The Nature of Phonological Processing and Its Causal Role in the Acquisition of Reading Skills

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Three bodies of research that have developed in relative isolation center on each of three kinds of phonological processing: phonological awareness, awareness of the sound structure of language; phonological recoding in lexical access, recoding written symbols into a sound-based representational system to get from the written word to its lexical referent; and phonetic recoding in working memory, recoding written symbols into a sound-based representational system to maintain them efficiently in working memory. In this review we integrate these bodies of research and address the interdependent issues of the nature of phonological abilities and their causal roles in the acquisition of reading skills. Phonological ability seems to be general across tasks that purport to measure the three kinds of phonological processing, and this generality apparently is independent of general cognitive ability. However, the generality of phonological ability is not complete, and there is an empirical basis for distinguishing phonological awareness and phonetic recoding in working memory. Our review supports a causal role for phonological awareness in learning to read, and suggests the possibility of similar causal roles for phonological recoding in lexical access and phonetic recoding in working memory. Most researchers have neglected the probable causal role of learning to read in the development of phonological skills. It is no longer enough to ask whether phonological skills play a causal role in the acquisition of reading skills. The question now is which aspects of phonological processing (e.g., awareness, recoding in lexical access, recoding in working memory) are causally related to which aspects of reading (e.g., word recognition, word analysis, sentence comprehension), at which point in their codevelopment, and what are the directions of these causal relations?

Phonological processing refers to the use of phonological information (i.e., the sounds of one’s language) in processing written and oral language. In this article we consider the nature of phonological processing and its causal role in the acquisition of reading skills through an integration of three bodies of research on phonological processing that have developed in relative isolation.

At the core of the first body of research is the development of phonological awareness, that is, one’s awareness of and access to the phonology of one’s language (Mattingly, 1972).¹ Phonological awareness is demonstrated by successful performance on tasks such as tapping the number of sounds in a word, reversing the order of sounds in a word, and putting together sounds presented in isolation to form a word (Lewkowicz, 1980). To an individual with well-developed phonological awareness, our alphabetic system—which conveys language at the phonological level—is a reasonable approach to visually representing our spoken language. Conversely, an individual lacking such awareness will find the correspondence between symbol and sound capricious at best (see, e.g., Liberman, Rubin, Duques, & Carlisle, in press, for a recent presentation of this argument).

¹ What we call phonological awareness is also referred to as linguistic awareness (Mattingly, 1980) and phonemic awareness (Lewkowicz, 1980; Rozin & Gleitman, 1977).
written symbols into a sound-based representational system that enables them to be maintained efficiently in working memory during ongoing processing (Baddeley, 1982; Conrad, 1964; Mattingly, 1980). Recent evidence suggests that the role of a speech-based, short-term store in normal reading comprehension may be less important than was originally thought, because a surprising degree of comprehension occurs so soon after reading a word that efficient storage processes are not required (see Crowder, 1982, for an introduction to this literature). However, efficient phonetic coding may play a vital role for beginning readers. The task faced by the beginning reader is to: (a) decode a series of visually presented letters, (b) store the sounds of the letters in a temporary store, and (c) blend the contents of the temporary store to form words. Efficient phonetic coding for storing the sounds of the letters enables the beginning reader to devote the maximum amount of cognitive resources to the difficult task of blending the sounds to form words (Baddeley, 1979, 1982; Torgesen, Kistner, & Morgan, in press).

This article is not intended to be an exhaustive review of three mature areas of research. For one thing, the length of such a review would be prohibitive. For another, adequate reviews of these separate literatures are available (see, e.g., Crowder, 1982; Kleinman, 1975; Liberman et al., in press; Mann, 1985; McCusker et al., 1981). Rather, our purpose is to provide a coherent account, spanning the three major areas of research, of phonological processing as it relates specifically to the acquisition of reading skills. Further, we focus on the causal status of relations between phonological abilities and the acquisition of reading skills.

Careful evaluation of causal relations between phonological processing and the acquisition of reading skills is especially important because the development of many cognitive skills and the acquisition of reading usually proceed hand in hand. Thus, it is difficult to distinguish cognitive skills that play a causal role in the acquisition of reading skill from those that are primarily by-products of learning to read. Ehri (1979) has distinguished four possible relations between phonological abilities and reading. First, a particular phonological ability can be a prerequisite of reading, without which the acquisition of reading skills is severely limited. Second, a particular phonological ability can act as a facilitator, in which case children with the ability acquire reading skills faster than those without it. Third, a particular phonological ability can be a consequence of learning to read, and thus a by-product rather than a cause of the acquisition of reading skills. Finally, a phonological ability might be a correlate of reading ability, that is, related to the acquisition of reading skill only via their shared relation with some third variable, such as IQ.

There are at least three major approaches to investigating the causal status of relations between phonological processing and the acquisition of reading skills, each of which has limitations when used alone. The first approach is to study individuals for whom the usual hand-in-hand development of phonological processes and reading does not occur (i.e., individuals for whom the acquisition of reading skills is particularly difficult; see Stanovich, 1982a, 1982b; Wagner, 1986b, for reviews of this literature). A number of difficulties are associated with this approach. For example, if reading disabled students or adult illiterates show marked deficiencies in some aspect of phonological processing, it is not easy to determine whether their deficiency in phonological processing caused their reading difficulties or is merely a by-product of their lack of reading skills. Most investigations of the deficiencies of reading disabled children in phonological processing do not inform us about causal relations between phonological processing deficiencies and reading disabilities. In this article we examine two other approaches to determining causal relations between phonological processing and the acquisition of reading skills: longitudinal correlational studies and experimental studies.

Longitudinal correlational studies involve obtaining measures of phonological processing and reading at several points in time, and then testing alternative models of causal relations by the fit of the models to the obtained covariances among measures (see, e.g., Kenny, 1979; Long, 1983a, 1983b, for introductions to causal modeling). Causal inferences can be drawn from such studies to the extent one assumes that all relevant variables that might be causally related to both phonological processing and reading are included in the model. This assumption relates to the "third variable" problem: A correlation between two observed variables may derive from their relations to an unmeasured third variable. One can never be sure about the extent to which this assumption is violated, but in practice, the longitudinal correlational approach yields valuable information about causal relations between phonological processing and reading.

Experimental studies are attempts to manipulate either phonological or reading skills, usually by providing a training program for the targeted skill. Whereas the experimental approach offers more protection against the third variable problem than the longitudinal correlational approach, the problem is not eliminated. The experimental approach assumes that one's manipulation or training directly affects the targeted independent variable and not another unobserved variable. Other limitations are associated with using training studies to experimentally manipulate phonological processing abilities and reading skill (see, e.g., Sternberg, 1983). For example, it could be the case that phonological awareness plays a causal role in learning to read but that phonological awareness cannot be trained, at least with the specific training program used. Conversely, training effects can be obtained even when the targeted ability has not been affected by training, especially when the training activities and the criterion share task characteristics (e.g., both are based on speed, both are presented on microcomputers) in addition to their both being measures of the targeted ability.

No approach by itself can definitively answer all the questions about causal relations between phonological processing and the acquisition of reading skill. Yet although each approach has its limitations, the limitations are to some degree complementary and thus tend to cancel out when the approaches are combined (Bradley & Bryant, 1985). This is why we are especially interested in results supported by both longitudinal correlational and experimental methods.

This article is divided into six parts. The first part is a brief introductory overview of the phonological nature of reading. This sets the stage for the parts that follow by clarifying (a) the definitions we have adopted, for purposes of the present discussion, for the set of highly confusable terms that make it difficult for interested observers to follow developments in the area of phonological processing; and (b) our assumptions about the
level of language conveyed by the printed word. In the second through fourth parts, we consider relations between the acquisition of reading skills and phonological awareness, phonological recoding for lexical access, and phonetic recoding to maintain information in working memory, respectively. Each of these three parts contains sections in which we examine longitudinal correlational studies and experimental studies that focus on causal relations between phonological processing and reading. Because the literatures we review are mature, replete with studies that, on their face, support all possible positions, our examination of these studies is more fine-grained than is normal for reviews of this sort. In several cases we have reanalyzed the original data. In the fifth part of the article, we explicitly consider hypotheses about the nature of phonological processing that emerge from examining interrelations among measures of different kinds of phonological processing. In the last part, we summarize the major empirical findings from our review, identify gaps in current knowledge and issues still to be resolved, and propose how the gaps in current knowledge and unresolved issues can be addressed in future research.

Overview: The Phonological Nature of Reading

We begin this overview by summarizing our use of the easily confused terms adopted in studies of phonological processing, and then we briefly discuss the level of language represented by our alphabet and orthography. Our presentation, which is intended to be modal rather than original, highlights conventional thought on the phonological nature of reading. However, many points are at issue about how language is represented in writing, and we sidestep the hot debates only because they are of secondary interest to our purpose.

Phones, Phonemes, and Phonetics

Exasperated readers of the phonological processing literature who get lost in terminology are justified in exclaiming, “It’s all Greek to me!” Many of the commonly used (and easily confused) terms derive from the Greek word *phone*, which translates into “sound” or “voice.”

At its most basic level, speech consists of continuously variable waves of acoustic energy. Spectrographic analysis of the speech stream has shown, for the most part, none of the segmentation we perceive when, for example, we hear three sounds in the word “cat” (Gleitman & Rozin, 1977). The apparent segmentation of the speech stream is a cognitive/perceptual phenomenon, not a characteristic of the acoustic stimulus itself.

One step removed from the acoustic stimulus is the phonetic level. Speech is represented at the phonetic level by *phones*, which are the exhaustive set of speech sounds. An example of a phone is the sound of the letter “t” in the word “ten.” Letters are associated with more than one phone. For example, the sound of the letter “t” in the word “stop” is a different phone than “t” in “ten.” The relations between phones and the acoustic waves from which they are perceived are complex and not well understood. A mapping occurs between parts of the speech wave and individual phones for some types of phones (e.g., non-diphthongized vowels, e.g., the sound of the “a” in “wave”). However, for other types of phones, what we perceive from a part of the speech wave depends on the characteristics of the preceding and succeeding speech sounds (Gleitman & Rozin, 1977).

