Speech Perception, Lexicality, and Reading Skill

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This study examined the interaction between speech perception and lexical information among a group of 7-year-old children, of which 26 were poor readers and 36 were good readers. The children's performance was examined on tasks assessing reading skill, phonological awareness, pseudoword repetition, and phoneme identification. Although good readers showed clearly defined categorical perception in the phoneme identification task for both the /*bif*/–/*pif*/ and the /*bis*/–/*pis*/ continua, the category boundary for /*bif*/–/*pif*/ was at longer VOTs than the boundary for /*bis*/–/*pis*/, which characterizes the classic lexicality effect. Poor readers showed less sharply defined categorical perception on both continua. Although poor readers did not show the classic lexicality effect, lexicality did affect the overall rate with which phonemes were identified as /*b*/ or /*p*/ at each VOT. These findings suggest that the lexicon may operate as a compensatory mechanism for resolving ambiguities in speech perception. Furthermore, statistical correction for group differences in phoneme identification made group differences in phoneme deletion disappear, suggesting that deficits in speech perception may play a causal role in the phonological core deficit associated with reading failure. © 2001 Academic Press

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There is now considerable evidence that reading disability is characterized by deficits in phonological awareness, the ability to make judgments about the phonological structure of oral language (Jorm & Share, 1983; Stanovich &

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Siegel, 1994; Wagner & Torgesen, 1987). Indeed, numerous longitudinal and training studies have established a causal connection between deficient phonemic awareness and reading disability (Adams, 1990; Bradley & Bryant, 1985; Wagner, Torgesen & Rashotte, 1995).

Given the importance of phonological awareness in reading acquisition, it is of no surprise that various attempts have been made to clarify the factors underlying deficits in phonological awareness. These attempts can be described as either domain-general or domain-specific. For example, some have proposed that growth in phonological awareness may be limited by a breakdown in the domain-general mechanisms, such as metacognitive skills operating within and outside the domain of language (Fletcher-Flinn & Snelson, 1997; Tunmer, 1988), or temporal processing mechanisms that also operate across domains (Farmer & Klein, 1995; Tallal, 1980, 1984).

Others have argued that domain-general mechanisms are unlikely to underlie deficient phonological awareness. This is because the deficit appears limited to very specific aspects of cognitive architecture. In particular, it appears limited to language processing, rather than reflecting more global cognitive deficits (Hall & Humphreys, 1982; Siegel, 1989; Stanovich, 1986). Arguments for domain-specific mechanisms are supported by findings that appear to contradict the possibility that domain-general mechanisms, such as metacognition and temporal processing, underlie deficient phonological awareness. For example, although children and adults with reading disabilities showed no impairments on nonlinguistic metacognitive tasks involving angles or figures, their performance was impaired on the same task operations when the items to be accessed or manipulated were phoneme segments (Fowler, 1991; Mann, Tobin, & Wilson, 1987). Similarly, although adults with reading disabilities were poorer at phoneme segmentation tasks than normally achieving individuals, their performance matched that of the controls on temporal processing measures such as visual gap detection, auditory gap detection, and temporal order judgment (Chiappe, Stringer, Siegel, & Stanovich, in press; see Mody, Studdert-Kennedy, & Brady, 1997, for related findings). These findings suggest that the mechanisms underlying deficient phonological awareness are specialized for linguistic processing, rather than operating across domains.

On the domain-specific view, difficulties in phonological awareness may result from deficits in basic phonological processing (Fowler, 1991; McBride-Chang, 1995; Metsala, 1997; Reed, 1989). Poorly defined phonological representations could interfere with, or delay, the discovery of the phonemic elements of spoken words (Fowler, 1991; Swan & Goswami, 1997). Failure to discover the phonemic elements of spoken words could impede the development of phonemic awareness. Indeed, McBride-Chang (1995) demonstrated that speech perception contributed unique variance to performance in phonemic awareness. Similarly, Metsala (1997) found significant correlations between performance in speech perception and deficits in phonological awareness among younger children. Reading disabled children with low phonological awareness have also shown greater diffi-

culties in speech discrimination than reading-disabled children with higher phonemic awareness (Manis et al., 1997).

Furthermore, a number of studies have reported that individuals with reading disabilities perform more poorly than same-age, nondisabled peers on tasks involving speech perception (Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Metsala, 1997; Reed, 1989; Watson & Miller, 1993). For example, disabled readers have been found to show less clearly defined categorical perception (Godfrey et al., 1981; Reed, 1989) and be less accurate than normally achieving peers at repeating words (Brady, Poggie, & Rapala, 1989) and pseudowords (Gottardo, Siegel, & Stanovich, 1997; Khami, Catts, & Mauer, 1990; Snowling, 1981).

