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## *Ability to Encode Phonological Representations: An Underlying Difficulty of Poor Readers*

Susan Amanda Brady

*University of Rhode Island and Haskins Laboratories*

Numerous phonological deficits are associated with reading disability. As the literature attests, poor readers have been documented to have difficulties on measures of metaphonological awareness and on several other phonological processes, such as verbal short-term memory and rapid naming (e.g., Brady & Shankweiler, 1991; Gough, Ehri, & Treiman, 1992; Wagner & Torgesen, 1987). This chapter entertains the possibility that many of these language weaknesses stem from deficits in a more basic phonological process—ability to encode phonological representations. In the first section, two relevant experimental procedures are discussed: categorical perception, because it fairly directly assesses phonological encoding, and pseudorepetition, because it incorporates many phonological processes, including encoding, and emerges as a powerful correlate of reading ability. Here the evidence linking each of these to individual differences in reading skill are reviewed, and the argument is made that the common demands of speech perception contribute to the difficulties poor readers encounter on both.

The second portion of the chapter critiques, and rejects, a hypothesis that a more general auditory problem causes the phonological deficits of poor readers. In the final section of the chapter, I discuss one of the mechanisms by which speech perception can exert influence on early reading; namely, through phoneme awareness.

## RESEARCH ON SPEECH PERCEPTION AND READING ABILITY

The phonological basis of skilled reading, and the associated phonological deficits seen in disabled readers, have prompted theorists to posit a core phonological process that could account for a variety of commonly observed correlates with reading performance (Brady, 1991; Fowler & Liberman, 1995; Liberman & Shankweiler, 1979; Shankweiler & Crain, 1986). There are a number of reasons to consider speech perception, the initial encoding of linguistic input, as a plausible candidate. For example, the range of success children experience in acquiring phoneme awareness could derive from the quality of perception of speech sounds: If the phonemic categories are less well defined or are broader for children having difficulty learning to read than for the better readers, discovery of the phonemic elements in words might be more elusive (e.g., Fowler, 1991). Second, the host of associated phonological deficits experienced by less skilled readers on measures of verbal short-term memory, vocabulary acquisition, and confrontation naming also could be viewed as compatible with problems encoding speech stimuli. In verbal memory, inefficient or inaccurate formation of phonological representations might limit resources available for recall or might result in a less durable memory trace. This, in turn, could impede reading by disrupting decoding and comprehension of text (for discussion see Perfetti, 1985; Shankweiler, 1989). For learning new words, if the phonological form of new items tends to be imprecise or unstable, more extensive exposure might be necessary to retain accurate representations of lexical items (Aguiar & Brady, 1991; Kamhi, Catts, & Mauer, 1990). Likewise, the problems reported on productive naming tasks for poor readers could be a by-product of the same difficulty establishing fully specified phonemic representations of words: If the input for the word is faulty in some way, subsequent production of that lexical item could in turn be hampered by the quality of the representation (Elbro, in press). In brief, deficits at the level of phonological encoding could have repercussions throughout the language system, contributing to the range of language weaknesses documented for less skilled readers.

### Categorical Perception

When interest in the speech perception abilities of poor readers emerged, categorical perception tasks were thought to be an ideal way to examine whether deficits were present. In this paradigm, a speech continuum is constructed, changing in equal acoustic steps from one phoneme to another (e.g., a nine-step continuum from /ba/ to /pa/). Identification and

discrimination measures are conducted, using stimuli from the continuum. In the identification portion, subjects are asked to identify randomized items from the continuum with each stimulus presented multiple times throughout the task. The stereotypic identification function has identification perfect within categories and sharply switching at the phoneme boundary. In the discrimination measure, pairs of stimuli are presented, usually at a fixed distance on the continuum (e.g., Items 1 and 3, 2 and 4, 3 and 5), and listeners are asked to judge whether they are the same or different. Discrimination in categorical perception shows an inverse pattern to identification performance: Subjects are very poor at noting the differences between variants within a phoneme category, but quite sensitive to comparable acoustic differences across a phoneme boundary. This phenomenon, first studied with normal adults, contrasted with the typical observation of continuous perception<sup>1</sup> with nonspeech stimuli, and was initially thought to be unique to speech processing (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Studdert-Kennedy, Liberman, Harris, & Cooper, 1970). Although subsequent research on perception of nonlinguistic stimuli has undermined that claim, nonetheless categorical perception is characteristic of speech, and categorical perception tasks have been useful for studying processes of speech perception (see Repp, 1984, for a review).

The nature of the categorical perception task seemed a promising technique to explore whether poor readers have differences in their phoneme categories: For example, would the phoneme boundaries of poor readers suggest broader, less well-defined categories? The relative normalcy of poor readers in ordinary speaking and listening suggested that, if present, deficits in speech perception would necessarily be slight. In the first study to examine this question, Brandt and Rosen (1980) tested dyslexic children, and normal children and adults, on /ba/-/da/ and /da/-/ga/ continua. Focusing mainly on the phoneme boundaries on the identification tasks, Brandt and Rosen reported that the groups performed comparably. They concluded that dyslexic children have normal consonant categories and were inclined to discount the potential importance of speech perception in reading ability. A number of subsequent researchers investigating this same question disagreed with Brandt and Rosen's conclusion, although they did not dispute the results discussed in Brandt and Rosen's paper. A second study by Godfrey, Syrdal-Lasky, Millay, and Knox (1981) confirmed a lack of difference in phoneme boundaries for stimuli from /ba/-/da/ and /da/-/ga/ continua and a predictable correspondence between identification and

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<sup>1</sup>For example, given a color spectrum with fine gradations of shade, subjects may divide the series reliably into discrete categories (e.g., purple, blue, green), but still be able to distinguish items within a category (e.g., a more purplish blue from a greener blue).

discrimination tasks (i.e., discrimination peaks at the identification boundaries). Nonetheless, these authors suggested that dyslexic and normal children do differ in important aspects of their speech performance. In particular, they reported a significant difference in consistency of labeling of the stimuli, even for the best exemplars (i.e., the endpoint stimuli in the continua), resulting in a more gradual slope near the phoneme boundary. In addition, significant effects were obtained on the discrimination measures, with the dyslexic subjects not only discriminating true variation between the stimuli more poorly than the controls, but also reporting identical stimuli to be different more often. Although Brandt and Rosen didn't make statistical comparisons of these aspects of identification and discrimination performance, Godfrey et al. and later Werker and Tees (1987) both commented that the descriptive data from Brandt and Rosen's report looked similar to the (significant) outcomes in their experiments.

