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Changing Relations Between Phonological Processing Abilities and Word-Level Reading as Children Develop From Beginning to Skilled Readers: A 5-Year Longitudinal Study

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Relations between phonological processing abilities and word-level reading skills were examined in a longitudinal correlational study of 216 children. Phonological processing abilities, word-level reading skills, and vocabulary were assessed annually from kindergarten through 4th grade, as the children developed from beginning to skilled readers. Individual differences in phonological awareness were related to subsequent individual differences in word-level reading for every time period examined. Individual differences in serial naming and vocabulary were related to subsequent individual differences in word-level reading initially, but these relations faded with development. Individual differences in letter-name knowledge were related to subsequent individual differences in phonological awareness and serial naming, but there were no relations between individual differences in word-level reading and any subsequent phonological processing ability.

Phonological processing refers to using the phonological or sound structure of oral language when one processes oral and written language (Jorm & Share, 1983; Wagner & Torgesen, 1987). Spoken words represent combinations of basic sounds or *phonemes*. In English, for example, there are roughly 30 to 45 basic phonemes, depending on the classification system that is used. Of the nearly infinite number of possible combinations of phonemes, only a relatively small number actually occur, and most combinations of phonemes occur in multiple words. Thus, *bat* and *cat* each contain 3 phonemes, the latter 2 of which are shared. This fact is represented by their spellings, which have different initial letters and identical medial and final letters because the spellings in alphabetic orthographies such as English represent sound as well as meaning.

Developmental and individual differences in phonological processing abilities appear to be related to the acquisition of reading skills, although the direction, magnitudes, and underlying mechanisms responsible for such relations have yet to be established (Brady & Shankweiler, 1991; Gough, Ehri, & Treiman, 1992; Wagner, Torgesen, & Rashotte, 1994). Further evidence of relations between phonological processing abilities and reading is provided by the fact that a deficit in phonological processing is a hallmark of poor readers. This is the case both for children whose poor reading is discrepant from their IQ (i.e., dyslexia) and for children whose poor reading is comparable to their IQ (''garden-variety'' poor reading; Fletcher et al., 1994; Manis, Custudio, & Szeszulski, 1993; Olson, Wise, Conners, Rack, & Fulker, 1989; Stanovich & Siegel, 1994).

Relations Between Phonological Processing Abilities and Reading

Three alternative views about the nature of relations between individual differences in phonological processing abilities and in word-level reading have been proposed (Wagner & Torgesen, 1987). The first view is that individual differences in phonological processing abilities influence the development of subsequent individual differences in reading skills. Support for this view comes from longitudinal studies in which performance on some phonological task, typically given in kindergarten, is predictive of subsequent performance on a measure of word reading (see, e.g., Byrne, Freebody, & Gates, 1992; Foorman, Francis, Novy, & Liberman, 1991). Additional support is provided by intervention studies in which training programs designed to facilitate phonological processing and its application to reading appear to enhance subsequent reading performance (Ball & Blachman, 1991; Bradley & Bryant, 1985; Cunningham, 1990; Lie, 1991; Lundberg, Frost, & Peterson, 1988; Torgesen, Morgan, & Davis, 1992).

The second view is that individual differences in reading skill influence the development of subsequent individual differences in phonological processing abilities (Ehri, 1984, 1987; Foorman et al., 1991; Morais, Alegria, & Content, 1987). Support for this view comes from poor performance on phonological tasks that has been shown by adult illiterates (Morais, Cary, Ale-

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gria, & Bertelson, 1979), prereaders (Liberman, Shankweiler, Fischer, & Carter, 1974; Wagner et al., 1987), and readers whose written language is nonalphabetic (Mann, 1986; Read, Zhang, Nie, & Ding, 1986). Additional support comes from evidence of the use of "spelling strategies" on phonological tasks. For example, when asked to count the number of phonemes in orally presented words, some children report four phonemes for words such as *rich* but five phonemes for words such as *pitch* (Bruck, 1992; Ehri & Wilce, 1980; Tunmer & Nesdale, 1985). Both words contain four phonemes, but *pitch* has one more letter than *rich.* On the basis of findings such as these, Ehri (1989) has argued that learning to read and to spell facilitates phonological awareness rather than vice versa, and Tunmer (1991) even has suggested that some phonological processing measures might be thought of better as indirect measures of reading achievement.