However, not all investigations of speech perception have reported reading-group differences. A number of studies have reported that in some situations, individuals with reading disabilities performed as well as normally achieving peers (Brady, Shankweiler, & Mann, 1983; Elliott, Scholl, Grant, & Hammer, 1990; Snowling, Goulandris, Bowlby, & Howell, 1986). Furthermore, Manis et al. (1997) reported that although some reading-disabled children showed deficits in speech perception, the majority of reading-disabled children showed normal categorical perception. Therefore, there remains some inconsistency about whether individuals with reading disabilities do in fact experience impairments in speech perception.

There are three reasons why there may be divergent findings. First, a variety of paradigms have been used to assess speech perception. These paradigms include, but are not restricted to, phoneme discrimination, the recognition of words using gating techniques, ABX, speech repetition, and temporal order judgment. These tasks place different demands on working memory and on articulation. For example, although speech repetition has been used to investigate the ability to encode and represent phonetic stimuli, accurate speech repetition also depends on phonological short-term memory and articulatory skill (Gathercole, 1995; Gathercole, Willis, Emslie, & Baddeley, 1991; McBride-Chang, 1995). Similarly, the temporal order judgment and ABX paradigms place heavy demands on working memory, as both require several stimuli to be presented before a decision can be made. In contrast, the phoneme identification paradigm both reduces demands on memory, by requiring subjects to provide an immediate response to a single stimulus, and eliminates confounds with articulation, by using a button-press or forced choice point as the response (McBride-Chang, 1995). For these reasons, phoneme identification may be considered a purer test of speech perception. Thus, the different paradigms may yield different patterns of results not because of reading-group differences in speech perception, but because the tasks themselves differ in their sensitivity to speech perception as a consequence of potential confounds with memory and articulation.

A second reason for the divergent findings may lie in the wide range of ages among the studies' participants, as there is growing evidence that children's phonological representations develop and change throughout childhood (Metsala & Walley, 1998). A number of theorists have proposed that children's phono-

logical representations shift from larger, global structures to more segmental, phonemic components (Fowler, 1991; Metsala & Walley, 1998; Walley, 1993). Furthermore, Metsala (1997) has argued that reading-disabled children's speech perception may be developmentally delayed. Using the gating paradigm, she found that reading-disabled children required more speech input than their normally achieving peers for words in sparse neighborhoods but not for words in dense neighborhoods. This pattern is consistent with the view that spoken word recognition in reading-disabled children may resemble the spoken word recognition of younger normally achieving children. Similarly, Hurford and Sanders (1990) found significant reader-group differences in phoneme discrimination for children in second grade, but not for children in fourth grade. Thus, the relationship between speech perception and reading skill may be developmentally limited.

Finally, investigations of children's speech perception use a variety of stimuli, ranging from high frequency, monosyllabic real words, to complex pseudowords. However, lexical factors may influence the studies' findings in a number of ways. For example, although reading-group differences tend to be robust when pseudowords are used (Brady et al., 1989; Gottardo et al., 1997; Khami et al., 1990; Snowling, 1981), reading-group differences are less likely to be reported when stimuli are high-frequency monosyllabic words (e.g., Lieberman, Meskill, Chatillon, & Schupack, 1985; Snowling et al., 1986). In fact, Snowling et al. (1986) found that reading-disabled children were less accurate than normally achieving children at repeating low frequency words and pseudowords despite showing comparable performance in repeating high frequency words. Other studies suggest that lexical factors, such as wordlikeness, make significant contributions to children's accuracy in pseudoword repetition (Gathercole, 1995; Gathercole et al., 1991). Similarly, Reed (1989) showed that reading-disabled children rely more heavily than normally achieving children on lexical information to identify ambiguous word onsets that vary in place of articulation. Thus, speech perception may depend on a combination of phonological and lexical factors (Gaskell & Marslen-Wilson, 1998), whereby lexical information may be used to resolve phonological ambiguity.

The current research is guided by three main issues. First, we wished to determine if reading-disabled children have less clearly defined categorical perception than normally achieving children in the first grade. These children are younger than the participants in many other investigations of speech perception, which may be important if the relationship between reading skill and speech perception is developmentally limited. Deficits in speech perception may play a particularly important role in reading disability at a time when young children are expected to acquire the alphabetic principle. Our sample of reading-disabled children is also unique because it represents a group of children who are treatment resisters. Vellutino and his colleagues (Vellutino et al., 1996) suggested that children's responsiveness to appropriate treatment should be an important consideration in the diagnosis of reading disability, as resistance to appropriate treatment

enables one to distinguish between children whose reading difficulties are caused by basic cognitive deficits and those whose difficulties are caused by experiential or instructional factors. The children in the current study had been identified as at-risk for reading failure a year earlier, when they were in kindergarten. The at-risk children had received phonological awareness training and explicit and systematic instruction in phonics since kindergarten. Because our sample of poor readers were resistant to appropriate intervention, their reading difficulties may be attributed to a basic cognitive deficit rather than experiential factors. In contrast, the disabled readers from most other investigations included children who were attending schools or classrooms for learning-disabled children, or who had been identified as reading-disabled based on their performance on reading tests at a single point in time. As a consequence, it is difficult to know whether their deficits in phonological processing reflect underlying cognitive deficits or instructional factors.