Although the sound of the letter “t” is different in the words “ten” and “stop,” such differences are not perceived in everyday speech. The perceived sound distinctions are referred to as phonemes. A phoneme consists of a group of phones that speakers of a language consider to be variations on the same sound (Balmuth, 1982). The individual phones that make up a phoneme are referred to as *allophones* of that phoneme. For example, the sounds of the letter “t” in the words “ten,” “stop,” “matter,” and “bit” are allophones of the English consonant phoneme /t/, and the sounds of the letter “i” in the words “bite,” “hide,” and “tile” are allophones of the English vowel phoneme /ai/. Midwestern spoken English can be represented by a total of 45 phonemes (16 vowel phonemes and 29 consonant phonemes; Denes & Pinson, 1963).

Phonemes represent language at the phonological level. Two additional terms are commonly used in reference to this level of language. The first, morphophoneme, aptly conveys the notion that meaning (morpheme) as well as sound (phoneme) is represented by our writing system and orthography. The second term, used interchangeably with the first, is systematic phoneme. This term derives from Chomsky and Halle’s (1968) analysis of the phonology of English. On their view, our knowledge of words is represented in our lexicons by abstract strings of systematic phonemes. What is systematic or abstract about this representation is that families of words that are related by meaning (e.g., heal, health, healthy) share one lexical entry: /hel/. The spelling of the lexical entry /hel/ is to some degree informative about its sound. Speech involves using phonological rules (e.g., the vowel shift rule responsible for the change in pronunciation of the second “e” in the word “extremity,” compared to its pronunciation without the suffix in the word “extreme”) to transform the abstract phonemes into surface phones that, in turn, relate to the articulatory gestures we know as speech.

The syllable, which is the smallest independently articular segment of speech, is yet another unit of speech segmentation. Vowels are produced when the vocal tract is open and the vocal folds are vibrating. Consonants are produced by constricting the vocal tract. The alternate opening and closing of the vocal tract roughly corresponds to a syllable, but it is often difficult to determine the precise beginning and end of a syllable (Balmuth, 1982).

It bears repeating that there is considerable debate about the specific nature of phones, phonemes, and syllables. The somewhat simplistic picture we have presented is intended to make it easier for the reader to follow the ensuing discussions. The issues under debate are by no means trivial, and their resolution will be consequential to our understanding of relations between phonological processing and reading.

3 In this overview of the phonological nature of reading, we have relied heavily on Balmuth (1982), Crowder (1982), and Gleitman and Rozin (1977). The interested reader is encouraged to consult these very useful sources.
Representing Spoken Language With Our Alphabetic Writing System

There are two common fallacies about how language is represented by our alphabetic writing system and our English orthography (the spelling conventions within our alphabetic writing system). The first fallacy is the commonsense yet oversimplified notion that writing is just the visual expression of language. What is fallacious about this idea is that there is great variety in the aspects of a language that a writing system might convey, ranging from levels close to the sound to levels close to the meaning (Crowder, 1982). Writing might represent articulatory gestures—with symbols corresponding to articulatory gestures, such as pressing one’s tongue to the roof of one’s mouth. Alternatively, writing might represent concepts such as “middle” in a logographic fashion (e.g., the symbols “中”) that conveys no information about pronunciation. The second fallacy is that English is a phonetic orthography, in which letters represent speech sounds. If English were truly a phonetic orthography, the pronunciation of the sequence of letters “heal” would be the same for the words heal and healthy, and words such as sword and knee would not exist at all!

Most researchers believe that our writing system represents language at the phonological level. When language is represented at the phonological level, writing is related to the sound of a word being represented but with compromises that sometimes reflect a word’s meaning (Crowder, 1982). Consider the previously mentioned example of heal and health. The letters roughly correspond to the sounds of the words—one would not pronounce either of the words as banana, for example—yet their spelling provides no clue that the first parts of the words are pronounced differently. Thus, the relation between the letter group “heal” and its pronunciation is compromised because the very same letter group is pronounced differently in the words heal and health, and this compromise reflects the words’ shared root meaning.

An alphabetic orthography such as ours, that represents language at the phonological level, is an optimal system of representation if we assume that lexical entries consist of strings of systematic phonemes. The optimal nature of our alphabetic orthography refers to the notion that our writing system represents words in terms of the same units (systematic phonemes) by which words are represented in our lexicon.2

With this background, we are ready to consider the role of phonological awareness in learning to read. The beginning reader really has two basic things to learn: Printed symbols represent units of speech, and the unit of speech represented is the phoneme (Crowder, 1982). Learning that printed symbols represent units of speech is fairly trivial. Even severely disabled readers can learn to read sentences in which words are represented as Chinese ideographs (Rozin, Poritzky, & Sotsky, 1971). What is difficult is learning that printed symbols represent systematic phonemes, that is, becoming aware of the phonological nature of our language.

Phonological Awareness and the Acquisition of Reading Skill

Proponents of the view that phonological awareness is vital to the acquisition of reading skill argue that an individual with phonological awareness has a number of advantages over an individual without it in learning to read. First, an individual with phonological awareness is likely to view our alphabetic orthography as a sensible way of representing her language. Otherwise, the patterns of letter–sound correspondences will seem strange and arbitrary (Mattingly, 1980). Second, it is argued that learning to read new words involves segmenting the letter string into units that correspond to individual sounds (phonemes) and blending the individual sounds together to pronounce the word. The point of this argument is that an awareness of phonemes is a prerequisite of the ability to segment letter strings into phoneme-based units and to blend the resulting phonemes into words.

The acquisition of reading skill might also affect the subsequent development of phonological awareness. The argument is that learning to read provides explicit knowledge of the phonological structure of language that complements the largely tacit knowledge acquired from experience at listening and speaking. The analogy of learning a foreign language may help clarify this point. Learning a foreign language typically requires considerable effort at mastering grammatical rules that a native speaker of the language takes for granted. Individuals sometimes report that learning the grammatical rules of a foreign language made them aware of grammatical rules of their own language, rules they previously were not aware of yet that guided their speech and writing nevertheless.

Relations Between Phonological Awareness and Reading

Phonological awareness develops at about the age children are taught to read. Liberman, Shankweiler, Fischer, and Carter (1974) examined the ability of 4-, 5-, and 6-year-olds to segment words by phonemes and syllables. None of the 4-year-olds could segment by phoneme, but half could segment by syllable. Only 17% of the 5-year-olds could segment by phoneme, and again half could segment by syllable. By age 6, 70% could segment by phoneme and 90% by syllable. Similar results were reported by Calfee, Chapman, and Venezky (1972), who asked 5½-year-old children (a) whether two words sounded the same at the end, and (b) to provide a word that rhymes with a presented word. Even after practice trials with corrective feedback, children responded at chance levels in saying whether two words sounded the same at the end. The children were able to produce a rhyming word 39% of the time, an average that resulted from a mix of some children doing very well at the task and some doing very poorly, with few in between. Further, success at producing words that rhymed was related to success at early reading.

Whether or not a young child demonstrates phonological awareness may depend critically on the nature of the task used. Fox and Routh (1975) found some evidence that phonological awareness may occur earlier than the age at which reading is taught. They had 3- to 6-year-olds listen to monosyllabic words, and asked the children to say “just a little bit” of the word. Even

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2 Our orthography cannot be truly optimal, because it contains anomalies (e.g., sword) whose spellings are not informative about their meanings.
the 3-year-olds could segment at least some sounds into their beginning and remaining sounds, and by age 5, children could segment first and remaining sounds for over half of the words.

Strong relations have been reported between performance on various measures of phonological awareness and reading skill. In a large-scale investigation, Caffee, Lindamood, and Lindamood (1973) gave the Lindamood Auditory Conceptualization Test (Lindamood & Lindamood, 1971) and the Wide Range Achievement Test (1978) to 660 students from kindergarten through Grade 12. The Lindamood Auditory Conceptualization Test uses colored blocks to represent sound sequences in wordlike units. For example, the unit sas could be represented by placing the different-colored block between the pair of same-colored blocks. Multiple correlations between reading and spelling composite scores and the score on the Auditory Conceptualization Test were .7 or higher at each grade level. However, the magnitude of the multiple correlations may overestimate the true degree of relation between phonological awareness and reading because IQ was not partialed out.

Rosner and Simon (1971) did control for IQ in a study of relations between the ability to say a word without one of its sounds and scores on the Stanford Achievement Test (1982). Subjects in this study were 284 students from kindergarten through the sixth grade. Partial correlations between their measure of phonological awareness and the achievement test scores ranged from .1 to .7, with a median of .5. The only nonsignificant partial correlation (.1) was obtained for the sixth-grade sample. Similar relations have been found between reading achievement and a variety of measures of phonological awareness (see, e.g., Fox & Routh, 1975; Helfgott, 1976; Liberman, 1973; Zifcak, 1981).

Having observed that the development of phonological awareness coincides roughly with learning to read, and that measures of phonological awareness are related to measures of reading ability, we need to consider the causal status of whatever relations may exist between phonological awareness and reading. Before examining the longitudinal correlational studies and the training studies that have been done, we briefly consider three studies of individuals with atypical developmental courses that avoid some of the previously mentioned limitations associated with this approach.

Morais, Cary, Alegria, and Bertelson (1979) examined the causal status of the relation between phonological awareness and the acquisition of reading skill by studying individuals who had not received training in reading. Morais et al. presented illiterate Portuguese adults from an agricultural community tasks such as saying words and nonwords without one of their sounds (e.g., burn—urn), adding sounds to words and nonwords (ant—pant), reversing the order of sounds in words (bat—tab), and reversing the order of syllables in words (packrat—ratpack). Half of the illiterate subjects failed every test, whereas every individual in a literate control group whose members learned to read as adults passed at least one test. Percentages of correct responses for illiterates on the deleting sounds task were 26% for words and 19% for nonwords, compared with 87% and 73%, respectively, for the literate controls. Finally, the illiterates reversed the order of sounds in words correctly only 9% of the time, but were able to reverse the order of syllables in words 48% of the time. These results led Morais et al. to conclude that phonological awareness does not arise automatically without learning to read an alphabetic orthography.

One limitation of Morais et al.'s study is a general limitation of all research on atypical subjects: The results may apply only to the atypical individuals studied, in this case, Portuguese illiterates. However, other investigators have recently replicated and extended this finding to groups of adult poor readers. Liberman et al. (in press) measured the phonological awareness of a group of adult poor readers who attended a community literacy class. On a first-grade level phonological awareness task that simply required identifying initial, medial, and final sounds in words, errors were made on over 40% of the items. Similar results have been reported by Byrne and Lederz (1983) and by Marcel (1980). However, there is an important difference between Morais et al.'s study of Portuguese illiterates and these other studies in terms of causal implications. We might assume that the Portuguese illiterates could not read because they were not taught how, and thus conclude that deficiencies in phonological awareness resulted from a lack of reading instruction rather than from deficiencies in phonological abilities. In contrast, the reading problems of more typical adult poor readers may result from deficiencies in phonological abilities, deficiencies in instruction, or some combination of the two.

