becomes apparent that the LI group's performance can be addressed by the LI group along the same continuum. This provides a method of validating the LI group's performance obtained for the identification task.

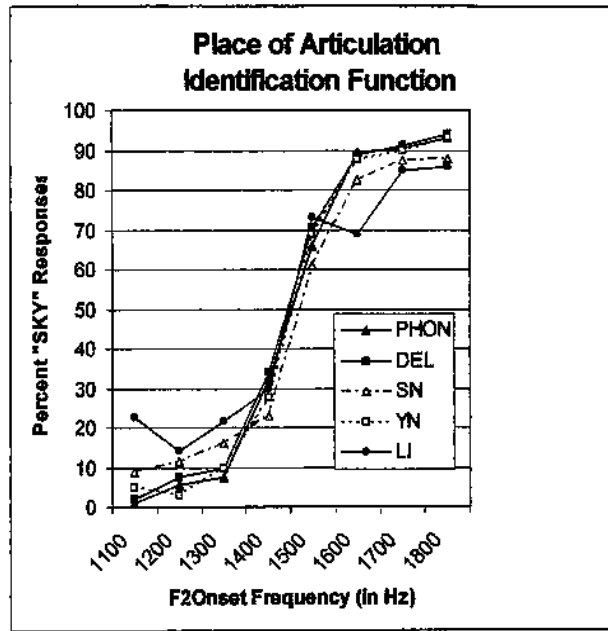
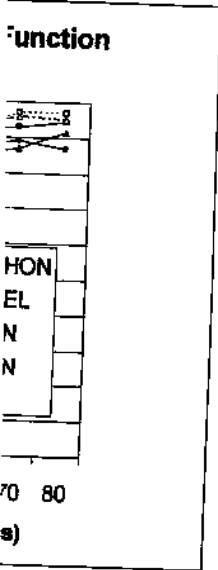


FIG. 5.2. Place of articulation (*spy-sky*) functions for the five groups in the study.



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SPEECH DISCRIMINATION IN DYSLEXIC AND NORMAL READERS

Previous studies exploring speech discrimination in dyslexic and normal readers have yielded an interesting mixture of results. In this task, subjects typically are given pairs of stimuli from a VOT or POA continuum and asked to judge whether they are the same or different. Discrimination of pairs that are different is expected to be poor for within-category pairs (e.g., two different stimuli from the /ba/ end of the /ba-/da/ continuum). Discrimination of pairs that cross a category boundary is expected to be much better. Brandt and Rosen (1980) reported no difference between dyslexic children and CA controls for both an identification and a discrimination task given for each of three continua—/ba-/da/, /da-/ga/, or VOT. However, as noted by Godfrey et al. (1981), the identification and discrimination functions were slightly flatter for dyslexics. Godfrey et al. (1981) reported weaker discrimination across the categorical boundary for /ba-/da/ and /da-/ga/ for dyslexics compared with CA controls. In addition, dyslexics were found to discriminate better than the controls for within-category items on the /da-/ga/ continuum. This finding is of

particular interest because it indicates dyslexics may be as sensitive as normal readers to subtle differences in the phonetic values of the stimuli. An inference can be made that dyslexics perceive the physical differences among the stimuli as well as the control group, but their phoneme boundaries are less sharp. Godfrey et al. (1981) classified dyslexics into dysphonetic and dyseidetic subgroups using Boder's (1973) criteria, but no differences in speech perception were found between these two subgroups. However, the number of subjects in each group (11 dysphonetics, 6 dyseidetics) was fairly small.

Werker and Tees (1987) collected both identification and discrimination data. They found that the slope of the identification function for /ba/-/da/ was shallower in the dyslexics. Dyslexic children performed more poorly than age-matched controls at discriminating different pairs for both one- and two-step pairings. Group differences were larger, favoring the control group, for cross-boundary pairs. Inspection of the figures indicates that there was a trend for dyslexics to discriminate within-category pairs better than the controls, but only at the /ba/ end of the continuum. The results replicate the Godfrey et al. (1981) findings showing better within- and poorer between-phoneme discrimination.