Subsequent studies have confirmed that less skilled readers apply normal category boundaries when labeling speech stimuli. Only occasional reports of differences in phoneme boundaries were noted by Steffens, Eilers, Gross-Glenn, and Jallad (1992) on one of three speech continua given to dyslexic adults, and by deWierdt (1988) with a group of prereaders who later emerged as poor readers. At the same time, several studies also found that the identification and/or discrimination of speech tends to be less accurate among poor readers (de Weirdt, 1988; Hurford, Gilliland, & Ginavan, 1992; Hurford & Sanders, 1990; Lieberman, Meskill, Chatillon, & Schupack, 1985; Manis, McBride, Seidenberg, Doi, & Custodio, 1993; Mody, Studdert-Kennedy, & Brady, in press; Pally, 1986; Reed, 1989; Steffens et al., 1992; Werker & Tees, 1987).<sup>2</sup> However, the particular task or stimulus characteristics yielding these differences are not always consistent. For example, whereas Godfrey et al. (1981) obtained significant reading group effects on both identification and discrimination tasks, poor readers studied by Werker and Tees (1987) were less accurate only on discrimination.

Although reading group differences in speech perception have most frequently been studied and obtained using synthetic stop contrasts such as /ba-/da/ or /da-/ga/, significant group effects are not restricted to this class of phonemes. Extending the affected stimuli beyond stop

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<sup>2</sup>To pinpoint reading-group differences in speech perception, it is important to note that, even for apparently simple speech perception tasks, accuracy may be influenced by the nature of the response required. In an interesting within-subjects comparison of 10 adult dyslexics, Lieberman et al. (1985) reported that the error rate went from 26.5% to 42.5% when, instead of saying which stop consonant they had heard, subjects were asked to write down their responses. This outcome raises concerns about the interpretation of studies that have relied on orthographic skills for subjects' identification responses (Manis et al., 1993; McBride-Chang, 1995).

contrasts, Lieberman et al. (1985) documented that dyslexic adults differed significantly on perception of phonetically similar, synthetic steady-state vowels (but see Steffens et al., 1992). Other synthetic speech contrasts such as /sa/-/sta/ (Steffens et al., 1992) have also yielded reading ability effects on identification or discrimination tasks (however, see Mody et al., in press, for lack of effect for /sei/-/steI/ ("say/stay")). Even with natural speech stimuli that convey more of the redundant acoustic information specifying phonemic identity, reading-group differences in speech perception are often evident when close phonetic distinctions differentiate a phonological contrast, especially under somewhat demanding speech recognition conditions. For example, using natural speech, deficits in discrimination performance by reading-disabled children were found on both stop consonant (/di/-/gi/) and on liquid (/ri/-/li/) pairs of stimuli (Hurford et al., 1992). Lieberman et al. (1985) also found less skilled readers to be less able to recognize consonant-vowel-consonant utterances excised from the presumably crude speech of 1½-year-old children.

The fact that reading-disabled individuals find close phonetic judgments difficult across such a variety of contrasts suggests that there is not a particular aspect of the acoustic requirements of speech signal processing that is the source of difficulty. Poor readers have been stymied for diverse kinds of stimuli manipulations: when the direction of the second and third formant transitions was altered for voiced stop consonant stimuli (e.g., Godfrey et al., 1981), when presented with vowel stimuli using different steady-state frequency levels for the first and second formants (Lieberman et al., 1985), and when a /sa/-/sta/ continuum was achieved by changing the amount of silence inserted between the offset of the /s/ and the onset of the /a/ (Steffens et al., 1992). It appears that the only common requirement for detecting subtle reading-group differences in perceptual ability is the need to use phonetically similar stimuli, and poor readers are hindered more if the stimuli are composed of minimal or degraded cues. Some authors, using multiple sets of speech stimuli, commented that if one of the contrasts were harder overall, then reading-group differences in perception between good and poor readers were more apparent for that contrast (e.g., Godfrey et al., 1981).

However, it does not seem that the large numbers of trials presented in the usual categorical perception study are always essential. Categorical perception studies, as described previously, routinely use multiple tokens of each item or pair in the continuum resulting in a task that, particularly for young children, is no doubt tedious. For example, Godfrey et al. (1981) administered 96 identification trials and 120 discrimination trials. The fact that reading group differences are evident on the endpoint stimuli, as discussed, rather than at the crossover point, suggests that future studies of speech perception might rely on endpoint stimuli, as long as a close

phonetic contrast with demanding stimuli (e.g., synthetic stimuli, infant speech) is employed. This conclusion is supported by occasional reports of group differences in how long children take to reach criterion on an introductory task using only endpoint stimuli (in order to ensure that the children understand the procedure and can reliably perceive the phonetic contrast under study). For example, in the Godfrey et al. (1981) study, all of the control participants were able to pass the initial criterion tests, whereas 47% of the dyslexic children required more practice to label the stimuli appropriately or were unable to reach a satisfactory level of performance to go on to the remainder of the experiment. Likewise, Mody et al. (in press) reported that their less skilled readers performed significantly worse on the training tasks for both the discrimination and identification training. In the study by deWierdt (1988), younger children (first graders) also had more difficulty on the training component. Such observations underscore that the problems with perception are not restricted to perceiving ambiguous stimuli near a phoneme boundary; they also occur for unambiguous but phonetically similar items.