The second goal of this study was to determine the relationship between speech perception and phonological awareness. To this end, we examined whether individual differences in speech perception could account for reading-group differences in phonological awareness.

Finally, we sought to determine whether lexical information plays a greater role in speech perception for reading-disabled children than for normally children. To this end, we explored lexical influences in speech perception using Miller, Dexter, and Pickard's (1984) pair of stimulus continua, /bis/–/pis/ and /bif/–/pif/, in the phoneme identification paradigm. Both had a real word (/pis/ and /bif/) at one end of the continuum and a pseudoword (/bis/ and /pif/) at the other extreme. The classic lexicality effect involves a boundary shift, in which the category boundary for the /bif/–/pif/ continuum is at longer VOT values than that of the /bis/–/pis/ continuum. It was hypothesized that reading-disabled children will show greater lexicality effects than normally achieving children, indicating that they are relying on lexical factors to compensate for deficits in phoneme discrimination.

METHOD

Participants

The present study was conducted at the end of the school year in May and June of 1999. The participants in this study were 62 first-grade children from a suburb of Vancouver. In this school district, children's beginning literacy skills and phonological awareness were assessed in kindergarten. Children who were identified as being at risk for reading failure in kindergarten received phonological awareness training using the prototype of the program, "Launch into Reading Success" (Bennett & Ottley, 2000). Throughout the first grade, reading instruction included explicit and systematic phonics instruction. The early intervention approach used by this district was effective, as can be demonstrated by district-wide performance on the reading subtest of the Wide Range Achievement Test (WRAT-3; Wilkinson, 1995). In kindergarten, 26% of the children throughout the

district were considered at risk for reading failure as their WRAT-3 reading scores were at or below the 25th percentile and the overall mean for the district was the 45th percentile. At the end of first grade, only 10% of the children had WRAT-3 reading scores at or below the 25th percentile and the overall mean was the 65th percentile. Thus, this school district had an effective approach to reading instruction with a focus on early intervention.

Children were classified as good readers or as poor readers based on their performance on the reading subtest of the blue form of the Wide Range Achievement Test—3 (WRAT-3; Wilkinson, 1995). The 26 children who had WRAT-3 reading scores below the 26th percentile were classified as poor readers. The use of the 25th percentile as the cut-off score has been recommended as an appropriate criterion for identifying children with significant difficulties in reading (Siegel & Heaven, 1986). All of these children had been in the school district in kindergarten and had received phonological awareness training. Therefore, these children were treatment resistors. Thirty-six children whose WRAT-3 reading scores were above the 29th percentile were classified as good readers. All children spoke English as their first language. The mean age of the total sample was 82.41 months, with a standard deviation of 2.96 months.

Procedure

Each participant was tested individually in two separate sessions. Testing took place in a quiet room in the children's schools during school hours. In the first session, which lasted approximately 40 min, the set of reading and phonological measures was administered. Approximately one month later, the phoneme identification task was administered. This task lasted approximately 10 min. In addition to the reading subtest of the WRAT-3, the following tasks were administered to the children:

Word Identification subtest of the Woodcock Reading Mastery Test—Revised (Woodcock, 1989) (form G). This test is an untimed naming task, in which a child is required to read a list of words out loud until the child reaches a ceiling level. Once the child reaches the ceiling level, the test is discontinued.

Word Attack subtest of the Woodcock Reading Mastery Test—Revised (Woodcock, 1989) (form G). This test is an untimed task, in which a child is required to produce phonemically plausible pronunciations for a list of printed pseudowords. Once the child reaches the ceiling level, the test is discontinued.

Phoneme deletion. Children's ability to delete phonemes from words was assessed using the Phoneme Deletion subtest from the Phonological Abilities Test (Muter, Hulme, & Snowling, 1997). There were four practice trials with corrective feedback and eight test trials without feedback in which the child deleted the initial phoneme of words ("Bus without /b/ says . . ."). This was followed by four practice trials with corrective feedback and eight test trials without feedback in which the child deleted the final phoneme of words ("Bus without /s/ says . . ."). Children were shown pictures of the target words to reduce the memory load for this task. This task had a maximum score of 16.