Maassen et al. (2001) compared dyslexic children to both CA and RL control groups on a voicing (/bak/-/pak/) and a POA (/bak/-/dak/) continuum using both identification and discrimination tasks. They found no differences in the mean slope for the identification function between dyslexics and either control group on the POA continuum. Dyslexics and the RL group differed from the CA group but not each other on the voicing continuum, with dyslexics and RLs showing shallower slopes than the CA group. Dyslexics demonstrated a lower level of performance on the discrimination task than both control groups for the POA as well as the voicing continuum. Inspection of the discrimination curves indicates that dyslexic-control group differences favoring the controls were found for stimulus pairs that crossed the categorical boundary, but also for pairs that were within category. This study replicated the Godfrey et al. (1981) and Werker and Tees (1987) findings of poorer cross-phoneme boundary discrimination in dyslexics, but not their findings of better within-category discrimination.

Serniclaes et al. (2001) utilized sine-wave analogues to speech stimuli to create a POA continuum to determine whether the deficit in categorical perception was specific to speech. The sine-wave stimuli were designed so that subjects could perceive them as tones or speech stimuli (/ba/ and /da/) depending on instructions. An additional set of modulated sine-wave stimuli that sounded more like the natural speech versions of /ba/ and /da/ were utilized. Serniclaes et al. (2001) found that the sine-wave stimuli designated as tones to the subjects were not perceived categori-

cally (discriminatively) than normal readers). In cross-category speech perception, the dyslexic group showed a perceptual bias for /ba/ and /da/ that was more speechlike by the control group. The dyslexic group showed a bias for /ba/ over /da/ at the boundary. Dyslexics showed a perceptual bias for /ba/ over /da/ at the boundary. Dyslexics showed a perceptual bias for /ba/ over /da/ at the boundary. Dyslexics showed a perceptual bias for /ba/ over /da/ at the boundary.

Adlard and Hazan (1982) reported no differences in speech perception between dyslexics and controls on a wide range of speech perception tasks. They reported no differences in speech perception between dyslexics and controls on a wide range of speech perception tasks. They reported no differences in speech perception between dyslexics and controls on a wide range of speech perception tasks. They reported no differences in speech perception between dyslexics and controls on a wide range of speech perception tasks.

FOLLOW-UP STUDY

In the present study, we examined the ability of dyslexic children to discriminate speech stimuli using a continuum of speech stimuli. The study was designed to replicate the findings of Godfrey et al. (1981) and Werker and Tees (1987) and to examine the ability of dyslexic children to discriminate speech stimuli using a continuum of speech stimuli.

The dyslexic children had to score below 60 on the Identification Test to be included in the study. Criteria for inclusion were the same as those used in the previous study. The dyslexic children had to score below 60 on the Identification Test to be included in the study. Criteria for inclusion were the same as those used in the previous study.

exics may be as sensitive as phonetic values of the stimuli receive the physical differences bound-p, but their phoneme boundaries classified dyslexics into disorder's (1973) criteria, but no boundary between these two sub-groups for each group (11 dysphonetics,

identification and discrimination identification function for dyslexic children performed discriminating different pairs differences were larger, favoring. Inspection of the figures indicates to discriminate within-category at the /ba/ end of the continuum. (1981) findings showing discrimination.

continuum to both CA and RL controls (/bak/-/dak/) continuum tasks. They found no difference in function between dyslexics and the RL group. Dyslexics and the RL group showed other on the voicing continuum. The slopes than the CA group. The difference on the discrimination continuum as the voicing continuum. The results indicate that dyslexic-control pairs and for stimulus pairs that pairs that were within category (1981) and Werker and Tees primary discrimination in dyslexic category discrimination.

analogous to speech stimuli to address the deficit in categorical speech stimuli were designed speech stimuli (/ba/ and /da/) set of modulated sine-wave speech versions of /ba/ and /da/ found that the sine-wave stimuli were not perceived categori-

cally (discrimination functions were flat for both dyslexics and normal readers). In contrast, the identical sine-wave stimuli designated as speech showed a peak for discrimination accuracy at the typical boundary for /ba/ and /da/ obtained for adult speakers of French. The third stimulus type, modulated sine waves, were apparently treated as even more speechlike by the children because the peaks were steeper at the phoneme boundary. Dyslexics showed less peaked discrimination curves, consistent with weaker phoneme boundaries, and they were better at perceiving differences within category for the sine-wave speech stimuli. A trend in this direction was found for the more natural sounding modulated sine-wave speech stimuli. Serniclaes et al. (2001) concluded that dyslexics' auditory discrimination is as good as that of normal readers, but their phoneme boundaries are less sharp.