Finally, the issue of top-down effects on speech perception needs to be considered. When reading-disabled children experience uncertainty about the identity of speech stimuli, they may draw more heavily on lexical information. Most of the studies on categorical perception have used nonsense syllable contrasts, thereby minimizing this issue. To examine whether reading-group differences in lexical effects might be present, Reed (1989) designed a pair of stimuli continua. The two continua both went from /b/ to /d/. In one, the /b/-end of the series was a real word (*bop*) and the /d/-end was not (*dop*). In the second, the /b/-end was nonsense (*bodge*) and the /d/-end was a real word (*dodge*). If top-down effects were influencing perception of these CVC stimuli, the phoneme boundary would differ in the two series. That is, the lexical attribute of the real words would compensate for ambiguous acoustic input near the crossover point, leading to more stimuli being identified as the real word in each continuum. By comparing differences in the phoneme boundaries for the two continua, Reed calculated an estimate of the potential top-down effects on speech perception. The good readers, like normal adults (Ganong, 1980), were not influenced by the presence of lexical anchors in the stimuli series. In contrast, significant shifts in the phoneme boundaries were seen for the poor readers. These results are similar to those of Perfetti and Roth (1981) in research examining the reading strategies of good and poor readers: Poor readers, when struggling to decode words, compensated for weak bottom-up ability to analyze the phonetic representation of written words by guessing based on the context. Good readers, although in fact better at contextual prediction, were so accurate and fast at decoding that contextual information made little difference in their reading performance. The Reed

results indicate that such compensatory reliance on world (and word) knowledge may also be a factor in ordinary speech perception for children with reading difficulties.

In sum, the categorical perception procedure has had mixed results. The initial hypothesis that the boundaries of the phonetic space of good and poor readers would reveal differences has not been supported: By and large, poor readers appear to have comparable boundaries and normal phonemic categories. However, other differences in performance on speech perception tasks have been documented for poor readers ranging in age from elementary years (e.g., Godfrey et al., 1981; Werker & Tees, 1987) to adulthood (e.g., Lieberman et al., 1985). Specifically, a number of studies have found that poor readers perform less accurately on perception measures when phonetically similar stimuli are presented, particularly if the phonetic specifications for the stimuli are somewhat impoverished. Although the reading group differences don't appear to be distinct enough to be useful for diagnostic purposes, the collective pattern of these studies points to less precise identification and discrimination of speech by individuals with reading disability.

### Speech Repetition

The second major means of examining the ability to encode phonetic stimuli is speech repetition. For this task the participant is asked to repeat speech stimuli immediately after each item is heard. Both real-word and pseudoword stimuli have been used. Those studies using words have generally not obtained reading group differences when high-frequency, one-syllable words were used (e.g., Lieberman et al., 1985). Presenting such items in noise has sometimes lowered the performance of poor readers significantly more than it has that of better readers (Brady, Shankweiler, & Mann, 1983; Watson & Miller, 1993), although this pattern does not appear to be reliable (Cornelissen, Hansen, Bradley, & Stein, 1996; Kamhi, Catts, Mauer, Apel, & Gentry, 1988; Pennington, Van Orden, Smith, Green, & Haith, 1990; Snowling, Goulandris, Bowlby, & Howell, 1986). On the other hand, manipulating the phonological demands by increasing the length of the words (e.g., *agriculture*) or the phonemic similarity of short phrases to be repeated (e.g., *blue plaid pants*) does result in significantly less accurate repetition by less skilled readers (e.g., Brady, Poggie, & Rapala, 1989; Catts, 1986, 1989; Rapala & Brady, 1990), mirroring clinical observations that individuals with reading difficulty are more apt to misproduce long, phonologically complex words such as *statistical* or *preliminary* (Johnson, 1980; Miles, 1974; Taylor, Fletcher, & Satz, 1982).

Reading-group differences have been more robust when pseudoword stimuli (e.g., *ponverlation*) have been used. Pseudowords, also referred to

as nonwords,<sup>3</sup> generally have been constructed by taking real words and substituting one or more phonemes to produce a nonword that has a phonological sequence and intonation pattern that conforms with English phonology. Snowling (1981) was among the first to emphasize the greater difficulty that poor readers have with nonlexical stimuli. Similarly, Brady et al. (1989) reported that 21% of the variance between their groups of good and poor readers was accounted for by performance on a monosyllabic pseudoword repetition task, whereas only 14% was accounted for by the multisyllabic real-word task. In recent years the evidence for reading-group differences on pseudoword repetition has been mounting. In several additional studies of elementary school children, those with reading difficulty have been documented to do less well than same-age peers for repetition of pseudowords or of lexical items with which they were not familiar (Aguiar, 1993; Futransky, 1992; Hansen & Bowey, 1994; Kamhi et al., 1988; Rapala & Brady, 1990; Snowling et al., 1986; Stone & Brady, 1995; Taylor, Lean, & Schwartz, 1989). Weaknesses in pseudoword repetition also characterized 4-year-old children who subsequently were making slower progress in learning to read (Gathercole, 1995). Likewise, inner-city kindergarten children (Robertson, 1997) had less accurate pseudoword repetition both in kindergarten and in first grade, and were also doing less well at reading acquisition, than were middle-class children. The reading group differences hold up in older subjects as well, although in order to avoid ceiling effects both for skilled and less skilled readers it appears the stimuli need to be made increasingly long and complex. For example, using polysyllabic pseudowords that were three to eight syllables long, a study with college students also reported significantly worse accuracy on a repetition task by a group of learning-disabled students, the majority of whom had reading or spelling difficulty (Apthorp, 1995).

Even more convincing, a number of studies have reported that less skilled readers are less accurate at pseudoword repetition than younger, reading-age-matched children (Stone & Brady, 1995; Taylor, Lean, & Schwartz, 1989; see also discussion of Snowling et al., 1986, later in this chapter). Furthermore, various statistical analyses indicate a noteworthy association with reading performance. In Stone and Brady (1995), pseudoword repetition was one of several other basic phonological measures, including verbal memory span, verbal working memory, multiple productions of words and of tongue twisters (e.g., saying "bublu" 10

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<sup>3</sup>Although the label "nonword" is shorter and correct in that the constructed stimuli are not actual words, the scope and construction of what a nonword is seems too open-ended. For example, environmental stimuli might potentially be designated as nonword items. In contrast, "pseudoword" reflects the phonological constraints generally adhered to in designing the stimuli. For the sake of clarity, the term "pseudoword" is used in this chapter.



times), and an object naming task. The individual variable most strongly associated with performance on reading measures was the pseudoword repetition task. A similar finding with a slightly different set of measures was reported by Taylor et al. (1989). The study by Hansen and Bowey (1994), using a correlational strategy rather than reading-level-matched groups, likewise included a number of basic phonological measures, but in addition assessed children's performance on odd-one-out meta-phonological tasks in which the "odd one" in sets of three differed in terms of the onset, the rime, or an individual phoneme in medial or final position. Using multiple regression techniques, Hansen and Bowey found that the pseudoword repetition task and the phoneme awareness measures shared a considerable amount of the variance in reading measures (i.e., decoding, word recognition, and comprehension). But, when pseudoword repetition scores were entered after the 11% to 14% accounted for by performance IQ and vocabulary scores, and after the 22% to 34% accounted for by phoneme awareness measures, repetition accounted for an additional 5% to 6% of the variance. These findings and the growing number of supportive findings from studies with reading-age controls, plus the relative ease of administering a repetition task, have led to rising interest in why pseudoword repetition reliably separates reading groups.