A final example of research using atypical subjects to investigate causal relations between phonological awareness and the acquisition of reading skill was reported by Bradley and Bryant (1978). They compared the performance of an older group of poor readers on measures of phonological awareness to a younger group of normal readers that matched the older group in reading level. They assumed that the older poor readers should have experienced at least as much reading instruction and practice as the younger normal readers, if not more. Thus, any deficiencies in phonological awareness for the older disabled readers could not be due to a lack of practice at reading. Two tasks were used to measure phonological awareness. The first required subjects to identify which of four words lacked a sound shared by the other three words (e.g., sun, sea, sock, rag). The older disabled readers performed more poorly on this task than the younger normal readers. The second task was to provide a word that rhymed with a target word. Again, the older disabled readers performed more poorly than the younger normal readers. Bradley and Bryant concluded that one aspect of phonological awareness—sensitivity to rhyme and alliteration—was a possible cause of reading difficulties.

**Longitudinal Correlational Studies**

The maximally informative longitudinal correlational study of phonological awareness and reading would consist of measurements, on at least three occasions, of reading skill, phonological awareness, and IQ for a large group of children. Ideally, the first occasion should occur before the children had learned to read (e.g., preschool or beginning kindergarten levels), in which case the reading measure should be a brief assessment to document that the children were indeed nonreaders. The sec-
ond occasion should occur at the very early stage of reading acquisition (e.g., first-grade level), and the third at a later stage of reading acquisition (e.g., second-grade level).

Support for phonological awareness as a determinant of success at early reading would be provided by finding that the phonological awareness of prereaders predicted their subsequent success at reading, provided adequate attention is given to other factors, such as IQ, that might be responsible for the predictive relation. Conversely, support for practice at reading as a determinant of phonological awareness would be provided by finding that success at early reading predicted subsequent performance on measures of phonological awareness, again provided adequate attention is paid to plausible third causes. Models positing reciprocal causal relations, or no causal relations whatsoever, could also be examined.

We know of no study that has incorporated the complete design for a longitudinal correlational study of relations between phonological awareness and reading just outlined. However, a number of studies have incorporated parts of the design, and we consider them next.

Mann and Liberman (1984) conducted a longitudinal study of phonological awareness, short-term memory, and reading for 62 children. We focus here on the results relating phonological awareness to reading. Phonological awareness was assessed in May of their kindergarten year with a syllable segmentation task that required the children to tap out the number of syllables in words they listened to. Reading achievement was assessed 1 year later.

The obtained correlation between kindergarten syllable segmentation and reading achievement 1 year later ($r = .40$, $p < .01$) is consistent with the view that phonological awareness is causally related to reading. However, there are at least two plausible alternative accounts of the relation between phonological awareness and the acquisition of reading skills to consider. The first is that the relation between syllable segmenting and later reading achievement is indirect, resulting from both variables being related to IQ. This account is implausible because the partial correlation, with IQ held constant, between syllable segmentation and later reading was identical to the simple correlation of .40. The second alternative account is that the causal relation is reciprocal, that is, that learning to read plays a causal role in subsequent phonological awareness, and vice versa. This alternative explanation cannot be fully examined because phonological awareness was not assessed again with first-grade reading and because a measure of reading skill at the time the phonological awareness measures were obtained is not available as a covariate. The children were, however, screened with the Woodcock Reading Mastery Test (1973) to eliminate blatantly skilled readers (V. A. Mann, personal communication, September 20, 1985).

Mann (1984) has reported a second longitudinal study that extends these results. In January of their kindergarten year, 44 children were given (a) a syllable awareness task that required reversing the order of syllables in 2- and 3-syllable words, (b) a phoneme awareness task that required reversing the order of phonemes in a 2-phoneme nonsense syllable, (c) an IQ test (Peabody Picture Vocabulary Test, 1981), and (d) several other measures that are not of interest to us here. One year later, the same children, now first graders, were given the Word Recognition and Word Attack subtests of the Woodcock Reading Mastery Test, and teachers rated them as being good, average, or poor in reading ability.

No relation was found between the kindergarten syllable reversal task and first-grade reading, which is surprising because of the relation between syllable segmentation and reading reported in Mann and Liberman's (1984) study. However, the correlation between kindergarten phoneme reversal and first-grade reading achievement was astonishingly high ($r = .75$, $p < .001$).

Mann's (1984) and Mann and Liberman's (1984) studies are both consistent with a causal role for phonological awareness in the subsequent acquisition of reading skills. However, whether this represents only half of the picture, that is, whether the causal relation might be reciprocal, cannot be determined from these studies.

In one of two recent large-scale longitudinal correlational studies, Bradley and Bryant (1985) examined relations between phonological awareness and reading in a 3-year longitudinal study. They also did a training study that we consider in the next section. The subjects in the longitudinal study were 368 nonreaders who ranged from 4 to 5 years old at the beginning of the study. (Bradley & Bryant excluded 20% of their original sample of 503 children because they had acquired at least some reading skills, and 35 children dropped out over the course of the study.) Phonological awareness was measured with a sound categorization task: Children listened to lists of three (for the 4-year-old sample) or four (for the 5-year-old sample) words— all but one of which shared an initial, medial, or final sound—and then indicated which word was the odd one out. For example, children would hear "cot," "hut," "man," and "fit," and identify "man" as the odd word.

At the beginning of the study, the children were given the sound categorization task, a memory span task requiring them to repeat the identical lists of words in order without identifying the odd one out, the English Peabody Picture Vocabulary Test, and miscellaneous other tests. Approximately 3 years later, the children were given (a) two standardized achievement tests of reading, a spelling test, and, for discriminant validation, a group-administered mathematics test; (b) the sound categorization test again; and (c) a short form of the Wechsler Intelligence Scale for Children (Wechsler, 1974). The correlations between performance on the sound categorization task and performance on achievement tests 3 years later were .52 and .57 for the two reading tests, .48 for the spelling test, and .33 for the math test. Holding constant the variables of (a) age at initial testing, (b) performance on each IQ measure, and (c) memory for the word lists, sound categorization uniquely accounted for between 4 and 10% of the variance in reading, 6–8% of the variance in spelling, and 1–4% of the variance in math scores. With the exception of the lower value of the percentage of variance accounted for in math scores, the contributions of the sound categorization score were significant at the .001 level.

These results suggest that the phonological awareness of prereaders is at least one causal factor in their success in early reading and spelling. Of course, most of the variance in early reading and spelling in this study was due to factors other than phono-
logical awareness (e.g., IQ, educational history), but it is important to note that phonological awareness was responsible for between 4 and 10% of the variance in reading and spelling achievement. With the large number of subjects, these results are quite reliable. Further, several aspects of the procedures used in the study suggest that the figure of 4–10% of variance accounted for represents a conservative estimate of the true degree of interrelation between sound categorization and reading. First, Bradley and Bryant determined the proportion of variance in achievement scores accounted for by sound categorization with a stepwise multiple regression of the achievement test scores on age, two IQ measures, and memory performance. Including both IQ measures individually rather than one composite score representing both can rob some variance simply by chance that rightfully belongs to the last entered phonological awareness variable. Second, the regressions were done separately for each of two standardized tests of reading, and separately for 4- and 5-year-old samples. Combining the reading measures should have yielded a more reliable criterion variable, and combining the 4- and 5-year-old samples may have been justified, because dropping 20% of the original sample based on their reading skill probably restricted the range of both independent and dependent variables. Finally, the 368 children for whom data analysis was performed included 52 children who had received some form of special training during the course of the study. Because training was given to children with the worst sound categorization skills and had a positive effect on final reading performance, including both trained and untrained children in the same analysis likely reduced the obtained predictive relation between sound categorization and reading skill.

Two aspects of Bradley and Bryant's procedures merit additional discussion. First, their sound categorization task might be a better measure of working memory than of phonological awareness. Recall that the task requires children to listen to lists of three or four words and then indicate which is the odd one out. As Bradley and Bryant correctly state, this is a test of memory as well as of phonological awareness because the child must remember the list of words in order to identify the odd one. Memory load apparently was a consideration in designing the task in that Bradley and Bryant (1985) decided to give lists of three words to 4-year-olds because "four words seemed to tax their memory too much . . . " and to give lists of four words to 5-year-olds because "three words seemed rather easy for the five year olds, whereas four seemed, nicely, not too easy and not too hard for them" (p. 39).

Including the memory span task in regressions of academic achievement on the sound categorization task is a creative attempt by Bradley and Bryant to tease out a measure of phonological awareness from the composite measures of phonological awareness and memory that the sound categorization task represents. Their logic was that variance in achievement test performance attributable to memory span should be captured in the regression analysis by the memory span measure, and that whatever remaining variance is captured by the sound categorization task should be due to that part of the measure that reflects phonological awareness rather than memory. Yet such a strategy can be called into question because the simple span measure may not be a valid measure of the memory requirements of the sound categorization task, a task that requires simultaneous maintenance of a list of words in a short-term store while performing the cognitive operations required for picking out the odd one. Tasks that assess storage and processing operations simultaneously can be thought of as more complex measures of working memory than are simple span tasks (Baddeley, in press). Whereas working memory tasks, which have processing demands similar to those of the sound categorization task, assess the ability to store items while engaging in complex processing, span tasks assess only isolated storage components of the working memory system. Support for the idea that Bradley and Bryant's span measure may not assess the "right" kind of memory is provided by the fact that measures such as those used are not strongly related to more complex working memory tasks (Daneman & Carpenter, 1980).

Although we have argued that Bradley and Bryant's sound categorization task may not be a good measure of phonological awareness per se, it just might be the right measure to use provided that the memory demand of the sound categorization task is similar to that experienced by an individual processing phonological information while actually reading. In such a case, the complex measure of sound categorization might be a more useful tool for studying phonological awareness as it is used in ecologically realistic situations than purer measures of either phonological awareness or memory alone. Just what is being measured by the sound categorization task is an important question for future research.