The third view of relations between individual differences in phonological processing and reading is that the influence is bidirectional: Individual differences in sensitivity to the sound structure of oral language, as demonstrated by one's appreciation of rhyme and alliteration, influence the development of subsequent individual differences in reading skills. Individual differences in reading skills influence the development of subsequent individual differences in more full-blown awareness, as demonstrated by the ability to segment syllables into their constituent phonemes (Perfetti, Beck, Bell, & Hughes, 1987; Stanovich, 1986; Wagner et al., 1994).

In a previous report of the development of the present sample through second grade, relations were examined between individual differences in word-level reading and in three kinds of phonological processing abilities: phonological awareness, phonological memory, and phonological naming (Wagner et al., 1994). *Phonological awareness* refers to one's awareness of and access to the sound structure of oral language. Phonological awareness can be subdivided into *analysis,* the ability to break words or syllables into smaller speech segments, and *synthesis,* the ability to blend smaller speech segments into syllables or words. Young children's developing phonological awareness is characterized by a progressively more refined awareness of shorter and more abstract segments of speech. The order of progression is awareness of (a) syllables, (b) subsyllabic units of onset (the initial consonant or consonant cluster in a syllable) and rime (the vowel and final consonant or consonant cluster), (c) individual phonemes within rimes, and (d) individual phonemes within consonant clusters (Adams, 1990; Liberman et al., 1974; McBride-Chang, in press; Stahl & Murray, 1994; Treiman, 1991; Wagner et al., 1987).

Phonological memory refers to coding information in a sound-based representation system for temporary storage (Baddeley, 1982, 1986; Conrad, 1964). Efficient phonological coding of information should enable the beginning reader to maintain an accurate representation of the phonemes associated with letters or parts of words as well as to devote the maximum amount of cognitive resources possible to ongoing decoding and comprehension processes.

Phonological naming refers to the rapid retrieval of phonological codes from permanent memory, typically names of items such as pictures of common objects, colors, digits, or letters. When reading, the efficiency with which children retrieve phonological codes associated with letters, word segments, and whole words should influence the success with which they can use phonological information in decoding (Bowers & Wolf, 1993; Wolf, 1991). Two kinds of naming tasks have been used in past studies. *Isolated naming* involves naming as quickly and accurately as possible individual items that are presented one at a time on a computer screen. The measure of performance is latency to begin a pronunciation, which trips a voice-activated relay and stops a clock. *Serial naming* involves naming a series of items as quickly and accurately as possible. The measure of performance is *how long it takes* to name the series, which often is converted into number of items named per second. Serial naming performance tends to be more highly correlated with reading than is isolated naming performance (e.g., Stanovich, 1981; Stanovich, Nathan, & Zolman, 1988). Although it is likely that serial naming tasks measure additional processes in addition to phonological ones (Wolf, Pfeil, Lotz, & Biddle, 1994), serial naming performance is sufficiently correlated with performance on other phonological processing tasks to include it as part of our assessment of children's phonological processing abilities (Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993; Wagner et al., 1994).

The present 5-year, longitudinal correlational study involves children who have been assessed annually from kindergarten through fourth grade. In the previous study that covered development through second grade, phonological awareness was found to influence the development of subsequent word-level reading from kindergarten to first grade, and from first grade to second grade (Wagner et al., 1994). The influences of phonological memory and naming were redundant with that of phonological awareness. Individual differences in letter-name knowledge were found to influence the development of subsequent individual differences in phonological awareness and serial naming, but no comparable influence was found between individual differences in word-level reading and subsequent phonological processing abilities.

The goals of this follow-up study were to examine potential changes in the directions and in the magnitudes of influences between phonological processing abilities and word-level reading skills as children move from beginning to skilled reading and to use the additional waves of data to answer questions raised by Wagner et al.'s (1994) study.