Adlard and Hazan (1998) contrasted dyslexics and CA and RL controls on a wide range of auditory and phoneme discrimination tasks. They reported no overall group differences on speech and auditory discrimination tasks. However, a subset of the dyslexics (4 out of 13) were poor at speech discrimination, particularly when it involved pairs of words that were not only phonetically similar (i.e., they differed by one phonetic feature), but in which the phonetic contrast was not acoustically salient (e.g., *sue/shoe*, *fine/vine*, *still/spill*, and *smack/snack*). Adlard and Hazan (1998) found no difference between the subgroup of four dyslexics and either normal reader control group in detecting differences among nonspeech auditory stimuli. Adlard and Hazan's (1998) findings suggest once again that only a small subgroup of dyslexics has difficulty with speech perception.

FOLLOW-UP STUDY OF SPEECH DISCRIMINATION

In the present study, we were able to retest some of the children participating in the Joanisse et al. (2000) study 9 to 10 months later on speech discrimination using the *spy-sky* continuum. The children were also retested on Woodcock Word Identification (Woodcock, 1989), WISC-III Vocabulary (Wechsler, 1992), Nonword Reading, and Phoneme Deletion.

The dyslexic and CA groups were all fourth graders. All dyslexic children had to score at or below the 25th percentile on the Woodcock Word Identification Test (Woodcock, 1989) in the retesting to qualify for the study. Criteria for classifying children as LI, PD, or Delayed dyslexics were the same as Joanisse et al. (2000). LI dyslexics scored at or below a scaled score of 6 on both WISC-III Vocabulary and CELF Word Structure in the previous year. Their scores from the third and fourth grades on Vo-

cabulary and for third grade for CELF Word Structure are shown in Table 5.2, along with the other scores from the fourth-grade testing. It can be seen that the LI children remained well below average in WISC-III Vocabulary at the second testing. The LI group consisted of seven of the nine classified as LI in Joanisse et al. (2000). PD dyslexics had to score one standard deviation or more below the original RL group ($n = 37$) in the previous year on either Nonword Reading (an experimental list of 70 nonsense words) or Phoneme Deletion (an experimental list of 24 real words and 14 nonwords). All but two of the LI dyslexics would also have qualified as PD dyslexics. The PD group consisted of 13 of the 16 originally classified as PD in Joanisse et al. (2000). Delayed dyslexics scored within one standard deviation of the RL group on both Nonword Reading and Phoneme Deletion in the previous year. The delayed subgroup consisted of 15 of the 22 classified in this group in Joanisse et al. (2000). The three subgroups were similar in overall word identification skill. The CA control group consisted of 20 children selected at random from the original group of 52 children. The RL group consisted of 10 children in second grade selected to have the same mean and range of Woodcock Word Identification grade-equivalent scores as the dyslexics. Descriptive data for all of the groups are shown in Table 5.2.

It is apparent from the Nonword Reading and Phoneme Deletion z scores collected at the time of the discrimination task testing that the PD and LI groups were the only groups with a phonological deficit (about one standard deviation below the original RL group across tasks). The delayed group was still well within the range of the RL group and did not differ from this group by Bonferoni-corrected t tests on either measure. All three dyslexic groups scored significantly below the range of the CA group on both measures (p values all less than .001). Other findings of note are that the PD group was intermediate in Vocabulary scores between the LI and delayed groups. The overall group comparison on Vocabulary was significant [$F(4, 61) = 3.92, p < .01$]. Tukey post hoc tests revealed the only significant differences to be between the LI group and each of the other groups (p values all less than .025). There were no differences in Woodcock Word Identification grade-equivalent or percentile scores between the subgroups, and none of the groups differed from the RL group on the grade-equivalent score by t test. CAs were higher than the other four groups on the grade-equivalent score (p values all less than .001).