*Factors Relevant to Pseudoword Repetition Performance.* Researchers have been quick to point out that pseudoword repetition has multiple cognitive requirements: First, the stimulus must be perceived and encoded; second, there is a very brief memory requirement; third, despite the lack of meaning for the stimuli, there may nonetheless be top-down effects from similar lexical items; and fourth, in almost all procedures the response is organized for a response and is articulated (see Corneliesen et al., 1996, for an exception). The separability of these cognitive steps is difficult to achieve, but it is widely appreciated that the efficacy of pseudoword measures may arise from the multiple demands such a task makes (see Gathercole, 1995; Gathercole, Willis, Emslie, & Baddeley, 1991; Snowling, Chiat, & Hulme, 1991 for discussion of phonological memory and output factors in repetition performance). Evaluating what factors influence performance on pseudoword repetition in the general population may help shed light on sources of difficulty for poor readers.

One issue that has drawn particular attention in investigations of performance factors influencing pseudoword repetition is the role of prior vocabulary knowledge. Because significant correlations between pseudoword repetition and vocabulary knowledge have been reported numerous times (e.g., Gathercole & Baddeley, 1989, 1990), the potential for top-down effects on repetition performance has been considered. Two aspects of current models of speech perception provide a basis for such effects.

Proposals that pseudowords may be processed element by element, with long-term representations being activated whenever a sequence matching a portion of an existing lexical item is encoded (Frauenfelder, Baayen, Hellwig, & Schreuder, 1993; Marslen-Wilson, 1987; McClelland & Elman, 1986), together with arguments that the lexicon may be organized in terms of phonological neighbors (e.g., Cluff & Luce, 1990), provide a rationale for the interface of pseudowords with phonologically similar real words. Evidence of priming effects of pseudowords on semantic associates of real words has added to the evidence that there may not be a sharp distinction between the processing of lexical and nonlexical items (Conine, Blasko, & Titone, 1993).

The implication for pseudoword repetition, of course, is that the extent of one's vocabulary would influence the likelihood of potential facilitatory effects of vocabulary knowledge on repetition tasks. Such benefits have been documented in samples of young children. Gathercole et al. (1991) focused on lexical factors in a study of the repetition abilities of more than 100 children in a longitudinal study extending from ages 4 through 6. For the 40 pseudowords used, a group of adults was asked to rate the "wordlikeness" on a 5-point scale of each of the 30 polysyllabic pseudowords in the set. The rated wordlikeness accounted for 10% to 18% of the variance in repetition scores for the three age groups even after length (i.e., number of syllables) was controlled. This association between wordlikeness and repetition accuracy was replicated in an independent longitudinal study conducted by Gathercole (1995). In addition, in the former study the stimuli were assessed for the presence of derivational/inflectional morphemes and/or root morphemes. In contrast to the first outcome described, the influence of the number of constituent morphemes, adjusted for confounding effects of nonword length, was not significant, although the particular morpheme counting procedure employed has been questioned (Dollaghan, Biber, & Campbell, 1995). Two additional studies have documented lexical influences on pseudoword repetition for normally achieving school-age children (Dollaghan, Biber, & Campbell, 1993, 1995). Both used pseudoword pairs in which one item included a syllable that was a familiar monosyllabic word (e.g., *BATHesis*), whereas the other did not (e.g., *FATHesis*). Repetition for the word-including items was significantly more accurate, even for the matching unstressed portion of the pseudowords. An analysis of the errors also suggests the impact of long-term lexical knowledge on pseudoword repetition: The vast majority of repetition errors consisted of transformations of pseudowords into real words (e.g., *spad* → *spell*). However, although lexicalization was prevalent, the authors pointed out that many of the errors, consisting of a single feature error (e.g., *flig* → *flick*), could also be interpreted as stemming in part from perceptual or articulatory factors.

Although vocabulary influences on pseudoword repetition appear to be considerable, other linguistic attributes also exert noteworthy effects. Several studies have now established that longer pseudowords, generally measured in terms of the number of syllables, tend to be harder to repeat accurately than shorter stimuli (Apthorp, 1995; Gathercole, 1995; Snowling, 1981). Countering the vocabulary effects, Gathercole (1995) reported that the effect of the number of syllables on repetition accuracy remained significant even when wordlikeness ratings were covaried out. At this point, two broad factors appear to effect repetition performance: lexical mediation and bottom-up phonological processing. Returning to the focus on the link between speech repetition and reading ability, the next question is whether one or both factors accounts for less accurate repetition by disabled readers.

*Exploring the Basis of Inaccurate Speech Repetition by Poor Readers.* The clear association of stronger vocabulary knowledge with better reading ability (e.g., Kail & Leonard, 1986; Vellutino & Scanlon, 1987), particularly as children get older, raises the obvious question as to whether reading-group differences in pseudoword repetition are simply the consequence of greater top-down influence on performance for skilled readers. However, a number of studies indicate that such an account is not sufficient. Some studies have statistically controlled for vocabulary size and have still obtained reading group differences in performance (e.g., Apthorp, 1995; Bowers, 1989; Taylor et al., 1989; see also Hansen & Bowey, 1994). In a further check of the role of vocabulary knowledge, Brady et al. (1989) reorganized the subjects from two reading groups with overlapping vocabulary scores into two groups of subjects with lower and higher vocabulary scores, regardless of reading status. Whereas the reading groups had significantly differed in repetition accuracy, the two vocabulary groups did not. More recently, Stone and Brady (1995) chose to handle the vocabulary issue by selecting chronological groups matched on vocabulary knowledge, and younger reading-age controls with less vocabulary knowledge than the older poor readers, but comparable IQ equivalent scores. As noted previously, the less skilled readers were nonetheless worse at pseudoword repetition than were both control groups, indicating that lexical mediation accounts are not sufficient to explain the difficulties encountered by individuals with reading problems. Similarly, Snowling et al. (1986) found that although reading-disabled children were comparable on a lexical decision task to reading-age control subjects who were an average of two years younger, thus confirming vocabulary weaknesses, their repetition for these words they did not know (in essence, pseudowords) was significantly worse.