Regarding changing influences as children move from beginning to skilled reading, very little is known beyond the period in which literacy first emerges. This represents an important gap in our knowledge. The influences of individual differences in phonological processing abilities on subsequent reading skills may be developmentally limited, and, in fact, the predominant direction of such influences may reverse as reading skill develops. As children move through the early elementary grades, they begin to diverge in their reading experience and skill with an ever widening gap between the performance of good and poor readers (Stanovich, 1986). The increasing disparity between good and poor readers may partially reflect differences in reading experience and practice (Wagner & Stanovich, 1996). For example, Nagy and Anderson (1984) estimated that within a regular classroom setting, children in a high reading group read an order of magnitude (10 times) more words than those in a low reading group. Further, studies of out-of-school reading indicated marked variability and skewness in the amount of reading done by children, with many children doing little out-of-school reading but a smaller number doing a large amount (Allen, Cipielewski, & Stanovich, 1992). The amount of out-of-school reading that children do has been shown to predict later reading performance, even when prior reading performance is used as a covariate to avoid the confound that better readers tend to read more than do poorer readers (Allen et al., 1992; Anderson, Wilson, & Fielding, 1988). If influences between phonological processing and reading are reciprocal, then the improved reading performance may affect subsequent phonological processing. In addition, some evidence suggests that skilled readers may use their orthographic knowledge and spelling strategies when performing phonological awareness tasks such as phoneme counting or phoneme reversal (Bruck, 1992; Ehri, 1989; Tunmer & Nesdale, 1985).

Regarding improvements made possible by the additional waves of data that now are available, two issues were of particular interest. First, the previous results indicated that individual differences in phonological processing abilities were remarkably stable over 1-year intervals. High levels of stability meant little change in the ordering or spacing of children from one assessment to the next and thus little variability that could be accounted for by any influence. The additional waves of data permitted us to examine influences for overlapping 2-year periods of time as opposed to the 1-year time periods that were used previously. This doubled the time period that influences could exert their effects and, consequently, our sensitivity to detect such influences. The second issue concerns our previous failure to find an influence of individual differences in word-level reading on subsequent phonological processing abilities; an influence was found only for letter-name knowledge. It may well be that influences of individual differences in literacy and subsequent phonological processing abilities indeed are limited to letter-name knowledge. Alternatively, this result may have been an artifact of limited individual differences in our word-level reading measures due to floor effects on our measures at the beginning of first grade. Data obtained in first grade represented the last wave of data that could be used to predict subsequent (i.e., second grade) phonological processing abilities at the time of the previous report. The additional waves of data now available should allow us to settle this important issue.

We used structural equation modeling to estimate the magnitudes and the directions of influences between individual differences in phonological processing abilities and in word-level reading. In doing so, we attempted to minimize the effects of several common sources of model misspecification. *Model specification* refers to the set of assumptions that are associated with any given model. Misspecified models can provide erroneous estimates of the magnitudes and even of the directions of influences that variables exert on each other. One common source of model misspecification is omitting known plausible additional influences, particularly the autoregressive effect of a variable that was measured at a prior time on the same variable at a later time (Gollub & Reichardt, 1987; Wagner et al., 1994). To minimize this source of model misspecification, our analyses included as possible influences autoregressive effects of variables on themselves as well as verbal ability. Two additional sources of model misspecification are the failure to allow for bidirectional relations and measurement error. We examined bidirectional relations in our analyses and minimized measurement error by obtaining multiple measures of key constructs and by analyzing latent rather than observed variables.

Our goals were to examine possible changes in influences between individual differences in phonological processing abilities and in word-level reading as children develop from beginning to skilled readers and to use additional waves of data now available to provide a more sensitive assessment of such influences; we also aimed to determine whether our previous inability to find an influence of individual differences in word-level reading on subsequent phonological processing abilities was an artifact of floor effects on our word-level reading measures.

Method

Participants

Participants were 216 children who remained from the previous sample of 244 children. The children were randomly sampled from kindergarten classrooms in six elementary schools in Tallahassee, Florida. The 28 children who were lost had moved out of the school district. A comparison of the 28 dropouts to the remaining 216 children revealed no group differences in background variables, second-grade reading variables, and seven of nine phonological variables. Of the 216 participants, 53% were girls, and 26% were members of minority groups, predominantly African American. All children spoke English fluently and had passed a screening measure to detect articulation difficulties that could affect their performance.

Materials

The tasks administered to our sample each year assessed (a) the phonological processing abilities of phonological awareness (which includes analysis and synthesis), phonological memory, and serial naming; (b) word-level reading; and (c) verbal aptitude.