The speech discrimination task required children to judge whether stimuli along the *spy-sky* (POA) continuum were the same or different. The children heard two words spaced 400 ms apart and responded "same" or "different." The words were played by a Macintosh Powerbook computer over headphones. The word stimuli were identical to those

used in the identification task of Joanisse et al. (2000). There were six practice trials using endpoint stimuli (two same and four different). This was followed by 52 experimental trials. The experimental trials consisted of eight same trials—four pairs of stimuli repeated twice each at F2 onset frequencies of 1,100, 1,400, 1,500, and 1,800 Hz. There were 44 different trials. Twenty-eight trials consisted of pairs separated by one step at each of seven points on the continuum (1,100–1,200 Hz, 1,200–1,300 Hz, etc.). There were four repetitions of each one-step pair, two in one order (e.g., 1,100–1,200) and two in the opposite order (e.g., 1,200–1,100). There were 16 trials of pairs differing by four steps on the continuum, four each at stimulus values of 1,100–1,500, 1,200–1,600, 1,300–1,700, and 1,400–1,800 Hz. Based on the identification data, we anticipated that the phoneme boundary would be located between 1,400 and 1,500 Hz. Thus, there was one pair in the one-step set that crossed the phoneme boundary (1,400–1,500) and six pairs that were within the boundary. All four pairs in the four-step set involved comparisons across the phoneme boundary. It should be noted that there were many more actual different trials than same trials. However, many times the children perceived stimuli differing by one step as same, so from the child's point of view, there was not a huge discrepancy in the number of same and different responses.

The results are displayed separately for same trials (Fig. 5.3), four-step different trials (Fig. 5.4), and one-step different trials (Fig. 5.5). Performance was fairly good on the same trials for all groups, except that the groups showed a dip in performance near the middle of the continuum (i.e., on the 1,400–1,400 and 1,500–1,500 Hz items), with the LI group per-

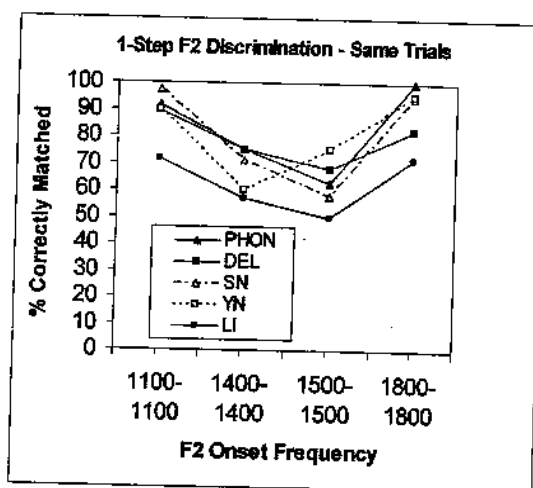


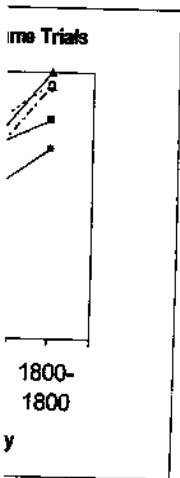
FIG. 5.3. Discrimination task (*spy-sky*)—same trials (percent correctly matched).

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al. (2000). There were six practice and four different). This was experimental trials consisted of repeated twice each at F2 onset frequencies. There were 44 different trials. created by one step at each of 1,000 Hz, 1,200-1,300 Hz, etc.). Each pair, two in one order (e.g., 1,200-1,100). There were 11 pairs in the continuum, four each at 1,100-1,300 Hz, 1,300-1,700, and 1,400-1,800 Hz. We anticipated that the phoneme boundary was at 1,500 Hz. Thus, there was a phoneme boundary (1,400-1,500 Hz) and a phoneme boundary. All four pairs in the continuum were the phoneme boundary. It is not clear if these are actual different trials than the other perceived stimuli differing in onset frequency. In other words, there was not a continuum of different responses.

same trials (Fig. 5.3), four-step different trials (Fig. 5.5). Performance was similar for all groups, except that the LI group performed worse in the middle of the continuum (LI group performs).