The second aspect of Bradley and Bryant's procedures to consider when interpreting their findings is that because they do not report relations between early reading achievement and later sound categorization, their conclusion that phonological awareness has a causal role in reading may be only half of the story: They did not address the possibility that learning to read has a causal role in subsequent phonological awareness.

Another large-scale longitudinal correlational study of relations between phonological awareness and later success at reading and spelling has been reported by Lundberg, Olofsson, and Wall (1980). This study is particularly interesting because Lundberg et al. used a number of measures of phonological awareness, including tasks to measure (a) segmenting and blending of syllables and phonemes; (b) determining whether a target phoneme is in the initial, medial, or final position in a spoken word; (c) reversing phonemes; and (d) rhyme. In addition, there were two versions of the blending tasks, one that used concrete materials, and another that did not. The concrete materials consisted of pegs used to represent either syllables or phonemes, depending on the task. Words were constructed by putting individual pegs into a pegboard. The subjects were 143 Swedish kindergarteners who differ from the kindergarteners in most other studies because their average age was 7 years. Formal instruction in Sweden begins 2 years later than in many other countries. Thus, subjects were considerably older, yet no more schooled, than the usual kindergarden student.

Near the end of their kindergarten year, the children were given nine measures of the kinds of phonological processing just mentioned, a screening measure of reading ability, and several other measures of phonological awareness and memory that were not of direct interest. One year later, at the end of first grade, the children were given an IQ test, as well as tests of silent reading and spelling. Teacher ratings of achievement also were obtained. Six months later, at the beginning of second
grade, the children were again given the IQ test and the silent reading test, but a new spelling test was given because of problems with the original test.

The correlations between the kindergarten measures of phonological awareness and first-grade reading achievement ranged from a low of .13 (p < .05) for segmenting words into syllables with concrete materials, to a high of .55 (p < .001) for phoneme reversal, with a median correlation of .45 (p < .001). Phonological measures requiring analysis of phonemes were more strongly predictive of reading skill than were those that required analysis of syllables (median correlations were .47 and .24, respectively, with a test of the difference between these values yielding p < .001). These simple correlations address the issue of relations between individual measures of phonological awareness and later reading; results from path analyses carried out by Lundberg et al. address the issue of the simultaneous relations between the phonological measures taken all at once and later reading achievement. Among the measures of phonological awareness, skill at reversing the order of phonemes (with path coefficients of .56 and .47 for first- and second-grade reading, respectively), and to a lesser degree, skill at producing rhymes (with path coefficients of .19 and .14, respectively) were reliable determinants of reading achievement. None of the other phonological awareness measures made a unique contribution to the prediction of reading achievement.

Lundberg et al.'s data represent a uniquely important contribution to our knowledge of empirical relations among measures of phonological awareness: To our knowledge, theirs is the only study in which a large number of common measures of phonological awareness were given to a large sample of individuals. We took advantage of these data by reanalyzing them to answer three questions. First, what is the nature of the interrelations among measures of phonological awareness? Second, are the observed relations between kindergarten phonological awareness and first-grade reading independent of general cognitive ability? Third, are the observed relations between kindergarten phonological awareness and first-grade reading independent of preexisting levels of reading skill?

Interrelations among phonological awareness tasks. The specific question we asked about the interrelations among measures of phonological awareness is whether different kinds of phonological awareness tasks (e.g., segmenting vs. blending, syllable vs. phoneme) tap different latent phonological abilities or whether the different kinds of tasks tap a single latent phonological ability. A principal-component solution for Lundberg et al.'s data yielded two components with eigenvalues greater than 1. The proportions of total variance accounted for by these principal components were .53 and .14. The proportion of common variance accounted for by the first principal component was .80. After varimax rotation, the loadings of the phonological measures on the first principal component were substantial (from .61 to .91, Mdn = .86) for all variables except segmenting words into syllables with concrete materials and rhyme. These two measures were the only substantial loadings on the second principal component, with values of .83 and .73. These results suggest that much of the variance in common measures of phonological awareness can be accounted for by a single latent ability. Confirmatory factor analyses carried out to determine (a) whether segmenting and blending represented different latent abilities, and (b) whether tasks involving syllables and tasks involving phonemes represented different latent abilities were also consistent with this view, in that neither distinction was supported.

Stanovich, Cunningham, and Cramer (1984) provide further support for this conclusion. They gave 10 phonological awareness tasks to 49 kindergarteners whose average age was 6 years, 2 months. With the exception of three tasks for which ceiling effects were obtained, the tasks were highly intercorrelated. The mean correlation between the pairs of tasks was .62. A first principal factor accounted for 47.8% of the total variance in the variables. Correlations based on 31 of the children between the kindergarten measures of phonological awareness and reading 1 year later ranged from .09 to .60, with a median of .41. Seven of the 10 correlations were significant at the .05 level. Holding IQ constant did not change the results much at all. The partial correlations ranged from .08 to .58, with a median of .35. However, it was impossible to determine from the data presented whether these relations were independent of preexisting differences in reading skill.

General cognitive ability. The partial correlations holding IQ constant between Lundberg et al.'s phonological awareness measures and first-grade reading scores were of special interest: With such a large sample, these partial correlations provide unusually stable estimates of the degree to which each measure of phonological awareness determines later achievement in reading, independent of general cognitive ability. The partial correlations we calculated from these data ranged from a low of .09 (p > .05) for segmenting words into syllables with concrete materials, to a high of .53 (p < .001) for phoneme reversal, with a median of .42 (p < .05). These results suggest that kindergarten phonological awareness is quite strongly related to first-grade reading, independent of general cognitive ability.

Effects of preexisting levels of reading skill. The partial correlations just presented provide relatively strong support for a causal role of phonological awareness in the acquisition of reading skill. However, it is obvious that at least some of Lundberg et al.'s sample had some reading proficiency before the study began, because performance on the reading screening measure given at the beginning of the study was related to first-grade reading achievement. (If none of the children could read, there would be no variance in this variable and thus it could not be related to any other variable.) Thus the observed relations between kindergarten phonological awareness and first-grade reading might originate from preexisting differences in reading skill. To answer this question, we calculated partial correlation coefficients between kindergarten phonological awareness measures and first-grade reading, with the score on the kindergarten screening test of reading held constant. The results were striking. In contrast to the simple correlations reported earlier, the median of which was .45 with all being significant, the partial correlations with kindergarten reading held constant ranged from -.07 (ns) to .21 (p < .01), with a median of .06 (ns). Only two of the nine partial correlation coefficients were significant at the .05 level. It appears that differences in original level of reading proficiency could have been responsible for the observed relations between kindergarten phonological awareness and first-grade reading achievement, thus making ambiguous the causal implications of these data.
We turn now to a consideration of experimental studies before summarizing all of the evidence relating phonological awareness to the acquisition of reading skills.

Experimental Studies

Experimental studies, often in the form of training studies, are a convergent approach to determining the causal status of relations between phonological awareness and reading. If training in phonological awareness can be shown to improve success in early reading, we can infer that phonological awareness plays a causal role in the acquisition of reading skill. Conversely, if training in some aspect of reading can be shown to improve phonological awareness, we can infer that reading plays a causal role in the development of phonological awareness. We now consider studies that address the effects of manipulating phonological awareness on subsequent reading, and of manipulating reading instruction on phonological awareness.

Effects of phonological awareness training on reading skill.

One of the most extensive training studies reported to date was carried out by Bradley and Bryant (1985) in conjunction with their longitudinal correlational study of sound categorization. The subjects were forty 4-year-olds, half of whom were randomly assigned to receive sound categorization training. Overall, the rank ordering of the four groups on the criterion measures of achievement was (a) best performance for the sound categorization group that did not get the letter training, (b) next best performance for the sound categorization group that did not get the letter training, (c) third best performance for the conceptual categorization control group, and (d) poorest performance for the no-treatment control group.

Of particular interest are comparisons of the sound categorization and concrete sound categorization groups with the conceptual categorization group, a group that is just the right control group for this training program. As predicted, the groups differed reliably on the reading and spelling tests but not on the math tests. However, nominal advantages of the sound categorization group over the conceptual categorization control group of 4 months for both reading and spelling and 3 months for mathematics were not reliable ($p > .05$). In contrast, the concrete sound categorization group—the group that used letters for concrete demonstrations—exceeded the conceptual categorization control group by about 9 months in reading ($p < .05$), about 17 months in spelling ($p < .01$), but by only 3 months in mathematics ($ns$).

In sum, these results suggest that long-term sound categorization training, in and of itself, does not result in greater achievement in reading or spelling. When supplemented with training in the sound–symbol correspondences provided by the spelling practice with plastic letters, marked gains are obtained. The unanswered question is whether a group that only received spelling practice with plastic letters and no sound categorization training per se would have shown gains similar to that of the concrete sound categorization training group.

Fox and Routh (1976) examined the effects of training children to blend phonemes on a paired-associate reading analogue task that required decoding "words" made up of letterlike symbols. The subjects were forty 4-year-olds, half of whom were randomly assigned to receive sound blending training. After training, the children learned to associate spoken sounds with letterlike symbols in a paired-associate learning procedure. The reading analogue criterion test was a paired-associate learning task for two lists of "words" constructed from the letterlike symbols. The items were repeatedly presented until either all items were named correctly on two consecutive trials or a maximum of 20 trials had been given.

No main effect of the blending training was found. However, when a median split was done by skill at segmenting words into their constituent syllables and sounds, a reliable interaction was found between sound blending training and segmenting skill. Sound-blending training improved performance on the reading-analogue task, but only for children who could segment words into sounds (high segmenters). There was no effect of blending training for children who were less able to segment words into sounds (low segmenters). This result has been widely cited in support of the view that both segmenting and blending skills are prerequisites of successful acquisition of reading skill. Although this view has intuitive appeal, a close examination of Fox and Routh’s work suggests that it may be a mistake to conclude from their study that both segmenting and blending skills are important to early reading. First, the interaction between blending training and segmenting skill occurred for only one of the two item lists used in the reading-analogue task. Second, it is likely that the interaction obtained is an artifact of floor effects. Taking, for example, the number of trials to criterion, the means were 9.3 and 17.2 for the trained and control groups for the high segmenters. Thus for high segmenters, blending training reduced the number of trials required for perfect performance on the reading-analogue task. The problem arises in the performance of the low segmenters. The mean number of trials...
to criterion for both the trained and control groups was 20.0, with a standard deviation of 0, which represents the maximum number of trials given before discontinuing the reading-analogue task. Because the performance of both the trained and control low-segmenter groups was at the floor for this variable, and because there was an effect of training for the high segmenters, it is impossible for there not to be an interaction of blending training and segmenting ability. For all we know, the floor effect for the low segmenters may conceal a main effect of blending training.