Phonological Awareness—Analysis Tasks

Phoneme elision. Children were asked to say a word, then to say the word after deleting a specified phoneme. For example, children were instructed to "Say the word *cup.* Now tell me what word would be left if I said *cup* without saying /k/." All phonemes to be deleted were consonants, the position of which varied at random. The remaining phonemes formed a word. For all grades, there were 4 practice items. For grades kindergarten through second, there were 15 test items consisting of three- to five-phoneme, one- and two-syllable words. At third grade, there were 15 different test items that consisted of three- to six-phoneme, one- and two-syllable words. For fourth grade, 5 items with seven or more phonemes were added to the list of 15 items given in third grade to extend the range of difficulty measured by the task.

Sound categorization. This task was an adapted version of Bradley and Bryant's (1985) sound categorization task. Children listened to sets of four words. For each set, one of the words was the odd one out by virtue of lacking a phoneme shared by the other three words. Children were instructed to identify the word that did not sound like the others. For example, *pin* is the odd one out in the set *fun, pin, bun,* and *gun.* Across test items, the location of the key phoneme was varied across initial, medial, and final position. For all grades, there were 4 practice items. For grades kindergarten through second grade there were 15 test items consisting of three- to four-phoneme, one-syllable words. Three test items were added at third grade, and 12 more items were included at fourth grade, giving a total of 30 test items. The added items were three- to five-phoneme, one-syllable words, deemed to be more difficult than the earlier items because of more subtle phoneme differences among the words.

Phoneme segmentation. Children listened to words and were instructed to "tell me each sound you hear in the word in the order that you hear it." There were 4 practice items. For grades kindergarten through second grade, there were 15 test items consisting of 2- to 5-phoneme, one- and two-syllable words. At third grade, 4 test items were added to the original 15 items consisting of 5- to 8-phoneme, three-syllable words. Finally, at fourth grade, 6 more test items were added, giving a total of 25 test items. The 6 additional items consisted of 7- to 11-phoneme, four- to six-syllable words. To receive credit, an item had to be segmented completely.

Phonological Awareness—Synthesis Tasks

Blending phonemes into words. Children listened to words presented phoneme by phoneme at a rate of two per second and were asked to pronounce the words that resulted when the phonemes were blended together. There were 6 practice items. The number of test items for kindergarten through second grade students was 15, consisting of 2- to 6-phoneme, one- to two-syllable words. At third grade, 5 more items were added that included 7- to 8-phoneme, three- to four-syllable words. The total of test items at fourth grade was 25, with 5 items added to the 20 third-grade test items. These final 5 items consisted of 9- to 11-phoneme, three- to four-syllable words.

Blending phonemes into nonwords. This task was the same as the previous one except that the items were nonwords. At third grade, similar to the previous task, five more items were added that included seven- to eight-phoneme, three- to four-syllable words. No further addition of items was made at fourth grade.

Phonological Memory Tasks

Memory for sentences. Children listened to recorded sentences that ranged in length from 4 to 21 words and were asked to repeat them verbatim. There were 3 practice items and 19 test items.

Digit span. Children listened to recorded series of digits. After 4 practice trials, the first of two test series commenced with pairs of two- through nine-digit items that totaled 16 trials. A second similarly constructed series of 16 trials followed immediately after the first series. Items were presented at a rate of one per second. A click was used as a cue to begin recall, and the task was discontinued after three consecutive failures. A scoring system that gives some credit for partially correct responses was used for this task (Torgesen & Houck, 1980). Scores from the two test series were averaged for a maximum possible score of 88.

Serial Naming Tasks

Naming digits serially. Six rows of five single digits per row were arrayed on a card, and children were instructed to name the digits as fast as they could, beginning with the top row and continuing to the bottom. Two trials were given with two cards with differently arranged numbers. Times were recorded on a stopwatch, and scores were based on average time for the two series. Performance was converted to the number of items named per second to make higher scores indicative of better performance.

Naming letters serially. The naming letters serially task was identical to the naming digits serially task except that the stimuli were common letters instead of digits. Again, there were two trials with scores based on the average time that the children spent for the two series.

Word-Level Reading Measures

Word identification. The Word Identification subtest, from the Woodcock Reading Mastery Test—Revised (Woodcock, 1987), required participants to name individually presented words.