Same trials (percent correctly)

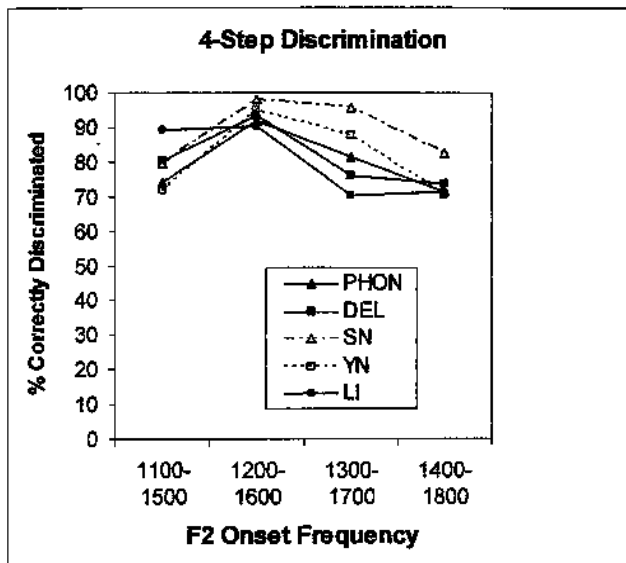


FIG. 5.4. Discrimination task—four-step different trials (percent correctly discriminated).

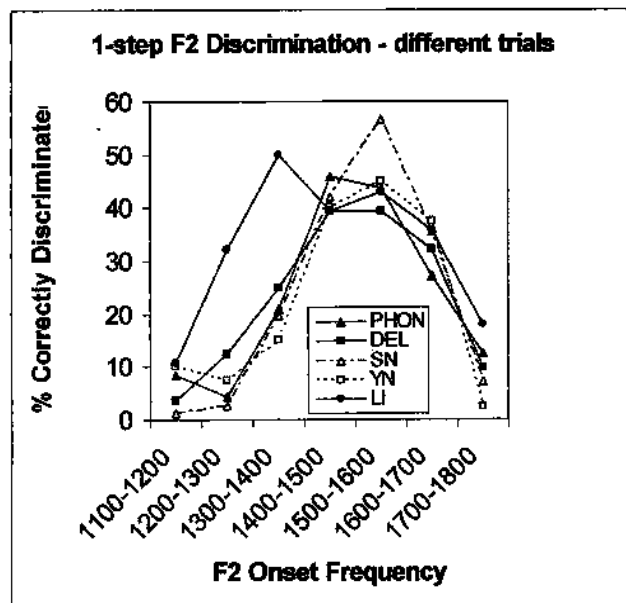


FIG. 5.5. Discrimination task—one-step different trials (percent correctly discriminated).

forming the poorest on these items. In fact the LI group's score of 50% correct and the CA group's score of 58% correct on the 1,500-1,500 item did not differ significantly from chance. *F* tests comparing the five groups at each of the four points on the continuum revealed group differences only for the 1,800-1,800 Hz pairs. This appeared to be due to lower performance by the LI and, to some extent, the Delayed groups relative to the other groups. However, the only pairwise comparison to attain significance by Tukey post hoc test was the PD versus LI comparison. The general lack of group differences on the same trials indicates that the dyslexic groups understood the task and were able to judge pairs that were acoustically identical with roughly the same accuracy as the control groups. The dip in performance at or near the category boundary (1,400-1,500 Hz) probably reflects unstable perception of items that are intermediate on the /p/-/k/ continuum. It makes sense that children would be more certain that pairs on the ends of the continuum matched one another as they should tend to encode these items most of the time as the same word. Pairs in the middle of the continuum sometimes might be encoded as one word and sometimes as the other, even within the same trial, resulting in more guessing or more different responses.

Figure 5.4 shows the percentage of correct different responses made on four-step pairs as a function of F2 onset frequency. These pairs should have been fairly easy to discriminate on two grounds: the fact that they crossed the phoneme boundary and that they were acoustically quite distinct (i.e., F2 onset frequency differed by four steps on the continuum). It can be seen in Fig. 5.4 that all groups achieved better than 70% accuracy across all four pair types, with mean accuracy on the 1,300-1,700 Hz pair exceeding 90% for all groups. There is a trend for the PD and LI groups to be somewhat lower in accuracy than the other groups. However, none of the *F* tests conducted for any of the four pairs revealed significant group differences. Results for the four-step comparisons once again illustrate that the children generally understood the task and were able to distinguish items differing by four steps on the continuum. However, because all of the items were both acoustically and phonemically distinct, it is not possible to determine whether this performance reflected categorical perception. The one-step items made this determination possible.