One final problem in interpreting these results deserves mention because Fox and Routh remedied it in a follow-up study. This problem is that segmenting ability was not manipulated and may have been a proxy for some other difference between the groups that is related to reading, such as IQ. Fox and Routh (1984) solved this problem by directly manipulating segmenting skill in a study of relations between segmenting, blending, and reading. The subjects in this experiment were 41 kindergarteners, 31 of whom could not segment syllables into phonemes, and 10 of whom served as a contrasting group of segmenters.

The 31 nonsegmenters were randomly assigned to one of three conditions, within the constraint of keeping the ratios of boys to girls proportional across groups. Members of a segmenting training group were trained to segment initial sounds from the remaining sounds of words. The training took place in sessions lasting up to 15 min, 4 or 5 days per week, for 5 weeks. Members of a segmenting and blending training group received the same segmenting training as the segmenting training group, as well as practice at blending the first sound with the remaining sounds in monosyllabic triphonic words, for example: m . . . an, p . . . at, and r . . . un. Members of a control group received no training. Measures to determine whether the training worked included Fox and Routh’s (1975) phonemic segmentation task and the Roswell-Chall Auditory Blending Test (1963). The transfer task for which the effects of training were examined was the paired-associate reading analogue task with letterlike forms used in the 1976 study.

The results showed that the segmenting training group performed no better than the control group on the reading analogue task, although there was evidence of training on Fox and Routh’s segmenting test. Thus, improving segmenting skill does not by itself appear to enhance learning words made up of letterlike forms. The segmenting and blending training group performed better than the control group on the reading analogue task, the Roswell-Chall blending task, and Fox and Routh’s phonemic segmenting task. In fact, their performance on the reading analogue task was present in a small but reliable interaction of segmenting and blending training. In this study, which suggests that as skill in phonemic analysis and synthesis increased, the effects of training began to appear for syllables that received repetition practice as well.

Effects of reading instruction on phonological awareness training. Alegria, Pignot, and Morais (1982) compared segmentation ability in two groups of 6-year-olds. Both groups had received approximately 4 months of reading instruction; however, the instruction given one group was based on a “phonics” method and that given the other group was based on a “whole-word” method. The segmentation tasks of interest were reversing the correspondences taught, or are general because training makes children aware of the basic fact that spelling–sound correspondences exist. In the second, and more powerful, of two experiments, they used a within-subject design to study the effects of training on 20 nonreading kindergarteners. Each subject practiced segmenting and blending the initial and remaining sounds of one set of triphonic spoken syllables (e.g., hem, lig, hig, hem). They also practiced another set of similar syllables by merely repeating them. Next, the children learned to associate the individual sound segments of the syllables from both sets with letters. Finally, children learned to “read” entire syllables in a paired-associates learning task. The syllables were of two types. Related syllables were syllables presented in their entirety in either the segmenting and blending or repetition training conditions, whereas unrelated syllables were syllables made from the same segments but that had not been practiced previously in their entirety.

Evidence for an effect of phonological awareness training on the reading analogue task was present in a small but reliable interaction between type of practice (segmenting and blending vs. repetition) and item type (related vs. unrelated). For syllables that received segmenting and blending training, an average of 9.2 errors were made on related items and 10.6 errors on unrelated items. For syllables that received repetition practice, an average of 9.6 errors were made on related items and 8.9 on the unrelated items. This means that children were more likely to combine written syllable segments into syllables on the reading analogue task if they had previously been trained to segment and blend the same spoken syllables. This is not a large effect, but it should be remembered that the training took place over only 4 days. Though the lack of a main effect of phonological awareness training suggests that its effectiveness was specific to the individual syllables trained, the interaction between type of practice and item relatedness declined over the 4 days of the experiment, which suggests that as skill in phonemic analysis and synthesis increased, the effects of training began to appear for syllables that received repetition practice as well.

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In sum, Fox and Routh’s (1975, 1976) studies demonstrate that phonological awareness training results in improved performance in a reading analogue task. Whether such improvement is evidence of an interaction of segmenting and blending skill or simply a main effect of blending skill is unknown because of the floor effects in the earlier study (Fox & Routh, 1976) and the lack of a blending training-only group in the present study.

Treiman and Baron (1983) carried the investigation of phonological awareness training a step further by asking whether the effects of training are specific to the actual spelling–sound correspondences taught, or are general because training makes children aware of the basic fact that spelling–sound correspondences exist. In the second, and more powerful, of two experiments, they used a within-subject design to study the effects of training on 20 nonreading kindergarteners. Each subject practiced segmenting and blending the initial and remaining sounds of one set of triphonic spoken syllables (e.g., hem, lig, hig, hem). They also practiced another set of similar syllables by merely repeating them. Next, the children learned to associate the individual sound segments of the syllables from both sets with letters. Finally, children learned to “read” entire syllables in a paired-associates learning task. The syllables were of two types. Related syllables were syllables presented in their entirety in either the segmenting and blending or repetition training conditions, whereas unrelated syllables were syllables made from the same segments but that had not been practiced previously in their entirety.

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words and reversing the order of phonemes in monosyllabic polyphonemic words or pronounceable nonwords.

Reliable effects were found for type of reading instruction—the phonics group did better—and for type of reversal—reversing syllables was easier than reversing sounds. These main effects are not particularly informative because (a) the groups were not randomly assigned to type of reading instruction but rather were sampled from two schools that happened to differ in method of reading instruction, and (b) others have shown that segmenting words into syllables is easier than segmenting words into phonemes (Liberman et al., 1974). What is informative is that there was a reliable interaction between type of reading instruction and type of reversal. On the syllable reversal task, the phonics and whole-word groups were correct on 67.5% and 73.5% of the items, respectively, a difference of only 6%. In contrast, on the phoneme reversal task, the phonics and whole-word groups were correct on 58.3% and 15.4% of the items, respectively, a difference five times larger than that found for the syllable reversal task. What remains to be determined is whether members of the phonics group were better at real reading than members of the whole-word group, and if so, whether the difference in reading skill resulted from the differences in phonological awareness between the groups or from some other source.

In a related experiment, Goldstein (1976) evaluated the effects of learning to read on the phonological awareness and sequential memory of 23 nonreading 4-year-olds. The 11 children in the experimental group were taught to read using Book 1 of Fuller’s (1974) “Ball-Stick-Bird” reading system. Training was provided daily in 10-min sessions for 13 weeks. A feature of this reading system is its emphasis on blending sounds to make words. The 12 children in the control group were read to from the same book but neither read themselves nor were trained in sound blending procedures. Segmenting and blending skills were assessed before and after training, as was sequential memory for sets of pictorial items whose names were similar in sound (e.g., cat, hat, can, bag) or not (e.g., horse, spoon, fish, hand).

The training program had reliable effects for sequential memory performance but not for either segmenting or blending. Actually, the pretest–posttest gain of the experimental group on segmenting and blending was about 20% greater than that of the control group, but with only 23 subjects, even this large difference was not significant. It is interesting to note that almost half of the variance in acquisition of reading skills by members of the experimental group was accounted for by pretest measures of segmenting and blending skills independent of general cognitive ability.

A study recently carried out in China provides support for reading instruction as a determinant of phonological awareness. Read, Ahang, Nie, and Ding (1984) compared the phonological awareness of a group of readers who had been trained in Chinese logographic characters with that of a group of readers who had been trained in the alphabetic spelling system pinyin. A logographic system is nonphonological because there is a separate symbol for each entire word represented in the logography. On a phonological awareness task that required the addition and deletion of phonemes, the group of readers that had been trained in the alphabetic system performed well, whereas the group that had been trained in the logographic system did not.

Summary

Phonological awareness appears to develop at about the age children are taught to read, although there is evidence that even younger children have rudimentary phonological awareness (e.g., Fox & Routh, 1975). The development of phonological awareness for syllables precedes that for phonemes, and phonological awareness tasks involving syllables appear to be easier than comparable tasks involving phonemes in general. Based on factor analyses of the commonly used measures of phonological awareness (e.g., segmenting syllables and phonemes, blending syllables and phonemes, counting syllables, reversing the order of phonemes), it appears that they are measures of a single construct or underlying ability, rather than of multiple and unrelated skills (Lundberg et al., 1980; Stanovich et al., 1984).

Performance on measures of phonological awareness is related to performance on measures of reading achievement. Further, the results of the longitudinal correlational studies taken together indicate that phonological awareness and reading are related independent of general cognitive ability. This conclusion is based on the partial and semipartial correlations we calculated from the reviewed studies between measures of phonological awareness and later reading achievement with IQ held constant, summarized in Table 1. In general, phonological awareness tasks involving phonemes are more highly related to subsequent reading skill than are those involving syllables.

The results in Table 1 from Mann (1984), Mann and Liberman (1984), and Bradley and Bryant (1985) support a causal role for phonological awareness in the acquisition of reading skills. However, these studies do not address the possible causal role for learning to read in the development of phonological awareness. To do so would have required obtaining measures of both phonological awareness and reading at several points in time. The deficits in phonological awareness found for adult illiterates and the effects on phonological awareness found for the phonics method of reading instruction suggest a causal role for learning to read in the subsequent development of phonological awareness.

The results of the training studies reviewed were mixed. Some evidence was obtained for effects of phonological awareness training on the acquisition of reading skill but there were also some glaring null results, as in the case of Bradley and Bryant’s (1985) sound categorization training. Although Bradley and Bryant reported impressive gains for children who received phonological awareness training in the form of concrete demonstrations using plastic letters, these gains may simply reflect the extensive practice these children received in letter–sound correspondences through the spelling activities that were part of the training. We consider potential reasons for the mixed results of training studies in some detail in the General Discussion.