Word analysis. The Word Analysis subtest, also from the Woodcock Reading Mastery Test—Revised (Woodcock, 1987), required participants to name individually presented nonwords.

Verbal Aptitude Measure

Stanford-Binet Vocabulary. Children were asked the meaning of words from the Vocabulary subtest of the Stanford-Binet Intelligence Scale (4th ed., Thorndike, Hagen, & Sattler, 1986), which is a standardized measure of vocabulary. Vocabulary consistently is the subtest most highly correlated with general verbal ability (Sattler, 1988).

Letter-Name Knowledge

In addition to these tasks, we assessed letter-name knowledge by asking participants to name all 26 uppercase letters that were presented individually in random order on individual cards.

Procedure

Tasks were individually administered by trained research assistants in the fall of the kindergarten through the third-grade years and in the spring of the fourth-grade year. Task order was randomized for each child, and the tasks were administered over three to four sessions within a 2-week interval to provide optimal performance on all tasks.

Results and Discussion

Basic Statistics

Basic statistics, including means, standard deviations, reliabilities, and bivariate correlations are presented by grade in Tables 1–5. These basic statistics support the psychometric adequacy of the tasks for the age range that we covered in our study. Reliabilities were good for all tasks for all grades. Performance was free from ceiling or floor effects, with several exceptions. Floor effects were apparent for the Word Identification and Word Analysis subtests of the Woodcock Reading Mastery Test in kindergarten. For the Word Identification subtest, 153 of the 216 participants obtained a score of 0, and all but 15 obtained scores of 5 or less. For the Word Analysis subtest, 199 participants obtained a score of 0, and all but 6 obtained scores of 5 or less. One apparently precocious reader obtained scores of 73 and 32 on the two measures, respectively. More modest floor effects were noted for several phonological awareness variables in kindergarten and for the Word Identification and Word Analysis subtests in first grade. Correlations were in expected directions, with magnitudes comparable to those reported in previous studies (e.g., Wagner et al., 1993, 1994).

Adequacy of Measurement Model

By obtaining multiple measures of our target constructs, we were able to construct latent variables that represented phonological awareness (both analysis and synthesis), phonological memory, phonological naming, and word-level reading. Latent variables consist of the common variance among the observed

Table 1
Correlations, Cronbach's Alpha or Split-Half Reliabilities (on Diagonal), and Descriptive Statistics for Kindergarten (N = 216)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Phoneme elision	(.90)											
2. Sound categorization	.37	(.91)										
3. Phoneme segmentation	.60	.25	(.85)									
4. Blending phonemes into words	.51	.38	.63	(.91)								
5. Blending phonemes into nonwords	.54	.37	.65	.82	(.87)							
6. Memory for sentence	.39	.32	.29	.28	.30	(.81)						
7. Digit span (oral)	.22	.21	.18	.22	.23	.47	(.84)[a]					
8. Naming digits serially	.46	.20	.34	.29	.28	.33	.22	(.89)[a]				
9. Naming letters serially	.51	.25	.37	.31	.32	.33	.21	.80	(.92)[a]			
10. Word identification	.45	.32	.28	.30	.32	.21	.14	.47	.51	(.98)		
11. Word analysis	.39	.23	.25	.27	.26	.15	.03	.38	.38	.85	(.96)	
12. Stanford-Binet Vocabulary	.37	.42	.32	.44	.43	.34	.28	.22	.18	.27	.25	(.81)
Maximum possible	15	15	15	15	15	19	88	—	—	106	45	46
M	2.79	4.51	1.02	2.88	1.80	6.30	28.86	0.92	0.83	2.03	0.40	16.75
SD	3.54	4.23	2.08	3.58	2.76	2.95	9.38	0.32	0.30	7.47	2.44	3.19

Note. Correlations greater than .13 are significant at .05 level.
[a] Split-half reliabilities after Spearman–Brown correction.

tasks that serve as their indicators. Because latent variables exclude task-specific variance, it is possible to minimize the effects of measurement error and task-specific strategies with careful task selection and study design (e.g., administering indicators on different occasions to address time-sampling error).