Phoneme deletion and substitution. Items selected from levels F, G, and H of the Auditory–Motor Skills Training (Rosner, 1973) were administered to children who had scores greater than zero on the Phoneme Deletion task. In this task, children attempted either to delete a phoneme from a word or substitute the target phoneme with a different phoneme. For example, when children deleted phonemes from words, the examiner said: "Say /bat/. Say it again but don't say /b/." When children substituted phonemes, the examiner said: "Say /bat/. Say it again, but instead of /b/ say /m/." There were six trials in which the target phoneme was in the initial position of the word, six trials in which the target phoneme was in the final position, and six trials in which the target phoneme was part of a blend. This task had a maximum score of 18.

Rapid automatized naming (RAN; Denckla & Rudel, 1974). A variation of the RAN task was used to assess phonological recoding in lexical access or word retrieval. In this task, children named 40 items on a chart consisting of 5 different items repeated 8 times. The stimuli were line drawings of a tree, a chair, a bird, a pear, and a car. To ensure that all children knew the target words, children were asked to identify each of the 5 items in the first row. All children could easily name each picture. The score was the time taken in seconds to complete the chart of 40 items.

Memory for sentences. The Memory for Sentences subtest of the Stanford Binet (Thorndike, Hagen, & Sattler, 1986) was administered as a measure of verbal working memory. In this task, children repeated sentences of increasing length and syntactic complexity. Once the children reached ceiling, the test was discontinued.

Pseudoword repetition. In this task, children repeated 32 pseudowords of increasing difficulty that had been read to them by the experimenter. This set of pseudowords had originally been developed by Gathercole et al. (1991) and was adapted for North American English by Gottardo et al. (1997). Pseudowords ranged in length from one syllable (e.g., *sep* and *grall*) to four syllables (e.g., *penneriful* and *bafmotbem*) and included equal numbers of items of high and low wordlikeness. Once a child produced five consecutive errors, the task was discontinued.

Phoneme identification task. Categorical speech perception was assessed by asking children to identify instances of the minimal pairs /bis/–/pis/, and /bif/–/pif/. The /bis/–/pis/ and /bif/–/pif/ stimuli were based on the work of Miller and her colleagues (Miller et al., 1984). For each pair, there was one real word (/pis/ and /bif/) and one pseudoword (/bis/ and /pif/). The stimuli were constructed by editing natural instances of /pis/ and /pif/ produced by a female speaking at a moderate rate using SoundEdit Pro v1.0. The natural speech tokens of /pis/ and /pif/ were used to make two 13-member series, in which the change from /p/ to /b/ was accomplished by varying the voice onset time (VOT) for the initial stop consonant in each word. The original VOT in the natural speech samples were 79 ms for /pis/ and 74 ms for /pif/. The 13-member continua were created by deleting successively larger portions of the unvoiced acoustic portions at the beginning

of the closure for /p/ from /pis/ and /pif/. Equally long voiced acoustic segments from the naturally recorded instances of /bis/ and /bif/ were added to the stimuli at the end of the closure, so that the total duration of each stimulus was 415 ms. In other words, a series of VOT values for the /bis/–/pis/ and /bif/–/pif/ contrasts were created while the other acoustic features, such as prosody, fundamental frequencies, and sound pressure levels, were held constant. The 13 VOT values used by Manis and his colleagues (Manis et al., 1997) were used for both sets of stimuli. The VOT values were 7, 12, 15, 19, 21, 26, 32, 35, 39, 45, 48, 53, and 59 ms. Pilot testing among adults revealed that the computer-edited stimuli were perceived as unedited tokens of natural speech. The stimuli were digitized at 16 bits and 44.1 kHz in mono and stored on disk. They were played through headphones connected to the audio output jack of a laptop computer. An NEC laptop computer running Superlab Pro for Windows was used to both present stimuli and collect responses.

There were two blocks of 104 experimental trials. For half the participants, the block of 104 /bis/–/pis/ stimuli was presented first, and for half the participants, the block of 104 /bif/–/pif/ stimuli was presented first. Within each block, children heard each of the 13 points on the continuum eight times and in random order. Stimuli were presented one at a time, and were separated by an interval of 750 ms in which they saw a yellow happy face in the center of the screen. For each trial, the stimulus would play while the choices *beef* and *peef* or *beace* and *peace* appeared on the computer screen. *Beef* and *beace* were always presented in cyan on the left of the screen, while *peef* and *peace* were always presented in red on the right side of the screen. Children indicated what they had heard by pressing one of two keys on the RB-400 response box connected to the serial port of the laptop. Children indicated that they heard /bif/ and /bis/ by pressing the left-most key that was marked with a cyan sticker. Children indicated that they heard /pif/ and /pis/ by pressing the right-most key that was marked with a red sticker.