Phonological Recoding in Lexical Access and the Acquisition of Reading Skills

In recent years a substantial body of research has converged on the conclusion that there are at least two common means of
### Table 1

**Correlations Between Phonological Awareness and Later Reading Achievement With IQ Held Constant**

<table>
<thead>
<tr>
<th>Study, phonological awareness task</th>
<th>Coefficienta</th>
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<tr>
<td>Bradley &amp; Bryant (1985)</td>
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<tr>
<td>Schonell reading</td>
<td>.31***</td>
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<tr>
<td>Sound categorization with 5-year-old sample:</td>
<td></td>
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<tr>
<td>Neal reading</td>
<td>.21***</td>
</tr>
<tr>
<td>Schonell reading</td>
<td>.20***</td>
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<tr>
<td>Lundberg, Olofsson, &amp; Wall (1980)</td>
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<td>Blending:</td>
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<td>Phonemes</td>
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<td>Phonemes/concrete materials</td>
<td>.47***</td>
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<td>Syllables</td>
<td>.21***</td>
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<tr>
<td>Syllables/concrete materials</td>
<td>.29***</td>
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<td>Segmenting phonemes/concrete materials</td>
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<td>Identification of phoneme position</td>
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<td>Phoneme reversal</td>
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<td>Rhyme production</td>
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<td>Mann (1984)</td>
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<td>Phoneme reversal</td>
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<td>Syllable reversal</td>
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<td>Delete initial phoneme</td>
<td>.36*</td>
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<tr>
<td>Segment initial phoneme</td>
<td>.40**</td>
</tr>
<tr>
<td>Replace initial phoneme</td>
<td>.08</td>
</tr>
<tr>
<td>Sound categorization:</td>
<td></td>
</tr>
<tr>
<td>Initial phoneme same</td>
<td>.32*</td>
</tr>
<tr>
<td>Initial phoneme different</td>
<td>.58**</td>
</tr>
<tr>
<td>Same as “initial phoneme different,”</td>
<td></td>
</tr>
<tr>
<td>but with negative instructions</td>
<td>.46**</td>
</tr>
<tr>
<td>Final consonant same</td>
<td>.3**</td>
</tr>
<tr>
<td>Final consonant different</td>
<td>.39*</td>
</tr>
<tr>
<td>Identify a rhyme</td>
<td>.22</td>
</tr>
<tr>
<td>Supply a rhyme</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*With the exception of data from Bradley and Bryant (1985), the reported values are partial coefficients. It was not possible to calculate partial coefficients from their data, so these values are semipartial coefficients holding constant two IQ test scores, age, and score on a memory span task. Semipartial coefficients are lower bound estimates of the values of the partial correlations. * Neither simple nor partial correlation was reported, though Mann (1984) indicated that the simple correlation was not significant.

...
seem to involve retrieving phonological codes, but not using them to make lexical access. In addition to being incomplete, another problem with this task is that it cannot be used with young children who do not know the alphabet. Further, differential knowledge of letter–sound correspondences can inflate correlations between the rapid naming of letters and later reading skill even among groups of children who know the alphabet. Switching from naming letters to naming objects should avoid this limitation, although once again, phonological codes are not used to make lexical access.

Naming real words seems to involve both retrieving phonological codes and using them to make lexical access. However, this task cannot be used with nonreaders, and, in common with letter naming tasks, differential mastery of letter–sound correspondences may account for much of the variance in performance for young children. Another problem is that it is possible to access the lexicon directly, especially for high-frequency words, and thus not use phonological codes at all. Switching to pseudowords avoids this limitation but introduces another problem: Pseudowords cannot have a lexical address; thus it seems that naming pseudowords cannot be a valid measure of using phonological codes to make lexical access.

**Longitudinal Correlational Studies**

Wolf (1984) has reported results from a longitudinal study of relations between a variety of naming measures and reading. The subjects were 115 kindergarteners, 98 of whom were followed through the end of second grade. The naming tasks, which were administered at the end of the kindergarten year, included (a) four continuous naming tests for colors, letters, numbers, and objects (hand, chair, dog, star, ball); (b) a continuous naming task for alternating digits and letters (e.g., 2 a 6 s 9 p); and (c) a continuous naming task for alternating digits, letters, and colors. Measures of oral reading, word recognition latency, and reading comprehension were administered at the end of the kindergarten, first grade, and second grade school years.

The correlations between the kindergarten naming measures and the first-grade measures of reading ranged from $-0.35$ ($p < .001$) for naming objects to $-0.71$ ($p < .001$) for naming alternate digits and letters. (The correlations are appropriately negative because the measure of naming proficiency was the amount of time required to name a series of items.) In general, the magnitude of the relations between the naming measures and later reading varied as a function of (a) the stimuli to be named, with letters and numbers being more related than objects; (b) grade level; and (c) reading ability.

Perhaps the most important of Wolf's results is that naming speed for objects reliably predicted later reading ability. This result is of greater interest than the larger correlations found between naming speed for letters and later reading ability because relations between letter naming speed and reading ability may reflect other properties they have in common besides requiring phonological recoding (e.g., knowledge of letter–sound correspondences).

The extent to which these results support a causal role for phonological recoding in lexical access in the acquisition of reading skills is difficult to determine from the data presented. First, the reported correlations, though large, may be inflated by the relations of both the naming tasks and the reading measures with IQ. Second, it is not clear that naming rate differences necessarily resulted from differences in the efficiency of phonological recoding. For example, the naming rate differences might reflect the differential use of direct lexical access, or, because the tasks were presented in a continuous naming format, the ability to sustain speeded performance. Third, the substantial correlations between the kindergarten reading test scores and the naming measures indicate that a nontrivial proportion of the kindergarten sample possessed some reading skills when the naming tasks were first administered, and thus, the observed differences in naming speed might have been caused by differential prior practice at reading. Finally, the naming tasks apparently were not administered again after the kindergarten year, making it impossible to test alternative causal models that might resolve the ambiguity about the direction of causality.

Lesgold and Resnick (1982) reported a 3-year longitudinal study of causal relations between word naming speed and reading comprehension that is at least indirectly related to the question of causal relations between phonological recoding and reading. Their subjects were 127 first graders, 46 of whom remained as third graders at the end of study. Word naming speed was measured on four occasions over the course of the study, and measures of reading comprehension were obtained on three occasions. Whereas word naming speed was related to subsequent comprehension (with one exception), comprehension was not related to subsequent word naming speed. Lesgold and Resnick concluded that speed or automaticity of word naming is causally related to the ability to extract meaning from a text and is not simply the result of more efficient language comprehension processes.

A strength of this study compared to other longitudinal studies of relations between phonological processing and reading is that the phonological measure (e.g., word naming speed) was given on multiple occasions over the course of the study, thus permitting Lesgold and Resnick to test alternative models of causal relations among the variables in their study. However, the results of this study are only indirectly linked to the question of causal relations between phonological recoding for lexical access and reading. Unlike naming speed for objects or colors, word naming speed is obviously a composite measure that includes important reading processes other than phonological recoding.

**Summary**

The importance to reading of phonological recoding in lexical access is supported by the magnitude of the differences between good and poor readers on naming speed for pseudowords and the naming speed differences between dyslexics and normal readers for objects, colors, numbers, and letters. Markedly fewer studies have addressed the specific question of causal relations between phonological recoding in lexical access and the acquisition of reading skills than for phonological awareness. As a result, there is little evidence of causal relations.
Phonetic Recoding to Maintain Information in Working Memory

A number of models of working memory have been proposed, each of which conceptualizes working memory as a storage system of limited capacity that supports ongoing cognitive processing (Torgesen, Kistner, & Morgan, in press). Baddeley and his associates (Baddeley, 1981; Baddeley & Hitch, 1974; Baddeley & Lieberman, 1980) have developed a model of working memory that has been applied to the problem of understanding beginning reading (Baddeley, 1979, 1982; Mann & Liberman, 1984). We briefly describe this model of working memory and the possible role of phonetic recoding in the acquisition of reading skills before beginning our review of work in this area.

Working memory is conceptualized as a collection of interrelated subsystems, three of which have been identified at least tentatively. The central executive is a limited capacity workspace that can be used to operate control processes (e.g., executive routines and decision making) or to briefly store information. The two other subsystems are "slave" systems to the central executive in that information is sent to them for storage at the discretion of the central executive. Which slave system information is sent to for storage depends on the kind of information to be stored. Visual or spatial information can be sent to a visuospatial scratch pad for storage. Verbal information can be sent to a phonological store for storage, a process that in the context of reading is carried out by an articulatory loop.

The phonological store and the articulatory loop are of primary interest to us here. According to the working memory model, verbal information is recoded phonetically and stored in working memory in terms of its phonological features. The means by which verbal information is registered in the phonological store depends on whether the information is heard or read. Verbal information that is heard is automatically registered in the phonological store. Verbal information that is read also may be registered in the phonological store, through an articulatory loop activated when the reader subvocally articulates the information (Baddeley, 1982).

A number of studies have demonstrated the important role of phonetic coding in working memory tasks. For example, Katz, Shankweiler, and Liberman (1981) had good and poor second-grade readers recall series of pictures that were either readily labeled common objects or abstract line drawings for which verbal labels were not apparent. Differences between good and poor readers were found for recall of objects that could be labeled but not for recall of the abstract line drawings. Katz et al. concluded that the problem for poor readers is not a general problem in working memory but a problem specific to coding items phonetically. Shankweiler, Liberman, Mark, Fowler, and Fischer (1979) found that letter-span performance of skilled readers was impaired when the names of the letters were phonologically confusable (e.g., b, c, d, p) compared to their span performance for nonconfusable letters, but less impairment was found for less skilled readers. This suggests that good readers make more use of phonological information in span tasks than do poor readers (see also, Bisanz, Das, & Mancini, in press; Brady, Shankweiler, & Mann, 1983; Byrne & Shea, 1979; Mann, Liberman, & Shankweiler, 1980; Perfetti & Lesgold, 1977, 1979; Perfetti & McCutchen, 1982; Swanson, 1978).

We next consider studies that address the issue of causal relations between phonetic recoding in working memory and the acquisition of reading skill.

Longitudinal Correlational Studies

Mann and Liberman (1984) examined relations between kindergarteners' memory span for word lists and first-grade reading. Their subjects were 62 children who, in May of their kindergarten year, were asked to repeat word strings that were either phonemically confusable or nonconfusable. One year later they were given the Word Recognition and Word Attack subtests of the Woodcock Reading Mastery Test. If efficiency of phonetic coding in working memory is related causally to the acquisition of reading skills, one would expect reliable correlations between the performance on the kindergarten measure of memory for word lists and reading skill 1 year later.