The observed indicators for each of our latent variables are the tasks that were listed with them in the *Materials* section. We used confirmatory factor analysis for a preliminary test of the adequacy of our measurement model. Separate analyses were done for each grade, with each confirmatory factor analysis including latent measures of analysis, synthesis, memory, naming, and word-level reading. The model fits were adequate at each grade (e.g., comparative fit index ranged from .97 to .99). One result of interest with regard to its implications for subsequent analyses was the correlation between the latent variables of analysis and synthesis. This correlation was high for each grade level and actually approached a perfect correlation of 1.0 at the third-grade level.

In subsequent modeling analyses in which all of the phonological latent variables are included as simultaneous predictors, having highly correlated predictors can result in suppression and large standard errors for structure coefficients. To minimize the effects of such a high degree of multicollinearity on subsequent modeling and to acknowledge that analysis and synthesis represent the same construct of phonological awareness, we added a second-order phonological awareness latent variable to our measurement model, with the first-order analysis and synthesis latent variables as its indicators. By using the second-order

Table 2
Correlations, Cronbach's Alpha or Split-Half Reliabilities (on Diagonal), and Descriptive Statistics for 1st Grade (N = 216)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Phoneme elision	(.93)											
2. Sound categorization	.55	(.90)										
3. Phoneme segmentation	.53	.47	(.87)									
4. Blending phonemes into words	.64	.50	.65	(.90)								
5. Blending phonemes into nonwords	.64	.46	.62	.83	(.87)							
6. Memory for sentence	.39	.40	.33	.41	.45	(.71)						
7. Digit span (oral)	.33	.33	.22	.31	.31	.56	(.88)[a]					
8. Naming digits serially	.43	.36	.34	.40	.37	.26	.22	(.93)[a]				
9. Naming letters serially	.50	.37	.44	.52	.47	.30	.25	.89	(.94)[a]			
10. Word identification	.60	.41	.50	.56	.55	.34	.28	.59	.66	(.98)		
11. Word analysis	.60	.38	.54	.57	.60	.34	.20	.45	.53	.81	(.93)	
12. Stanford-Binet Vocabulary	.36	.48	.34	.45	.46	.54	.28	.26	.29	.35	.34	(.77)
Maximum possible	15	15	15	15	15	19	88	—	—	106	45	46
M	6.52	7.85	3.94	6.44	4.44	8.22	34.11	1.31	1.26	14.47	3.30	18.29
SD	4.75	4.47	3.62	4.16	3.49	2.37	10.34	0.41	0.41	15.31	5.32	3.00

Note. Correlations greater than .13 are significant at .05 level.
[a] Split-half reliabilities after Spearman–Brown correction.

Table 3
Correlations, Cronbach's Alpha or Split-Half Reliabilities (on Diagonal), and Descriptive Statistics for 2nd Grade (N = 216)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Phoneme elision	(.90)											
2. Sound categorization	.41	(.88)										
3. Phoneme segmentation	.48	.36	(.83)									
4. Blending phonemes into words	.70	.40	.56	(.85)								
5. Blending phonemes into nonwords	.68	.40	.54	.76	(.81)							
6. Memory for sentence	.48	.34	.33	.49	.49	(.73)						
7. Digit span (oral)	.29	.33	.19	.29	.32	.59	(.88)[a]					
8. Naming digits serially	.34	.29	.34	.34	.33	.22	.25	(.95)[a]				
9. Naming letters serially	.45	.33	.39	.44	.40	.32	.27	.86	(.94)[a]			
10. Word identification	.63	.47	.43	.61	.62	.46	.34	.57	.65	(.97)		
11. Word analysis	.62	.51	.45	.61	.67	.47	.32	.43	.49	.86	(.96)	
12. Stanford-Binet Vocabulary	.35	.28	.38	.41	.44	.58	.38	.24	.35	.46	.45	(.76)
Maximum possible	15	15	15	15	15	19	88	—	—	106	45	46
M	10.61	9.64	7.23	10.22	7.77	9.53	39.00	1.76	1.72	40.15	12.75	20.19
SD	3.83	4.01	3.33	3.26	3.02	2.37	11.74	0.46	0.42	17.09	10.28	3.04

Note. Correlations greater than .13 are significant at .05 level.
[a] Split-half reliabilities after Spearman–Brown correction.

phonological awareness variable as a predictor in subsequent modeling analyses, we were able to avoid the severe multicollinearity that would have arisen had the highly correlated analysis and synthesis factors been used as simultaneous predictors.