These outcomes indicate that vocabulary differences probably contribute to reading-group differences in repetition performance, but are not

the whole explanation. In the Gathercole (1995) longitudinal study mentioned earlier, the pseudoword stimuli were divided into two lists, low and high wordlikeness, and the correspondence of performance on these two types of stimuli with other variables was examined. At both age 4 and age 5, better repetition was obtained for the high-wordlike set, and greater developmental improvement was seen on the high-wordlike set, as one would anticipate if vocabulary growth were a factor. Beginning reading scores, however, were not correlated significantly with scores on high-wordlike set, but with performance on the low-wordlike set at age 4. The lack of a significant association at age 5 suggests that these findings need to be replicated to ensure their reliability, yet they may indicate the importance of early phonological representation in reading acquisition.

Other studies likewise point to an association between phonological factors in repetition performance and reading ability. Paralleling the results with real words, increasing the length and the complexity of pseudoword stimuli also has been documented to widen the gap between skilled and less skilled readers. For example, Apthorp (1995) found that her learning-disabled group showed a steeper decline in accuracy for the longer stimuli than did the control group, even when covarying for vocabulary and memory span scores. Snowling (1981) likewise showed significant effects of pseudoword length on repetition of four-syllable stimuli, even though the reading-matched control subjects were several years younger in age.

In sum, speech repetition measures, and particularly pseudoword repetition tasks, genuinely seem to be harder for impaired readers. The contrast in reading-group performance appears to be reliable enough to suggest that repetition measures may have clinical value, provided that the appropriate level of stimulus difficulty is used to avoid ceiling effects. In addition, the evidence that reading-group differences cannot merely be attributed to extent of vocabulary knowledge heightens the theoretical interest of this kind of measure. Preliminary results that the deficits of poor readers pertain to the phonological attributes of pseudowords (e.g., syllable length and phonological complexity) indicate it would be worthwhile to further explore the role of phonological factors. To advance our understanding, it would be beneficial to attempt to clarify the respective roles on pseudoword performance of encoding, phonological memory, and output components of the task. The evidence for encoding difficulties for poor readers on simple phoneme identification tasks, as reviewed earlier, provides a rationale that the perceptual requirements for pseudoword repetition contribute to inaccurate performance by disabled readers on this task as well. Likewise, the fact that reading-group effects are more pronounced with novel stimuli, which necessarily have greater encoding demands, than for real words also is compatible with the pro-

posal that encoding processes figure in the pseudoword repetition deficits of poor readers.

### **DO SPEECH PERCEPTION DEFICITS STEM FROM A MORE GENERAL AUDITORY TEMPORAL PROCESSING PROBLEM?**

In contrast to the growing consensus that a specific deficit in phonological processes is the basis of reading disability and associated language problems, for a number of years Tallal has championed an alternative explanation. She proposed that a more general auditory temporal processing difficulty accounts for the deficits of individuals with reading problems (Tallal, 1980, 1984; Tallal, Miller, & Fitch, 1993), as well as those of language-impaired children (Tallal, 1990; Tallal & Piercy, 1973, 1974, 1975; Tallal & Stark, 1981) and adult aphasics (Tallal & Newcombe, 1978). Although this position recently has been carefully critiqued in two publications (Mody, Studdert-Kennedy, & Brady, 1997; Studdert-Kennedy & Mody, 1995), because the issues are central to a discussion of speech perception and reading ability a brief overview of the claims regarding reading-disabled children are summarized here.

The core of the temporal processing hypothesis with respect to children with reading problems is that auditory limitations in processing brief and/or rapidly changing acoustic events cause the deficits observed on language measures. That is, the inaccuracies that poor readers demonstrate on tasks such as stop consonant identification are thought to arise from a nonlinguistic difficulty processing the brief formant transitions in consonant stimuli (Tallal, 1980). Thus, although not disagreeing about the prevalence of language problems for poor readers, the auditory temporal processing position ascribes the basis to a nonlinguistic origin. If true, diagnosis and treatment of reading disability conceivably would hinge on assessing and remediating the more general auditory deficit, rather than targeting language skills (cf., Tallal et al., 1996).

A key argument in this line of reasoning is that deficits should be present not only on speech tasks, but also on measures using nonspeech sounds. Accordingly, a procedure used with both speech stimuli and tones, referred to as temporal order judgment (TOJ), has played a central role in the research examining this question. In a TOJ task, designed to assess rate of auditory processing, the subject is asked to judge the identity and order of two stimuli (i.e., was the order 1-1, 2-2, 2-1, or 1-2). Two dimensions are typically manipulated, the length of the interval between the stimuli and the duration of the stimuli themselves. In the initial study with reading-impaired children using this paradigm, Tallal (1980) re-

ported that 9 of the 20 subjects performed less well on discrimination and on TOJ for brief, rapidly presented tones (75 ms in duration) than did a group of control subjects from a previous study. Despite the lack of uniformity in this outcome, a significant correlation was obtained between tone TOJ and decoding scores for the reading-impaired subjects. Three subsequent studies also found an association between reading attainment and performance on TOJ for brief tones (Bedi, 1994; Reed, 1989; Watson & Miller, 1993). In addition, one of these (Reed, 1989) demonstrated TOJ difficulty by reading-disabled subjects with stop consonant stimuli (i.e., /ba-/da/ tokens consisting of formant transitions for the first 35 ms to 40 ms followed by steady-state vowel patterns for a total of 250 ms), but not for steady-state vowels (i.e., /ε-/ae/, each 250 ms in duration). This pattern of results, similar to that observed by Tallal with the other language impaired groups noted previously, has been interpreted as an indication of a general auditory deficit, not one specific to speech. The rationale has been that the deficit results in difficulty processing rapidly changing stimuli (e.g., consonant transitions) or brief stimuli (e.g., tones), but not longer, steady-state items such as vowels. Likewise other perception studies reporting a lack of significant reading-group problems on other perceptual tasks with vowel stimuli such as discrimination measures (e.g., deWierdt, 1988) have been seen as compatible with this interpretation.