The simple correlations between first-grade reading and kindergarten word string span measures were .39 (p < .01) for nonconfusable word strings and .26 (p > .05) for confusable word strings. Partial correlations with IQ held constant are identical to the simple correlations because IQ was unrelated to the criterion measure of reading.

In a follow-up study of 44 children, Mann (1984) replicated these results. The correlation between kindergarten memory for lists of nonconfusable word strings and first-grade reading obtained in this study was .56 (p < .001). Holding IQ constant, a partial correlation of .55 (p < .001) is obtained.

These results, then, are at least consistent with the view that efficiency of phonetic coding in working memory is causally related to the acquisition of reading skills, although a stronger case could have been made had a measure of reading skill at the time the phonological measures were obtained been available as a covariate. We turn now to experimental studies that have investigated causal relations between phonetic recoding in working memory and the acquisition of reading skills.

Experimental Studies

Alegria et al., (1982), using two groups of 6-year-olds, compared memory span performance for drawings of objects with either phonologically confusable or nonconfusable names. One group had received 4 months of reading instruction using a phonics method, the other received 4 months of reading instruction using a whole-word method. Although the groups differed in their ability to segment sounds, there were no group differences in memory span performance. This result is not consistent with the view that instruction in reading emphasizing the phonological features of words leads to greater efficiency of phonetic recoding in working memory. We do not want to make too much of this null result, however, because it is based on groups of only moderate size (32 children in each of two groups) that were preexisting rather than created by random assignment to method of reading instruction.

In addition to examining the effects of reading instruction on working memory performance, we can also examine the effects of training designed to improve memory span performance on
subsequent reading skill. The problem here, of course, is that performance on span tasks is affected by several different kinds of processing operations (Dempster, 1981). Large improvements in span performance can be obtained by teaching special mnemonic strategies like cumulative rehearsal (see, e.g., Butterfield, Wamgold, & Belmont, 1973) or temporal chunking (see, e.g., Torgesen & Houck, 1980). Furthermore, there is substantial evidence that children with reading problems perform poorly on many memory tasks because they do not use appropriate strategies efficiently (Bauer, 1977, 1979; Shepherd, Geelhofer, & Solar, 1985; Torgesen, 1977).

Even though memory span performance might be improved by teaching mnemonic strategies, there is little reason to expect such training to affect reading performance. It is doubtful that elaborate strategies for improving simple storage of items on span tasks can be used effectively while performing complex tasks like reading (Torgesen, Kistner, & Morgan, in press). Reading occurs at a rate that probably precludes the use of elaborate strategies to store individual letters, words, or phrases during processing. Further, the use of elaborate mnemonic strategies may tie up cognitive resources that could be more usefully applied to other important processes in reading.

Summary

One important rationale for expecting efficiency of phonetic coding in working memory to be related to the early acquisition of reading skills is that efficient phonetic coding should enable the reader to apply maximum resources to the difficult task of blending together isolated phonemes to make words. There is considerable evidence that good and poor readers differ on memory span tasks and that these differences derive primarily from differences in the efficiency of phonetic recoding in working memory. Further, the relation between efficiency of phonetic recoding in working memory and reading skill is independent of general intellectual ability.

Results of the longitudinal correlational studies that have addressed the issue suggest a causal role for efficiency of phonetic coding in working memory in the acquisition of reading skills. As was true for research on phonological awareness and phonological recoding in lexical access, insufficient attention has been paid to a possible causal role for learning to read in the development of phonetic coding in working memory.

Relations Among Phonological Awareness, Phonological Recoding in Lexical Access, and Phonetic Recoding in Working Memory

We have reviewed three literatures that have developed in relative isolation. Each literature has its own set of tasks, and for the most part, its own set of researchers. With few exceptions (e.g., Blachman, 1984; Crowder, 1982; Liberman & Shankweiler, in press; Mann, 1985), the focus has been on relations between one of the three kinds of phonological processing—usually operationalized by a single task—and reading. The question we address here is whether the tasks commonly used to measure phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory represent substantively distinct kinds of phonological processing or skill. We briefly consider the theoretical and practical significance of this question.

Theoretical Implications

The theoretical importance of the question concerns how many latent phonological abilities or kinds of processing there are. It is possible that the phonological tasks commonly used to measure awareness, recoding in lexical access, and recoding in working memory are basically measures of one general latent ability. Alternatively, it is also possible that phonological awareness and the actual use of phonological information—either in lexical access or in working memory—represent separate latent abilities. Finally, awareness, use in lexical access, and use in working memory might represent separate latent abilities or kinds of phonological processing.

The ambiguity about the nature of latent phonological abilities carries over into interpreting performance on any given phonological task. For example, two measures of phonological awareness that reliably predict the acquisition of reading skills are phoneme reversal and Bradley and Bryant’s (1985) sound categorization task. Compared to other commonly used phonological awareness tasks, phoneme reversal and sound categorization would seem to place the greatest demands on working memory. Should we view these tasks as measures of phonological awareness, working memory, or some combination of both?

Practical Implications

Reading skill has been shown to be related to measures of phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory. Determining whether each kind of phonological processing is related to reading independent of the other kinds of phonological processing is a first step in constructing a phonological battery that could be used to identify children who are at risk of reading failure even before reading instruction has commenced. For example, based on previous studies, it might be assumed that prereading measures of phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory each correlate with first-grade reading at the .3 level. Depending on their degree of interdependence, a battery that includes measures of each of the three kinds of phonological processing could account for a modest 9% (completely overlapping measures) to an astonishing 81% (completely nonoverlapping measures) of the variance in first-grade reading.

In addition to the practically important issue of identifying children at risk for reading failure, another implication of the question about the number of latent phonological abilities concerns training programs for enhancing the acquisition of reading skills. If, for example, there should turn out to be basically three distinct phonological abilities, each may represent a potential locus of intervention. Alternatively, if there should turn out to be basically one general phonological ability, then training programs should probably be directed at improving that ability.

Empirical Studies

We know of only a handful of studies that address relations among measures of phonological awareness, phonological re-
coding in lexical access, and phonetic recoding in working memory. With two exceptions (Blachman, 1984; Mann, 1984), these studies have addressed relations between (a) phonological awareness and phonetic recoding in working memory, or (b) phonological recoding in lexical access and phonetic recoding in working memory.

Mann and Liberman (1984) gave a syllable counting task as a measure of phonological awareness and a memory span test for phonemically nonconfusable word strings as a measure of phonetic recoding in working memory to kindergarten prereaders. The partial correlation we calculated between these two measures after holding IQ constant was .32 \( (p < .01) \). We carried out a multiple regression of first-grade reading scores on IQ, syllable counting, and memory for word strings, which yielded an \( R^2 = .25 \) \( (p < .01) \). With IQ held constant, reliable proportions of variance in first-grade reading were accounted for by syllable counting \( (\beta = .32, p < .01) \) and word string memory \( (\beta = .31, p < .01) \). In sum, performance on a measure of phonological awareness was related reliably to performance on a measure of phonetic recoding in working memory, yet both measures contributed to predicting first-grade reading performance. Similarly, Goldstein (1976) reported a partial correlation holding IQ constant between a composite measure of phonological awareness (segmenting and blending) and memory span of \( .47, p < .05 \).

Mann (1984) gave a phoneme reversal task, a word string memory task, and a letter naming speed task to kindergarten prereaders. We calculated partial correlations with IQ held constant of \( .11 (ns) \) between phoneme reversal and word string memory, \( -.09 (ns) \) between phoneme reversal and letter naming speed, and \( -.11 (ns) \) between word string memory and letter naming speed. These partial correlations indicate that performance on these measures is not related at beyond-chance levels. We carried out a multiple regression of first-grade reading scores on phoneme reversal, word string memory, and letter naming speed, which yielded an \( R^2 = .74 \) \( (p < .001) \). With IQ held constant, reliable proportions of variance in first-grade reading were accounted for by phoneme reversal \( (\beta = .61, p < .001) \) and by word string memory \( (\beta = .39, p < .001) \), with letter naming speed approaching significance \( (\beta = -.12, p < .1) \).

Blachman (1984) has reported similar results for measures of phonological awareness (segmentation and rhyming) and phonological recoding in lexical access (naming speed for objects, colors, and letters). She concluded that the measures were tapping different aspects of linguistic processing, each of which was predictive of reading skill.

Naming speed measures of phonological recoding in lexical access have been found to be related to span measures of phonetic recoding in working memory by a number of investigators (Mann, 1984; Spring, 1976; Spring & Capps, 1974; Spring & Farmer, 1975; Spring & Perry, 1983; Torgesen & Houck, 1980). For example, Spring and Perry (1983) reported a correlation of \( .57 \) \( (p < .01) \) between digit naming speed and memory for pictures with nonrhyming names for a mixed group of 30 reading disabled and nondisabled children.

Summary

The issue of the interrelations among measures of phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory is of theoretical and practical importance.

The practical importance of the issue of interrelations among measures of phonological processing concerns (a) predicting reading difficulties even before reading instruction begins, and (b) identifying loci for possible training interventions. The combined predictive power of measures of phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory can be considerable. Mann (1984), for example, accounted for almost three-fourths of total variance in first-grade reading with three phonological tasks administered in kindergarten. In addition, the fact that phonological awareness and phonetic recoding in working memory each accounted for unique variance in first-grade reading when both were used as predictors suggests that each should be viewed as a potential locus of remedial efforts.

General Discussion

We began this article by distinguishing three kinds of phonological processing: phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory. We have addressed two major interdependent issues: the nature of phonological processing and the nature of its causal relations with the acquisition of reading skills. In this section we (a) summarize for these two issues the major empirical findings from our review, (b) identify important gaps in current knowledge and issues to be resolved, and (c) propose the means by which these gaps and unresolved issues can be addressed in future research.

Nature of Phonological Processing

Our interest in the nature of phonological processing is focused on the question of whether phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory represent distinct kinds of phonological abilities. Although we cannot answer this question with any degree of certainty, we can provide a partial answer. Skill at phonological processing is to some degree general across tasks that purport to measure phonological awareness, phonological recoding in lexical access, and phonetic coding in working memory. Further, the generality of phonological processing skill goes beyond that which may be accounted for by individual differences in general cognitive ability. These conclusions are based on finding significant interrelations among tasks that purport to measure
each of the three kinds of phonological processing after holding IQ constant. However, the generality of skill at phonological tasks is not complete, and there is an empirical basis for distinguishing phonological awareness from phonetic receding in working memory: Tasks that measure each of these two kinds of phonological processing uniquely account for variance in later reading skill.