Figure 5.5 depicts the percentage of correct responses on one-step trials (a correct response is a response of different). The curve shows that a sharp phoneme boundary at about 1,400 or 1,500 Hz exists for some of the groups, with performance rising from less than 10% correct at the endpoints to 50% to 60% correct for items crossing the phoneme boundary. The peak appeared to be between 1,500 and 1,600 ms for the CA and RL groups and between 1,400 and 1,600 ms for the PD and Delay groups. The most interesting finding is that the LI group showed a broad peak that ex-

tended to items than other groups (e.g., discrimination of other groups).

F tests conducted on the 1,300-1,400 Hz pair group, using the Tukey test revealed that LIs performed better than the PD ($p < .025$) group ($p < .05$) and RL ($p < .05$) group appears to perform better than the other groups, this difference was significant.

The results for the four-step comparisons of lexics as a whole and the results of Werker (1984) indicate a boundary for the LI readers. However, the results attributed to the LI group overlapped substantially with the better discrimination of the other groups. Based on their superior auditory discrimination. However, the mean performance of the LI readers (and the other groups) at the phoneme boundary are perceived as a sharp peak that could not ignore the fact that the LI group showed a sharp peak.

REGRESSION ANALYSIS REEXAMINED

Although it is a follow-up speech perception test for dyslexics and normal language impairment, language perception, language impairment, and speech perception. If this were

the LI group's score of 50% correct on the 1,500–1,500 item did not differ from the other groups at comparing the five groups at revealed group differences only to be due to lower performance of the delayed groups relative to the other groups. The general comparison to attain significance indicates that the dyslexic group performed as well as the control groups. The results indicate that the dyslexic group did not perform as well as the control groups on the 1,400–1,500 Hz boundary (1,400–1,500 Hz) as that are intermediate on the other groups. The results indicate that the dyslexic group would be more certain than the other groups as they matched one another as they did on the same word. The results indicate that the dyslexic group might be encoded as one in the same trial, resulting in

different responses made on different frequency. These pairs should be compared on the grounds: the fact that they were acoustically quite different (steps on the continuum). It is better than 70% accuracy on the 1,300–1,700 Hz pair for the PD and LI groups to compare the other groups. However, none of the groups revealed significant group differences once again illustrating that the groups were able to distinguish between the different frequencies. However, because the groups are acoustically distinct, it is not clear how well they reflected categorical perception. The results indicate that the dyslexic group might be encoded as one in the same trial, resulting in

responses on one-step trials. The curve shows that a sharp peak exists for some of the groups. The results indicate that the dyslexic group might be encoded as one in the same trial, resulting in

tended to items that were clearly within the /p/ phoneme category for the other groups (e.g., 1,200–1,300 ms). The LI group appeared to show better discrimination of the items at 1,200–1,300 and 1,300–1,400 Hz than the other groups.

F tests conducted at each point on the continuum revealed group differences on the 1,200–1,300 Hz pair [$F(4, 61) = 3.99, p < .01$] and on the 1,300–1,400 Hz pair [$F(4, 61) = 3.03, p < .025$]. Pairwise comparisons of each group, using the Tukey HSD test to control for cumulative Type I error, revealed that LIs performed better than the CA ($p < .01$), RL ($p < .05$), and PD ($p < .025$) groups on the 1,200–1,300 Hz pair and better than the CA ($p < .05$) and RL ($p < .025$) groups on the 1,300–1,400 Hz pair. Although the CA group appears to have a higher peak at 1,500–1,600 Hz than the other groups, this difference was not significant.

The results for the LI group parallel previous findings reported for dyslexics as a whole by Serniclaes et al. (2001) and noticeable in the graphed results of Werker and Tees (1987). The central finding is that the category boundary for the POA phoneme is not as sharp for dyslexics as for normal readers. However, in the present case, the findings can clearly be attributed to the LI subgroup of dyslexics—the PD and Delayed subgroups overlapped substantially with the normal reader groups. The finding of better discrimination by the LI group for two within-category pairs indicates that LI dyslexics do not have less acute auditory discrimination. Based on their superior performance, an argument could be made that their auditory discrimination is more acute than that of normal readers. However, the more reasonable interpretation of the data is that normal readers (and the PD and Delayed groups of dyslexics) have a sharp phoneme boundary and tend to ignore acoustic differences among pairs that are perceived as within the /p/ or /k/ categories. In contrast, LI dyslexics could not ignore these acoustic differences because they had not established a sharp phoneme boundary.