In order to reduce the possibility that children's limited reading proficiency may interfere with their knowledge of which button was associated with which sound, during the instructions, children were asked to indicate which of the buttons was associated with /bis/ or /bif/, and which button was associated with /pis/ or /pif/. In addition, both blocks were preceded with 19 practice trials. There were three trials with VOT values of 7 ms, followed by three trials with VOT values of 59 ms. Children received help from the experimenter in selecting their response for the first six practice trials. These six practice trials were followed by stimuli at each of the 13 points on the continuum in random order.

The percentage of /pis/ and /pif/ responses for each VOT was calculated for each child for the /bis/–/pis/ and /bif/–/pif/ continua, respectively. In addition, an identification function was created for each child for both continua by graphing the percent of /pis/ and /pif/ responses as a function of VOT (7 through 59 ms). Individual slope values were derived using logistic regression. The slope of the /bis/–/pis/ continuum was calculated using the 13 VOT values (in ms) to predict the percentage of /pis/ responses at each VOT. Similarly, the slope of the

/bif/–/pif/ continuum was calculated using the 13 VOT to predict the percentage of /pif/ responses at each VOT. The individual slope values of both identification functions were used as dependent measures. Because the /bis/–/pis/ and /bif/–/pif/ identification slopes were significantly correlated ($r = .71$, $p < .001$), the mean of these two slopes was also calculated, to be used as the mean /b/–/p/ identification slope variable.

RESULTS

Group Comparisons on Individual Tasks

The participant characteristics are summarized in Table 1. A series of t tests was calculated to compare the performance of good and poor readers. Because Levene's test for equality of variances revealed that the two groups had unequal variances for all measures except Pseudoword Repetition and Phoneme Deletion and Substitution, the adjusted t values and degrees of freedom were used. The degrees freedom and t values were unadjusted for Pseudoword Repetition and Phoneme Deletion and Substitution.

On the selection measure, WRAT-3 reading, poor readers had lower raw scores, $t(50.9) = 11.86$, $p < .001$, and percentile scores, $t(48.4) = 20.63$, $p < .001$ than good readers. Convergent evidence for the weaker decoding skills of poor read-

TABLE 1
Participant Characteristics

Variable	Good readers	Poor readers
Age (in months)	81.28 (2.78)	83.69 (2.59)
WRAT-3		
Raw score	25.56 (3.80)	17.12 (1.66)
Percentile	77.50 (16.48)	15.08 (6.47)
Word identification		
Raw score	36.89 (15.89)	12.31 (8.09)
Percentile	73.11 (21.24)	20.62 (11.27)
Word attack		
Raw score	16.72 (8.90)	5.50 (4.32)
Percentile	67.92 (19.61)	24.88 (12.88)
Pseudoword repetition	27.6 (3.23)	24.23 (3.65)
Phoneme deletion	13.64 (3.94)	8.40 (5.74)
Phoneme deletion and substitution	11.06 (4.36)	7.15 (3.39)
RAN		
Latency (s)	49.42 (9.32)	60.88 (14.51)
Errors	0.14 (0.35)	0.54 (1.21)
Memory for sentences		
Raw score	18.44 (4.16)	15.92 (2.21)
Standard age score	49.14 (11.42)	44.12 (4.45)
Phoneme identification		
/bif/–/pif/ slope	1.82 (0.41)	0.94 (0.51)
/bis/–/pis/ slope	1.48 (0.48)	0.82 (0.51)

ers was revealed by the Word Identification's raw scores, $t(54.8) = 7.96$, $p < .001$, and percentile scores, $t(55.7) = 12.58$, $p < .001$.

The results from this sample of poor readers converged with those from the majority of other samples in the literature, whether treatment resisters or not, by displaying significant deficits in phonological processing (Adams, 1990; Bradley & Bryant, 1985; Stanovich & Siegel, 1994; Vellutino et al., 1996; Wagner & Torgesen, 1987). Poor readers showed significant impairments in pseudoword reading, as was evident by their lower Word Attack raw scores, $t(53.6) = 6.57$, $p < .001$, and percentile scores, $t(59.6) = 10.42$, $p < .001$. Similarly, poor readers were less skilled than good readers at Pseudoword Repetition, $t(60) = 3.91$, $p < .001$, Phoneme Deletion, $t(39.3) = 3.96$, $p < .001$, and Phoneme Deletion and Substitution, $t(52) = 3.44$, $p < .001$. Although both groups of children showed comparable accuracy on the RAN task, $t(28.1) = 1.64$, ns, poor readers named pictures more slowly than good readers, $t(39.6) = 3.54$, $p < .001$.