Recall, however, that correct performance of the TOJ task requires both identification and ordering of the stimuli. As discussed in the reviews cited previously (Mody et al., 1997; Studdert-Kennedy & Mody, 1995), errors on this kind of task could either arise from faulty identification (e.g., in a 1-2 trial, erroneously classifying the first item as "2" and hence labeling the sequence as 2-2) or from difficulty ordering the stimuli (e.g., misjudging 1-2 for 2-1). Although both Tallal and Reed acknowledged identification problems as a potential source of difficulty, the temporal processing explanation has been favored by Tallal, as noted earlier. Yet, for some time the appropriate control conditions to evaluate these alternatives had not been conducted. Recent experiments attempting to resolve the ambiguity of TOJ performance by poor readers fail to support the temporal processing explanation.

Mody et al. (1997), in keeping with the categorical perception results for poor readers described earlier in this chapter, proposed that difficulties in identifying /ba/ and /da/ at rapid rates of presentation occur because of their close phonetic similarity rather than from a deficit in judgments of temporal order itself. By this account, children who are less skilled readers should find TOJ for /ba-/da/ to be more difficult than TOJ for less phonetically similar pairs of speech sounds (i.e., /ba-/sa/ and /da-/ja/). That is, if perception of speech is somewhat impaired, dis-

criminating or identifying phonemes that differ on a single phonetic feature should be more difficult, particularly with short intervals between the stimuli, than for stimuli contrasting in three features, thus leading to less accurate performance on the TOJ task. In contrast, to support a temporal order explanation, all of these pairs of stimuli should be comparably difficult for poor readers. The results supported the former account: Whereas significant reading-group differences occurred for discrimination and TOJ for the /ba/-/da/ condition, a minimal number of errors were made by poor readers on the other pairs and no group differences were present. Thus, poor readers can judge the temporal order of two items, even if they are presented rapidly, provided that they can identify the items to be ordered.

Although the Mody et al. (1997) findings just described indicate that difficulty on /ba/-/da/ TOJ doesn't reflect a general weakness with temporal order analysis, a second experiment was conducted to test whether the difficulty arises because this particular contrast entails close analysis of brief formant transitions. A nonspeech task was administered, using sine wave stimuli that mirrored the frequencies of the second and third formants from the /ba/ and /da/ stimuli. Consequently, these stimuli had the rapidly changing acoustic properties of their speech equivalents, but did not sound like speech. The children were given identification training (labeling them as a rising or a falling sound) and discrimination training at long intervals (400 ms). Unlike the speech results, no reading-group difference was obtained on a subsequent discrimination task with reduced intervals. Indeed, the less skilled readers were not affected by the differences in the rate of presentation for the nonspeech pairs. These results support the conclusion that the problems experienced by poor readers with speech stimuli pertain to the phonological requirements, not the acoustic demands (also see Pallay, 1986).

A last experiment by Mody et al. (1997) likewise confirmed that poor readers are adept at processing the acoustic aspects of signals conveying speech, even if such information requires phonetic processing of brief formant transitions. The logic for this experiment hinges on characteristics of the speech cues in syllables with a fricative stop cluster such as /steI/. Such syllables have initial frication noise, followed by a silent gap, and then a vocalic portion. Two cues specify the stop consonant: the silence after the fricative, indicating that the vocal tract has closed; and the rising formant transition after the silence at the beginning of the vocalic portion, indicating that the tract is reopening. These two cues, the duration of the silence and the extent of the first formant (F1) frequency rise, are usually reciprocally related and can be synthesized to "trade": In other studies, the presence of a stop has been specified either by a short silence and a sharp F1 rise in frequency, or by a longer silence and a more gradual

F1 frequency rise (e.g., Best, Morrongiello, & Robson, 1981). In recent years, an interesting finding has emerged that adults and children differ somewhat in which cue is more salient. These age effects have been reflected in differences for younger and older subjects in the category boundaries (e.g., in a /seI/-/steI/ continuum) for stimuli incorporating "trading cues." Young children (3-5 years old) have been interpreted to rely more on subtle differences in formant transitions than do adults, who give more weight to the duration of the silence (Morrongiello, Robson, Best, & Clifton, 1984; Nittrouer, 1992). Note that the age pattern demonstrates that adults, who presumably have mature perceptual skills, were *less* sensitive to rapid intrasyllabic formant transitions (i.e., the transition information was weighted less heavily in categorizing stimuli). This is contrary to the prediction the temporal processing position has made; indeed, a study by Tallal and Stark (1978) with language-impaired children and one by Steffens et al. (1992) with adult dyslexics both reported that the impaired subjects were less sensitive to the extent of the F1 transition.

Returning to the Mody et al. (1997) experiment, the goal was to examine whether skilled and less skilled readers would differ in perception of stimuli from a /seI/-/steI/ continuum in terms of how much of an F1 transition is necessary to cue the presence of /t/. They did not: The phoneme boundaries were the same for the two groups. Thus, not only are the skilled and less skilled readers comparable on the nonspeech sine wave task, but even in the context of a speech task, perception of brief formant transitions does not appear to be the locus of difficulty for children with reading problems. Instead, this set of experiments clarifies that poor readers are at a disadvantage when phonetically similar stimuli must be distinguished. Rather than temporal ordering presenting a problem for less skilled readers on speech TOJ tasks, the underlying weakness entails identification of phonemes.