REGRESSION ANALYSES: JOANISSE ET AL. (2000) REEXAMINED

Although it is apparent from the Joanisse et al. (2000) study and the follow-up speech discrimination study that group differences between dyslexics and normal readers were concentrated among dyslexics with language impairments, an important question is whether the speech perception, language, and phonological deficits are part of the same underlying problem, such as poor phonological representations for familiar words. If this were the case, the speech, language, and phonological proc-

TABLE 5.3
Common and Unique Variance for Key Variables
in the Prediction of Word Identification

Variable	Variance Explained	Significance (<i>p</i>)
<i>Spy-sky</i> slope (unique)	2.8%	< .05
Phoneme Deletion (unique)	17.3%	< .001
CELF Word Structure (unique)	2.7%	< .05
WISC Vocabulary (unique)	2.1%	< .05
Total Unique	24.9%	
Total Common	22.9%	

essing tasks should account for considerable common and little unique variance in word-reading skill.

To address this question, data from the original Joanisse et al. (2000) data set were subjected to additional regression analyses for the present chapter. We conducted commonality analyses on the language tasks (CELF Word Structure and WISC-III Vocabulary), on phonological awareness (Phoneme Deletion) and speech perception (*spy-sky* identification slope). These tasks were entered as independent variables in regressions predicting Woodcock Word Identification at Grade 3. All of the third graders participating in the Joanisse et al. (2000) study (48 dyslexics and 52 CA controls) and the 37 RL controls (who were in Grades 1 and 2) were included in these analyses.

Results are summarized in Table 5.3. The total amount of variance in Word Identification accounted for by all of these variables was 47.8%, with 22.9% common across the tasks and the remainder unique variance. Phoneme Deletion accounted for the largest share of independent variance. The other three variables entered into the regression equations—*spy-sky* slope, CELF Word Structure, and WISC-III Vocabulary—accounted for small but statistically significant amounts of variance.

The fact that about half of the variance accounted for was common variance suggests a construct such as phonological skill could underlie some of the variables' relationships to word reading. However, there was considerable unique variance. Phoneme awareness and speech perception were partially independent sources of word identification skill. The two language measures were also partially independent of the speech and phoneme awareness tasks. However, these tasks do not represent all aspects of language functioning. It would be interesting to see whether other language tasks would show more overlap with the speech and phoneme awareness measures.

CONCLUSION:

The studies reviewed here have conducted impairment exist file of a phonolo phoneme aware children tested b nological skill be almost as comm- impairments wa ments discussed also have signif

One of the m were actually su tions (see Fig. 5. and phonologic (Ahissar, Proto Tervaniemi, Alh Fitch, 1993; Tall the view that at to speech stimuli al., 2001).

Our findings ception difficult lexic sample. Wl is that poor pho: lems in languag 2000; Vellutino, boundaries mig sound elements in delays in m poor performar (2000). Poor pho of vocabulary a comparison of p because they le with oral comm

It is possible cits, with the m ception difficul 1999) that persi

CONCLUSIONS

The studies reviewed here and the data from the two investigations we have conducted indicate that different kinds or degrees of phonological impairment exist in dyslexic children. The commonly perceived core profile of a phonological processing deficit (e.g., poor nonword reading and phoneme awareness) was indeed observed in over half of the dyslexic children tested by our research group. However, the delayed profile (phonological skill below age level, but on par with overall reading skill) was almost as common in our sample. A subset of children with phonological impairments was found to have deficient speech perception. The experiments discussed here strongly suggest that this subset of dyslexic children also have significant problems in other aspects of language.