Poor readers also showed significant impairments in verbal working memory. On the Memory for Sentences subtest, poor readers had significantly lower raw scores, $t(55.7) = 3.08$, $p < .01$, and standard age scores, $t(48.27) = 2.40$, $p < .05$, than good readers. These findings are convergent with other reports of impaired verbal working memory among poor readers (Chiappe, Hasher, & Siegel, 2000; Gathercole et al., 1991; Siegel & Ryan, 1988; Swanson, 1994).

Phoneme Identification Performance

The phoneme identification functions for both continua are presented in Fig. 1a for good readers and Fig. 1b for poor readers. Across individuals, the functions were regular, with short VOT values associated with /bis/ and /bif/, and long VOT values associated with /pis/ and /pif/. A 2 (reading group) × 2 (stimulus type: /bis/–/pis/ vs /bif/–/pif/) repeated measures ANOVA, with stimulus type as a repeated measure, revealed that poor readers had significantly shallower slopes than good readers, $F(1, 60) = 52.38$, $p < .001$, indicating that poor readers' perception along the /b/–/p/ continua was less categorical than that of good readers. Thus, poor readers' representations of /b/ and /p/ may be less clearly defined than those of good readers. Similarly, examination of Figs. 1a and 1b reveal that poor readers' performance at either end of the continua was closer to chance. That is, poor readers were more likely to identify clear instances of /b/ as /p/, and clear instances of /p/ as /b/. Although the slopes were steeper for the /bif/–/pif/ continuum, $F(1, 60) = 15.69$, $p < .001$, the interaction between stimulus type and reading group was not significant, $F(1, 60) = 3.58$, ns. The slopes for the /bis/–/pis/ and /bif/–/pif/ identification functions featured a strong positive correlation, $r = .71$, $p < .001$. Thus, children showed similar patterns of performance for both continua.

The influence of lexical status on the phoneme identification functions of good and poor readers was examined using a 2 (reading group) × 2 (stimulus type: /bis/–/pis/ vs /bif/–/pif/) × 13 (VOT) repeated measures analysis of variance, with stimulus type and VOT as repeated measures. The significant interac-

a Good Readers
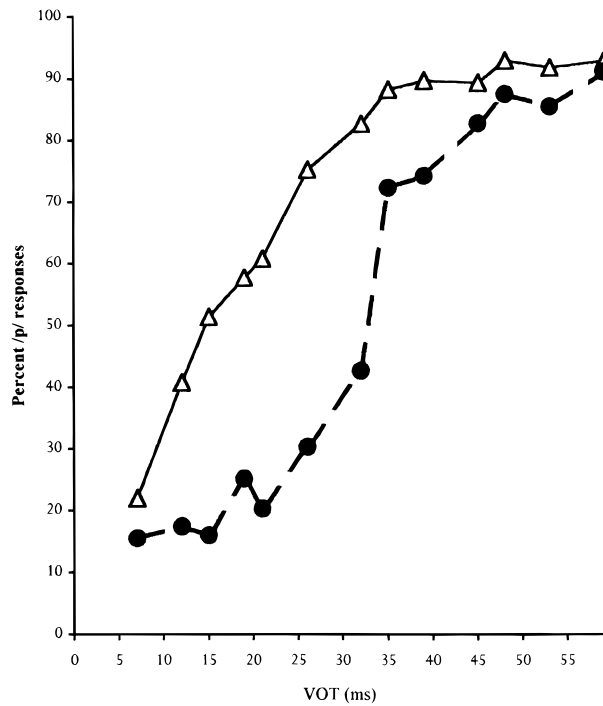
b Poor Readers
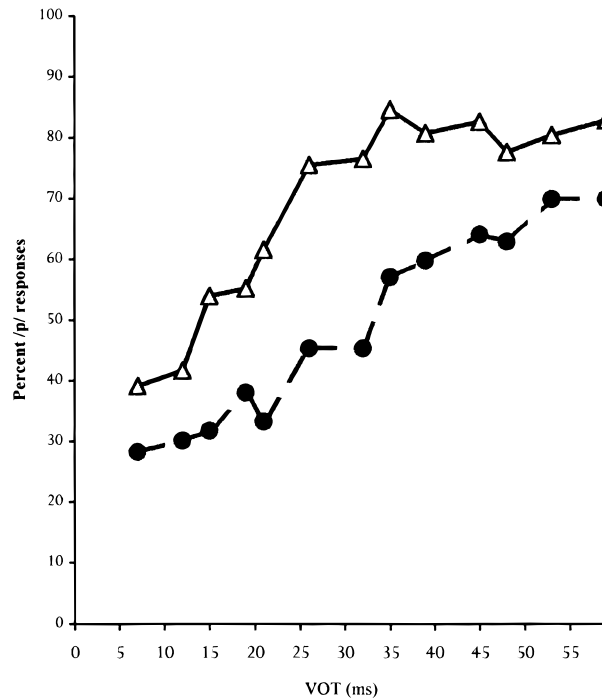
FIG. 1. Phoneme identification functions for good and poor readers.