Although the converging evidence indicates that the basis of language difficulties for poor readers is phonological, the question of why poor readers have been documented on occasion to perform less well on the nonverbal tone versions of the TOJ remains to be resolved. One important issue concerns the construct tapped by this task. Recent work by Watson and Miller (1993) raised questions about whether tone TOJ even should be viewed as an optimal measure of temporal processing *per se*. In their study, a sample of 94 undergraduates that included 24 reading-disabled individuals were given a battery of 35 tests designed to assess nine factors possibly relevant to reading skill. The latent variable of auditory temporal processing was assessed by three tasks in addition to one for temporal order of tones. These three were: (a) single-tone duration, in which subjects were asked to discriminate whether the duration of a test tone is the same



or different from the duration of a target tone; (b) pulse-train discrimination, in which subjects judged whether a sequence of six short tones differs in the temporal separation of the tones from a comparison sequence; and (c) embedded test-tone loudness, in which subjects were instructed to detect an extra tone varying in duration (and perceived loudness) in a sequence of nine tones. All clearly call for evaluation of a temporal dimension (duration), whereas tone TOJ requires identification of the frequency of the tone (not a temporal property), and only secondarily an evaluation of the order. Reading-group differences, as noted earlier, were obtained for tone TOJ, but not for the three auditory temporal measures. Furthermore, using a structural equation approach, nonverbal temporal processing was *not* found to be related to phonological or to reading variables.

These findings add to the reservations about the relevance of tone TOJ to reading performance: Although less skilled readers do sometimes perform less well on this measure, the Mody et al. (1997) and Watson & Miller (1993) studies demonstrated that a common problem does not appear to underlie difficulty on tone TOJ and on phonological measures, nor is tone TOJ clearly a measure of temporal processing (see Mody et al., 1997, for further discussion of this point). Furthermore, performance on tone TOJ does not bear a consistent association with reading disability. Rather, just as attention deficits often co-occur with reading disability but have an independent cause (Shaywitz, Fletcher, & Shaywitz, 1994), so too might tone TOJ have a spurious link with reading. The practical implication of this conclusion, of course, is that reading remediation strategies targeting performance on nonverbal skills such as tone TOJ are not justified (cf. Tallal et al., 1996).<sup>4</sup>

## CONSEQUENCES OF SPEECH PERCEPTION ON EARLY READING: THE MECHANISM OF PHONEME AWARENESS

Given the apparent link between speech perception and reading problems, by what mechanism does speech perception bear on reading acquisition? In this final section, current evidence regarding the association between speech perception and phoneme awareness is considered.

*Phoneme awareness* refers to the ability to segment the consonants and vowels in words, and to be able to categorize words on the basis of these

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<sup>4</sup>See Brady, Scarborough, and Shankweiler (1996) for a critique of other methodological limitations of the training studies by Merzenich, Jenkins, Miller, Schreiner, and Tallal (1996) and Tallal et al. (1996), and for a discussion of the validity for the treatment of dyslexia.

individual phonemic segments (e.g., Brady, Fowler, Stone, & Winbury, 1994). The necessity of accurate phoneme identification in phoneme awareness implicates the relevance of speech perception. It has long been known that certain phonemes (e.g., fricatives) are easier to discover because of their perceptual salience (e.g., Marsh & Mineo, 1977; Treiman & Baron, 1981). Even for less advanced awareness measures such as rhyme oddity (i.e., picking out which of three words does not rhyme with the others), children make more errors if the odd word is phonetically similar to the other words than if the contrast is more extreme (e.g., Snowling, Hulme, Smith, & Thomas, 1994). These findings again point to the importance of perceptual factors in ability to analyze the phonological structure of words. Accordingly, the variance shared by phoneme awareness and pseudorepetition measures (e.g., Hansen & Bowey, 1994) may be because both depend on accurate speech perception.

If speech perception abilities indeed play an underlying role in the development of phoneme awareness, one would anticipate that the quality of a poor reader's phonological representations for words somehow differs from that of a good reader's. Two hypotheses, not incompatible, have been articulated in recent years about how the representations of less skilled readers may differ. First, as Fowler (1991) discussed, the child's phonological system may initially represent lexical items in terms of more global phonological attributes (i.e., gestures) that extend through the word. Shifting to a fully phonemic representation for words may be a gradual process that takes place over a number of years. Consequently, Fowler proposed, the emergence of phoneme awareness may be constrained for some children, not only by metaphonological demands but also by a poor fit between the phonemic targets and a child's internal phonological representations. Thus, Fowler's hypothesis, echoed in similar terms in related articles (e.g., Treiman, Zukowski, & Richmond-Welty, 1995; Walley, 1993), is that the phonology of children changes from larger structures to more segmental phonemic elements, and that the nature of a child's representations will influence both perception and retrieval of speech, and related literacy skills. The usual progression of awareness from larger to smaller phonological segments, as well as the nature of spelling errors (e.g., difficulty accurately representing clusters), are seen as compatible with this position.

The second argument is that the phonological representations of poor readers are "faulty or impoverished" (e.g., Snowling et al., 1988). Variations on this concept have been introduced for a number of years by researchers referring to the speech perception, verbal working memory, or confrontation naming difficulties of poor readers (e.g., Brady, 1991; Katz, 1986). Recently, Elbro (in press) proposed a "distinctness hypothesis," suggesting that the errors evident on various tasks occur because the lexical repre-

sentations of poor readers are less distinctly or less completely specified. According to this position, the phonemic structure is essentially the same for poor readers, but the robustness of the phonemic details differs. Although there might be sufficient detail to allow poor readers usually to identify words or to remember them and pronounce them, the reduced quality would tend to make performance of these tasks slightly less accurate. Supporting this view, Elbro, Nielsen, and Petersen (1994) found some indications of less distinct phonological representations by adult dyslexics on word recognition and word production tasks. For example, given phonologically similar alternatives on a vocabulary measure (e.g., "is capital punishment the same as *excursion*, *exclusion*, or *execution*"), the dyslexic subjects were more often incorrect, although this group difference was not evident when semantic vocabulary alternatives were presented. Likewise, taking advantage of a frequent characteristic of Danish that phonological variants of words are permissible, Elbro et al. (1994) documented that adult dyslexics more often produced the reduced forms that preserve less of the distinctness of the words (for an example of an English equivalent: "scuse me" versus "excuse me"). Elbro (in press) left open whether the problem originates with the encoding of words, or from other processing requirements such as lexical accessibility.