There are at least two means by which our understanding of the nature of phonological processing might be advanced. The first is to give a relatively large number of children tasks that measure each of the three kinds of phonological processing, ideally on several occasions over the course of their early development of phonological skills. Alternative models of the nature of phonological processing could be tested formally with confirmatory factor analysis on the basis of their accounting for observed covariances among the phonological processing measures. Plausible models of the nature of phonological processing to consider include (a) a general ability model, which proposes that performance on the three kinds of phonological processing tasks derives from one latent phonological ability; (b) an awareness versus use model, which proposes that performance on phonological awareness tasks and on tasks measuring the use of phonological information in lexical access or in working memory derive from separate latent phonological abilities; and (c) a specific ability model, which proposes that performance on the three kinds of phonological tasks derives from separate latent phonological abilities. Developmental changes in the nature of phonological processing could be examined by comparing results across multiple administrations of the measures.

A second means by which our understanding of the nature of phonological processing could be increased is to look for relations between particular kinds of phonological processing and specific aspects of reading that should, in theory, be related to them. For example, one might expect that phonological awareness, especially in the form of segmenting and blending skill, would be particularly salient to the acquisition of sound-based reading skills at the word level. Measures of phonological awareness would thus be better predictors of performance in reading programs that emphasize a phonics approach than of performance in reading programs that primarily use a whole-word or basal reader approach. Furthermore, there is no reason to expect direct relations between individual differences in phonological awareness and reading comprehension.

Crowder (1982) has proposed an account of the relations between phonological processing and reading that also has implications for differential relations between various aspects of phonological processing and reading. He suggests that when a word is encountered, lexical access is obtained very rapidly by activating an abstract phonological representation associated with the visual representation of the word. In addition, as a result of subvocal articulatory processes, the word is phonetically coded in short-term memory right after lexical access occurs. Because lexical access can occur before words are actually placed in working memory, quite a bit of comprehension can occur without analyzing words stored in working memory. However, storing word strings in working memory is important for tasks such as resolving pronomial referents, following convoluted syntax, and making sense of difficult to comprehend material, tasks that require examining relations among words in complete phrases. Thus, although efficiency of phonetic recoding to maintain items in working memory may not be related to comprehension performance for easy material, for certain kinds of difficult text, efficient phonetic recoding may be crucial. For reasons we have outlined previously, the efficiency of phonetic recoding in working memory should also be related to the accuracy of initial attempts at using word attack skills, but might not be as predictive of the eventual speed of decoding highly familiar words.

The existence of specific relations between certain aspects of phonological processing and of reading could be determined by administering measures of several aspects of phonological processing (e.g., awareness, recoding in lexical access, and recoding in working memory) and of reading (e.g., word analysis, word recognition, and comprehension). If specific relations were found, they would provide an empirical basis for distinguishing the different aspects of phonological processing skill.

Causal Relations Between Phonological Processing Skills and the Acquisition of Reading Skills

We have reviewed two major sources of evidence about causal relations between phonological processing skills and the acquisition of reading skills: longitudinal correlational studies and training studies.

On the basis of longitudinal correlational studies, we conclude that phonological awareness plays a causal role in the acquisition of reading skills. There is considerable evidence for such a relation from a number of longitudinal correlational studies, but not enough to determine whether similar causal roles exist for phonological recoding in lexical access or phonetic recoding in working memory. However, the description just given of the causal relations between phonological processing and the acquisition of reading skills is probably incomplete, as it neglects a likely causal role for learning to read in the development of phonological skills. The longitudinal correlational studies we reviewed simply were not designed to determine whether learning to read plays a causal role in the development of phonological abilities. Further, the results of our reanalysis of Lundberg et al.'s (1980) data are consistent with the view that learning to read plays a nontrivial causal role in the development of phonological abilities.

The training studies that have been carried out to address the causal relations between the development of phonological abilities and the acquisition of reading skills have yielded mixed results. There are at least three important reasons for this outcome. Before introducing these reasons, we must first reintroduce two rationales for expecting phonological skills to be useful in learning to read.

The first rationale is provided by Mattingly (1980), who has argued that a child with phonological awareness is likely to view our system of writing as a sensible way of representing one's language. Otherwise, the patterns of letter–sound correspondences will seem strange and arbitrary. The second rationale

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Stanovich, Cunningham, and Feeman (1984) used path analysis to show that phonological awareness affects comprehension only indirectly, through its influence on decoding speed.
starts with the idea that beginning readers have three basic tasks to perform. They must (a) decode a string of visually presented letters, (b) store the products (i.e., the sounds of the letters) in a temporary store, and (c) blend the contents of the temporary store to form words (Baddeley, 1979, 1982; Torgesen et al., in press). Phonological skills, in the form of efficient use of phonological codes to store letter sounds, enable the beginning reader to apply the maximum amount of processing resources to the difficult task of blending sounds to form words. Whereas these rationales suggest that the effects of training in phonological abilities should be largest very early in the acquisition of reading skills, none of the large-scale phonological training programs we reviewed began training until well after reading instruction had begun.

A second possible reason for the mixed outcome of training studies is that phonological abilities may be difficult to train. Consider how one might train phonological awareness. The typical approach is to present exercises requiring children to work with individual phonemes in isolation and then perhaps to blend them together to form words. Yet in everyday speech, phonemes are coarticulated, and the interpretation given of a target phoneme depends on the immediately preceding and succeeding phonemes. Thus, there will be differences between what is experienced in everyday speech and what is experienced in phonological training programs, and these differences may be non-trivial.

There have been two approaches to addressing this problem, each of which attempts to simplify the phonological task to be trained. The first approach teaches segmentation and blending of syllables rather than of phonemes, because syllables appear to be more accessible to early readers than phonemes. Gleitman and Rozin (1973, 1977; Rozin & Gleitman, 1977) took this approach in a training program for inner-city children. A rebus approach was used in which syllables were represented by pictographs (e.g., an outline of a bee for the syllable "be") or by letter sequences. Children were trained to combine pictographic representations of syllables to make words. Preliminary results suggested that children could learn to use the system easily, and thus got practice at segmenting and blending they might not have otherwise. However, it was not demonstrated that benefits of training extended to phonemic segmentation or to reading in the absence of the rebus. We are not aware of any more recent studies of the effectiveness of this particular approach.

The second approach has been to provide concrete materials to help train children to segment and blend phonemes. Bradley and Bryant's (1985) use of plastic letters is one example, although whether the concrete materials need be letters is at issue. Elkonin (1971, 1973) has devised a program to train children to segment words into phonemes. In the first stage of training, subjects are shown pictures of objects. Below the pictures are a series of unmarked connected squares, one representing each sound of the word. Children are taught to say words by pronouncing each sound in succession while placing the squares in their proper positions. In the second stage, the concrete materials are removed, and in the final stage, the child does not verbalize the sounds. A series of training studies were carried out with 6-year-old nonreaders who were unable to segment words into phonemes before training. After training, the children could segment words into phonemes.

After over a decade of research, we know more about relations between phonological processing and reading than we do about relations between reading and just about anything else. Yet perhaps the most important fruit of this labor is the realization that it is no longer enough to ask whether phonological skills play a causal role in the acquisition of reading skills, or even whether learning to read plays a causal role in the development of phonological skills. Rather, the question we must now ask is both more complex and more to the point: Which aspects of phonological processing (e.g., awareness, recoding in lexical access, recoding in working memory) are causally related to which aspects of reading (e.g., word recognition, word analysis, sentence comprehension) at which point in their codevelopment, and what are the directions of these causal relations?

Not one of the studies reviewed is of the scope necessary to answer this question. What is required are longitudinal correlational studies that obtain multiple measures of each kind of phonological processing and reading at a number of points in time, as well as training studies that obtain similar kinds of measures.

We describe one admittedly speculative proposal (Wagner, 1986a) in order to give an example of what an answer to the question just posed might entail. The two-part proposal is based on a quantitative synthesis of 16 longitudinal correlational and training studies with a combined $N > 1,200$. It is largely an integration of the views of Perfetti, Beck, and Hughes (1981) and Baddeley (1979, 1982).

First, it is proposed that the ability to blend phonemes plays a causal role in the acquisition of beginning reading skills. However, it is not the simple awareness that phonemes can be blended to form words that matters, but rather the ability to use phonological codes to efficiently store the sounds of letters and letter combinations when blending sounds to form words.

Evidence from the quantitative analysis that blending rather than segmenting plays an important causal role in the acquisition of reading skills comes from the fact that there are reliably stronger causal relations for blending than for segmenting in the acquisition of word analysis skills. Evidence that use rather than simple awareness is what matters comes from the fact that blending tasks are highly correlated with measures of use of phonological information either in lexical access or in maintaining information in working memory, yet segmenting tasks are not. Finally, evidence that blending phonemes as opposed to syllables is what matters comes from the reliably stronger causal relations for tasks involving phonemes than for tasks involving syllables in the acquisition of word analysis skills.

Second, it is proposed that the acquisition of reading skills—especially those measured by word analysis tasks—plays a causal role in the development of both awareness that words can
be segmented into phonemes and efficient phonetic recoding to maintain information in working memory. Regarding phonetic recoding, it is proposed that reading instruction and practice facilitate the efficiency with which phonological codes are retrieved and paired with letters and the efficiency with which the codes can be maintained in working memory once they have been retrieved.

Evidence that reading plays a causal role in the development of awareness that words can be segmented into sounds comes from the fact that the acquisition of word analysis skills plays a reliably stronger causal role in the development of segmenting ability than blending ability. The quantitative analysis also provided evidence of a causal role for reading in the development of efficient phonetic recoding in working memory.

Whether this particular proposal about causal relations between phonological processing and reading or some other proposal ultimately will be supported by further empirical work is unimportant. What is important is that our future work should begin to answer the question of how phonological processing and reading are related causally, in a framework that allows different answers for different kinds of phonological processing and reading, at different points in their codevelopment.

References


Rozin, P., & Gleitman, L. R. (1977). The structure and acquisition of reading II: The reading process and the acquisition of the alphabetic principle. In A. Reber & D. Scarborough (Eds.), *Towards a psychology*
of reading: The proceedings of the CUNY conferences (pp. 55-139). Hillsdale, NJ: Erlbaum.


Received January 1, 1986
Revision received April 7, 1986