Stability of Phonological Processing Abilities

The stability of phonological processing abilities refers to the consistency of individual differences from 1 year to the next year. Correlations between latent phonological processing abilities and word-level reading from year to year are presented in Table 6.[1] The correlation of .64 in the first row and third column of the table aids in its interpretation. This represents the correlation between the latent variable of phonological awareness in kindergarten with the same latent variable in third grade. These results indicate that individual differences in phonological processing abilities are remarkably stable and equal the stability of individual differences in word-level reading. Stability was high for each phonological processing ability but particularly so for phonological memory. The stability of individual differences in word-level reading was high after kindergarten but relatively low from kindergarten to subsequent grades. This relative lack of stability of word-level reading in kindergarten probably reflects the limited individual difference variability at that time due to floor effects on the Word Identification and Word Analysis subtests, which are the indicators of word-level reading.

High levels of stability indicate that there is relatively little change in the ordering or spacing of children's performance from 1 year to the following year. This of course limits the amount of individual difference variability that can be accounted for by any influence over a 1-year time period. With the additional waves of data now available to us, we attempted to increase the sensitivity of our analyses by examining influences over (overlapping) 2-year blocks of time as opposed to the 1-year blocks that we used in our previous report. Thus, we examined influences from kindergarten to second grade, from first to third grade, and from second to fourth grade.

Influences of Individual Differences in Phonological Processing Abilities on Subsequent Individual Differences in Word-Level Reading

Structural equation models were constructed to assess the influences of individual differences in phonological processing abilities on subsequent individual differences in word-level reading. We assessed the time periods from kindergarten to second grade, from first grade to third grade, and from second grade to fourth grade. Factor loadings and model fit statistics presented in Table 7 indicate that adequate model fits were obtained for each time period.

The results of primary interest are the structure coefficients presented in Table 8. The structure coefficient for a given exogenous variable represents the predicted change in word-level reading that is associated with a one-unit change in the exogenous variable when the values of the other variables in the model are constant. In other words, structure coefficients provide estimates of the unique influence of each exogenous cause. Structure coefficients are comparable to path coefficients in *path analysis* (which is the special case of structural equation modeling in which all variables are observed) and regression coefficients in multiple regression. The proportions of variance accounted for indicate the proportions of total variance in word-level reading accounted for by the set of phonological variables, the control variables, and the combined variables, respectively.

[1] Although these estimates can be interpreted as correlation coefficients, they are not Pearson product–moment correlation coefficients but rather standardized maximum likelihood estimates of covariances among latent variables. Each estimate is made to maximize the fit between the actual variance–covariance matrix obtained from our sample and a variance–covariance matrix that is implied by the specified model and parameter estimates. This explains the fact that the correlation between kindergarten and second-grade phonological memory is .93 rather than 1.00, even though the correlations between kindergarten and first grade, and between first grade and second grade, are 1.00.

Table 4
Correlations, Cronbach's Alpha or Split-Half Reliabilities (on Diagonal), and Descriptive Statistics for 3rd Grade (N = 216)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Phoneme elision	(.89)											
2. Sound categorization	.51	(.81)										
3. Phoneme segmentation	.49	.33	(.86)									
4. Blending phonemes into words	.60	.41	.53	(.89)								
5. Blending phonemes into nonwords	.62	.46	.61	.73	(.84)							
6. Memory for sentence	.50	.40	.41	.48	.53	(.68)						
7. Digit span (oral)	.36	.41	.17	.30	.31	.55	(.86)[a]					
8. Naming digits serially	.30	.33	.26	.28	.27	.16	.27	(.93)[a]				
9. Naming letters serially	.35	.36	.27	.30	.31	.25	.30	.84	(.94)[a]			
10. Word identification	.68	.58	.42	.56	.58	.45	.35	.49	.52	(.97)		
11. Word analysis	.76	.51	.50	.59	.60	.46	.33	.40	.43	.83	(.95)	
12. Stanford-Binet Vocabulary	.44	.30	.39	.48	.52	.59	.36	.21	.31	.52	.46	(.80)
Maximum possible	15	18	19	20	20	19	88	—	—	106	45	46
M	10.24	12.87	9.20	13.30	9.28	10.27	43.69	2.11	2.04	55.83	21.11	22.81
SD	4.33	3.40	3.98	4.39	3.53	2.21	13.44	0.47	0.43	15.18	11.20	3.19

Note. Correlations greater than .13 are significant at .05 level.
[a] Split-half reliabilities after Spearman–Brown correction.