Some empirical support for an association between phoneme awareness and speech perception has accrued (e.g., Hansen & Bowey, 1994; Hurford, 1991). Four recent studies have focused on this question with children or adults beyond the beginning stages of reading. McBride-Chang (1995), using structural equation modeling on a data set from regular third- and fourth-grade children, found that a speech perception factor based on three identification tasks contributed unique variance to a phonological awareness construct. A second, unpublished study of somewhat older school-age dyslexic and normal readers also reported an interesting association between phoneme awareness and speech perception (Manis et al., 1993). For a subgroup of dyslexic children who were particularly low in phoneme awareness skill, their scores on identification of stimuli from a bath-path continuum were correspondingly poorer, especially for the endpoints. The interpretation of both of these studies is qualified by the fact that subjects had to respond by pointing to written versions of the stimuli they heard, which may have amplified the group differences, but a third study likewise found an association between speech perception and awareness. Watson and Miller (1993), as mentioned earlier, tested 94 college undergraduates, including 24 reading-disabled students, on a variety of phonological and cognitive constructs. Using a structural equation approach, they found a substantial relationship between speech perception and phoneme awareness. Interestingly, speech perception was not related directly to reading ability, but was

identified as an underlying factor for phonological awareness, as mentioned, and for other constructs for verbal short-term memory and for long-term verbal memory (although see McBride-Chang, 1995, for a different association between perception and short-term memory). Last, a study using a training strategy (Hurford, 1990) provided intriguing evidence on this issue. Reading-disabled children from second and third grades were trained for a total of 2 to 3 hours on phoneme discrimination for a number of phoneme pairs, proceeding from a vowel pair to a liquid pair and finally to a pair of stop consonants. Subsequently, performance on phoneme awareness for the experimental group was found to have improved significantly, although this had not been the target of the training procedures.

In light of the association between speech perception and phoneme awareness in older readers, one might project that those prereaders with good speech perception skills would be particularly adept at discovering the sounds in words and at learning to read. However, a small number of predictive studies with more typical samples of young children failed to obtain noteworthy correlations between early speech perception and later reading success (e.g., Mann & DiTunno, 1994; see Scarborough, 1996, for a review). Three explanations for these results can be considered. First, speech perception ability may indeed be a negligible factor in becoming a reader, despite the apparent correspondence later on. The training study by Hurford (1990) stands alone as contrary evidence; the other studies with older subjects described previously don't address the question of causality. On the other hand, the measures used with young children, often simple discrimination or identification tasks with high-frequency monosyllabic words, may not be sufficiently sensitive to tap individual differences. Earlier, the study by Gathercole (1995) was discussed, noting that performance on the pseudoword repetition task at age 4 did correspond significantly with beginning reading measures taken in following years.

A third explanation may be that variations in early speech perception skills are overshadowed by changes in phonology induced by the development of awareness. Recent work by Fowler and her colleagues (Fowler, Brady, & Eisen, 1995) demonstrated sharp differences in speech perception for 5-year-old children who had attained phoneme awareness versus those (normal) children who still were naive about phonemic segments. Fully 100% of the children who were phonemically aware could identify unambiguous end point stimuli on "s(vowel)" and "sh(vowel)" contrasts, whereas only one third of those lacking awareness of phonemes could identify to 90% criterion which syllable had been presented. This pattern suggests a close tie between perception and awareness; although accurate phonemic perception was sometimes observed to be present without awareness, the reverse never occurred.

A subsequent phonemic awareness training study (Fowler, Brady, & Yehuda, 1995) was designed to examine whether perceptual accuracy precedes phoneme awareness or if phoneme awareness sharpens perceptual accuracy. Following a total of approximately 90 minutes of awareness training on /s/ and /j/ phonemes with children who were initially perceptually inaccurate, effects were seen on perception as well. The perceptual identity functions for these phonemes now reflected systematic categorization of the endpoints, suggesting that acquiring awareness sharpens differentiation of phonemic categories. Whether the discovery of some phonemes cascades to improved perception of other phonemes remains to be studied, and whether such changes would take place in children at risk for reading problems also should be explored, but the results indicate that it may be fruitful to take a close developmental perspective on the link between perception and awareness.

In conjunction with the Hurford (1990) results cited previously, Fowler, Brady, and Yehuda (1995) proposed a reciprocal relationship between perception and awareness: Not only is perception evidently a central element of phoneme awareness, and enhancing perception can facilitate awareness, but heightening phonemic awareness in turn impacts on perception of close phonemic contrasts. The importance of fostering the connection between perception and awareness is compatible with the efficacy for reading-disabled children of the Lindamood program (Lindamood & Lindamood, 1969; see, e.g., Alexander, Anderson, Heilman, Voeller, & Torgesen, 1991). For children struggling to apprehend the presence of phonemes in spoken words, Lindamood's focus on how speech sounds are articulated may provide a way to identify phonemic segments, and perforce to attain awareness of them.

## CONCLUDING REMARKS

In closing, the role of speech perception in reading development and reading disabilities is complex. The results of categorical perception studies reveal a persistent pattern of difficulty on identification and discrimination by poor readers, suggesting that they are less accurate in their ability to form phonological representations. The subtleness of this phenomenon makes categorical perception less than ideal as a diagnostic tool, yet it may be helpful in reaching an understanding of the various phonological deficits that poor readers experience. The evidence that poor readers are also consistently less accurate on pseudorepetition measures appears to have better potential for applied purposes, but is harder to explain theoretically because of the numerous factors affecting pseudoword performance. Here it is proposed that inferior pseudoword

repetition by disabled readers results in part from difficulty establishing speech representations.

Recent studies (e.g., Mody et al., 1997; Watson & Miller, 1993) failed to support the hypothesis that a general auditory temporal processing deficit is the basis of language and reading problems. Instead, several findings added to the impetus to focus on the quality of phonological representations of disabled readers: the evidence reviewed here of less accurate speech perception by poor readers, and of an association between perceptual performance and phoneme awareness, and the indications of less phonemically accurate entries in the lexicons of less skilled readers (e.g., Elbro et al., 1994; Katz, 1986). Understanding how the phonological representations of poor readers differ, whether less segmentally (Fowler, 1991), less distinctly (Elbro, in press), or both, stands as an important challenge. Attaining this knowledge may be central to fully explaining, and addressing, the phonological deficits of disabled readers.

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