tion between reading group and VOT, $F(12, 696) = 12.07$, $p < .001$, indicated that poor readers had different phoneme identification functions than good readers. The interaction between stimulus type and VOT, $F(12, 696) = 13.54$, $p < .001$, indicated that lexical status influenced phoneme identification functions, so that children were more likely to report that they had heard /pis/ at shorter VOT intervals than /pif/. Finally, the three-way interaction between reading group, stimulus type, and VOT, $F(12, 696) = 3.45$, $p < .001$, indicated that lexical status influenced the phoneme identification functions of poor readers differently than those of good readers. The phoneme identifications for both reading groups were investigated further with separate 2 (stimulus type: /bis/–/pis/ vs /bif/–/pif/) × 13 (VOT) repeated measures analyses of variance. For both good readers (F_1) and poor readers (F_2), there were significant main effects of stimulus type, $F_1(1, 35) = 98.80$, $p < .001$, $F_2(1, 25) = 30.27$, $p < .001$, and VOT, $F_1(12, 420) = 164.40$, $p < .001$, $F_2(12, 300) = 30.27$, $p < .001$. For good readers, there was a significant interaction between stimulus type and VOT, $F_1(12, 420) = 16.75$, $p < .001$. This interaction is consistent with the classic boundary shift, so that the identification functions for /bis/–/pis/ and /bif/–/pif/ were very similar at the extremes, but the VOTs for the category boundaries differed (the boundary was at shorter VOTs for the /bis/–/pis/ continuum than the /bif/–/pif/ continuum). However, the interaction between stimulus type and VOT was not significant for poor readers, $F_2(12, 300) < 1$, ns, indicating that poor readers showed two parallel phoneme identification functions. That is, at each VOT, poor readers were more likely to report that they had heard /p/ for the /bis/–/pis/ continuum than they were for the /bif/–/pif/ continuum.

Interrelations across Tasks

Next, we examined whether reading-group differences in phonemic awareness could be explained by group differences in speech perception. A pair of ANCOVAs was calculated with the mean /b/–/p/ identification slope as the covariate and reading group as the between-subjects factor. When statistically controlling for phoneme identification, reading-group differences were no longer significant for Phoneme Deletion, $F(1, 58) = 2.38$, ns, and Phoneme Deletion and Substitution, $F(1, 51) = 2.59$, ns.

Because differences in phoneme identification explained group differences on measures of phonemic awareness, we wished to determine whether the relationship between phoneme identification and phonemic awareness was symmetrical. That is, we asked whether reading-group differences would persist after statistically correcting for performance in Phoneme Deletion and Phoneme Deletion and Substitution. A second pair of ANCOVAs was calculated with the mean slope in Phoneme Identification as the dependent variable, reading group as the between-subjects factor, and Phoneme Deletion and Phoneme Deletion and Substitution as covariates. When statistically controlling for Phoneme Deletion, good readers still had significantly steeper identification slopes than poor readers, $F(1, 58) = 27.54$, $p < .001$. Similarly, reading-group differences remained when Phoneme

Deletion and Substitution was the covariate, $F(1, 51) = 19.95$, $p < .001$. A third ANCOVA was calculated in which both Phoneme Deletion and Phoneme Deletion and Substitution were entered as covariates. Once again, reading-group differences in Phoneme Identification remained when both phonemic awareness tasks were entered as covariates, $F(1, 50) = 17.54$, $p < .001$. Therefore, differences between good and poor readers on measures of phonemic awareness could be explained by individual differences in phoneme identification. In contrast, measures of phonemic awareness did not account for reading-group differences in speech perception.

DISCUSSION

The findings of this study are as follows: First, the phoneme identification task revealed that poor readers who were difficult to remediate had significant deficits in speech perception. Poor readers had shallower phoneme identification slopes, indicating that their categorical perception was less clearly defined than good readers. Moreover, poor readers' difficulties in phoneme identification were not restricted to the category boundary, as they were less accurate at identifying clear instances of /b/ and /p/ at either end of the continua than normally achieving children. These findings were consistent with previous studies of older children with reading disabilities (Godfrey et al., 1981; Reed, 1989; Snowling et al., 1986), and they support the view that the phonological representations of poor readers are not fully differentiated at the phonemic level (e.g., Brady, 1991; Metsala, 1997).