One of the most interesting findings in the study was that LI dyslexics were actually superior to the other groups at within-category discriminations (see Fig. 5.5). This finding is quite problematic for the view that SLI and phonological dyslexia result from basic auditory processing problems (Ahissar, Protopapas, Reid, & Merzenich, 2000; Kujala, Myllyviita, Tervaniemi, Alho, Kallio, & Naatanen, 2000; Tallal, 1980; Tallal, Miller, & Fitch, 1993; Tallal & Stark, 1982). Instead our results are consistent with the view that auditory processing problems among dyslexics are limited to speech stimuli (Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes et al., 2001).

Our findings are consistent with the view that categorical speech perception difficulties are associated with broad language deficits in a dyslexic sample. What is not clear is the direction of causality. One hypothesis is that poor phonological representations cause a cascading series of problems in language and reading development (Goswami, 2002; Snowling, 2000; Vellutino, 1979). Children who do not develop sharp phonemic boundaries might experience difficulty perceiving the small but critical sound elements that define grammatical inflections in English, resulting in delays in morphological development (e.g., Scarborough, 1990) and poor performance on the morphology tasks utilized by Joannis et al. (2000). Poor phonological representations might interfere with the process of vocabulary acquisition either because they hinder the encoding and comparison of phonologically similar, but semantically distinct, words or because they lead to general word-name retrieval problems that interfere with oral communication and performance on verbal ability tests.

It is possible that there is a continuum of severity in phonological deficits, with the most severe problems manifesting themselves as speech perception difficulties early in development (e.g., Molfese, 2000; Pihko et al., 1999) that persist into the school years in the most extreme cases. If this

for Key Variables
Identification

Variance Explained	Significance (p)
2.8%	< .05
17.3%	< .001
2.7%	< .05
2.1%	< .05
24.9%	
22.9%	

ble common and little unique

original Joannis et al. (2000) regression analyses for the present analyses on the language tasks (vocabulary), on phonological perception (*spy-sky* identification), on phonological independent variables in regression at Grade 3. All of the third (2000) study (48 dyslexics and 52 controls in Grades 1 and 2) were in-

total amount of variance in these variables was 47.8%, remainder unique variance. share of independent variables—the regression equations—WISC-III Vocabulary—accounted for was common

logical skill could underlie reading. However, there was phoneme awareness and speech perception identification skill. The two independent of the speech and reading tasks do not represent all aspects of reading. It is interesting to see whether other aspects of reading, such as the speech and phoneme

were the case, one might argue that LI dyslexics were the most impaired, followed by the PD and then the Delayed groups. However, this prediction does not fit our data because the LI dyslexics were *not* the most impaired group on nonword reading, phoneme awareness, and word identification, the three tasks most commonly associated with developmental dyslexia. LI dyslexics performed at about the same level as the PD dyslexics. This argument is further complicated by the observation that the Delayed dyslexics were as impaired in word reading as the other groups at both test times (third and fourth grade; see Tables 5.1 and 5.2).

An alternative argument is that there are multiple factors associated with the occurrence of word-reading problems in children (Griffiths & Snowling, 2002; Manis et al., 1996). Speech perception problems might be uncommon in dyslexics and, when present, lead to wider language delays. The most common profile among dyslexics might entail difficulties in developing segmental representations, rather than deficits at the level of the individual phoneme or in overall phonological representations. Dyslexics who fail to develop segmental representations would tend to show the classic phonological dyslexia profile, involving interrelated problems in developing phoneme awareness, learning grapheme-phoneme associations, and spelling (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997), but would not necessarily perform poorly on speech perception tasks. In other cases (such as the Delayed dyslexics), factors affecting the encoding and storage of item-specific word knowledge (such as poor letter recognition, low print exposure) might combine with mild phonological deficits to produce what appear to be general delays in reading (Bailey, Manis, Pedersen, & Seidenberg, 2004; Harm & Seidenberg, 1999). In still other cases, language problems might involve aspects of language other than phonology and phoneme awareness (e.g., receptive vocabulary) and hence interfere with higher order aspects of reading (comprehension rather than word recognition and decoding).

Dyslexia is a dynamic, developmental disorder. It is likely that the importance of different language skills (phoneme perception, representation of word phonology, segmental phonology, and semantic representations) varies with development. It is important to investigate speech and language skills in individuals of a variety of ages (from infancy to adulthood) to shed further light on the etiology of this complex problem.

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