Second, the results of the current study suggest that impaired speech perception may play a causal role in the deficits in phonemic awareness that characterize reading disability. A number of studies investigating speech perception and phonological awareness have shown correlations between speech perception and measures of phonological awareness (Godfrey et al., 1981; Manis et al., 1997). For instance, Manis et al. (1997) found that reading-disabled children with lower levels of phonemic awareness had shallower phoneme identification slopes than those with higher phonemic awareness. These studies indicate that there is an association between speech perception and phonological awareness. However, they do not indicate the direction of causality or rule out the possibility that the relationship between speech perception abilities and phonological awareness is mediated by a third variable, such as reading experience. We found that although good and poor readers differed in their ability to delete and substitute phonemes in words, these differences were eliminated when they were statistically corrected for children's phoneme identification slopes. That is, variance in speech perception explained group differences in phonemic awareness. However, the converse was not true. Variance in phonemic awareness did not explain group differences in phoneme identification. It is possible that the asymmetrical relationship between phoneme identification and phonemic awareness may reflect the different cognitive requirements of the two tasks. For example, children who have difficulties attending to a less cognitively demanding task, such as phoneme identification, will likely experience difficulties on a more

demanding task, such as phoneme deletion. In contrast, children may perform poorly on a demanding, metalinguistic task for a variety of reasons, such as limited working memory or poor problem solving skills, despite average or above average performance on tasks assessing basic processing skills. However, the data are also consistent with the view that an impairment in speech perception may underlie deficits in phonemic awareness.

Further support for the view that inadequate speech perception leads to impaired phonemic awareness comes from McBride-Chang's (1996) work with older children. McBride-Chang used structural equation modeling to reveal that a speech perception factor based on three phoneme identification tasks contributed unique variance to phonological awareness. Similarly, Watson and Miller (1993) reported a significant relationship between speech perception and phonemic awareness among college students. These studies, together with the current findings, provide further support for the hypothesis that deficits in speech perception may constrain the development of phonemic awareness (Fowler, 1991; McBride-Chang, 1996).

A third major finding was that the lexicon appeared to influence speech perception for both groups of children. Good readers showed the classic lexicality effect that had been revealed in a sample of college students (Miller et al., 1984). That is, the category boundary for the /bif/–/pif/ continuum was at significantly longer VOT intervals than the category boundary for the /bis/–/pis/ continuum. Thus, the lexicon's influence in good readers' speech perception was largely restricted to category boundaries, where the acoustic input itself contained greater ambiguity. In contrast, although the lexicon influenced phoneme identification for poor readers, they did not show the classic lexicality effect. Instead of affecting perception only at the category boundary, the lexicon influenced poor readers' perception of /b/ and /p/ at each VOT of the continuum. That is, poor readers reported that they had heard /p/ at each VOT of the /bis/–/pis/ continuum with greater frequency than they did for the /bif/–/pif/ continuum.

In explaining the different lexicality effects shown by the two reading groups, it is important to recall that poor readers' representations of the consonant phonemes were inadequate throughout the continuum. They experienced difficulties in identifying clear instances of /p/ and /b/ at either extreme of the VOT continuum. Because poor readers experienced greater ambiguity for acoustically clear instances of /b/ and /p/, they allowed the lexicon to influence their phoneme identification throughout the continuum. Thus, poor readers may be more susceptible to lexical influences in spoken word recognition throughout the VOT continuum because they have more holistic phonological representations. In contrast, the lexicon's influence in phoneme identification for good readers was restricted to the category boundary. Good readers showed more adult-like lexicality effects in spoken word recognition because their phonological representations are better differentiated at the phonemic level. Therefore, the different lexicality effects shown by good and poor readers may not reflect differences in the function of the lexicon in speech perception. Instead, the different lexicality

effects may reflect differences in the quality of the phonological representations of the two reading groups.

Although there have been numerous studies that have investigated the speech perception of reading-disabled children, this is the first study that included poor readers who were treatment resistors. By restricting our sample of poor readers to children who were resistant to intervention, we isolated a group of children whose reading difficulties are unlikely to have been caused by instructional factors. Thus, the poor readers' deficits in speech perception likely reflect intrinsic deficits in cognitive processing. Furthermore, whereas Metsala (1997) reported that poor readers' deficits in spoken word recognition were limited to words from sparse phonological neighborhoods, we have extended these findings to stimuli from dense phonological neighborhoods with a group of young treatment resistors. Thus, the difficult-to-remediate poor readers may have greater impairments in speech perception than the poor readers in other samples, as their lexical representations may be holistic for words in dense neighborhoods. Further research is required to develop a better understanding of the spoken word recognition of poor readers who are treatment resistors.

In conclusion, our results supported two claims. First, deficits in speech perception appear to play a causal role in the deficient phonological processing. Thus, insufficiently differentiated phonological representations may underlie deficits in phonological awareness. Second, lexical information was used by both good and poor readers to resolve ambiguities in speech stimuli. However, the scope of lexical influences on speech perception was far broader for poor readers as a result of their less segmented phonological representations.

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