The structural equation models included all of the exogenous variables listed in Table 8 as simultaneous predictors.

There were four main results of interest. First, for every time period, children's individual differences in phonological awareness influenced subsequent individual differences in word-level reading. Second, individual differences in naming and vocabulary independently influenced subsequent individual differences in word-level reading initially, but with development, these influences faded when faced with the increasing stability of individual differences in word-level reading (i.e., the increasing autoregressive effect of prior word-level reading on subsequent word-level reading). Third, individual differences in phonological memory did not independently influence subsequent individual differences in word-level reading for any time period. Fourth, the proportion of total variance in word-level reading accounted for by the phonological processing and control variables was considerable for each time period, which supports the adequacy of the model. As children developed from beginning to skilled readers, the proportion of variance attributable to the phonological variables declined and that attributable to the control variables increased.

Influences of Individual Differences in Letter-Name Knowledge and in Word-Level Reading on Subsequent Individual Differences in Phonological Processing Abilities

In our previous report that examined children's development through the beginning of second grade, we found evidence of

Table 5
Correlations, Cronbach's Alpha or Split-Half Reliabilities (on Diagonal), and Descriptive Statistics for 4th Grade (N = 216)

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Phoneme elision	(.91)											
2. Sound categorization	.59	(.92)										
3. Phoneme segmentation	.52	.45	(.86)									
4. Blending phonemes into words	.63	.49	.56	(.92)								
5. Blending phonemes into nonwords	.55	.49	.59	.73	(.84)							
6. Memory for sentence	.44	.55	.37	.47	.53	(.73)						
7. Digit span (oral)	.36	.49	.33	.39	.45	.67	(.86)[a]					
8. Naming digits serially	.31	.23	.26	.34	.33	.23	.22	(.94)[a]				
9. Naming letters serially	.37	.28	.30	.36	.37	.34	.29	.86	(.93)[a]			
10. Word identification	.72	.58	.55	.58	.57	.53	.47	.45	.45	(.96)		
11. Word analysis	.77	.58	.59	.63	.64	.50	.47	.40	.43	.86	(.95)	
12. Stanford-Binet Vocabulary	.50	.49	.48	.48	.56	.66	.48	.25	.34	.64	.60	(.80)
Maximum possible	20	30	25	25	20	19	88	—	—	106	45	46
M	14.98	18.45	10.13	15.50	9.92	11.49	48.96	2.51	2.37	66.09	27.25	25.04
SD	5.19	6.68	4.22	5.77	3.56	2.29	14.19	0.55	0.51	13.30	10.34	3.09

Note. Correlations greater than .13 are significant at .05 level.
[a] Split-half reliabilities after Spearman-Brown correction.

Table 6
Stability of Phonological Processing Abilities and Word-Level Reading: Year-to-Year Correlations

Variable	K	1st	2nd	3rd	4th
Awareness					
K	—	.83	.62	.64	.63
1st grade		—	.89	.83	.86
2nd grade			—	.95	.94
3rd grade				—	.95
4th grade					—
Memory					
K	—	1.00	.93	.89	.77
1st grade		—	1.00	.94	.88
2nd grade			—	.98	.87
3rd grade				—	.86
4th grade					—
Naming					
K	—	.84	.64	.60	.55
1st grade		—	.87	.77	.72
2nd grade			—	.85	.82
3rd grade				—	.84
4th grade					—
Word-level reading					
K	—	.69	.39	.33	.27
1st grade		—	.84	.70	.62
2nd grade			—	.96	.87
3rd grade				—	.96
4th grade					—

Note. K = kindergarten.

an influence of individual differences in letter-name knowledge on subsequent individual differences in phonological processing abilities but found no influence for individual differences in word-level reading.

Replicating our previous analyses with the present data, we present the influences of individual differences in letter-name knowledge on subsequent individual differences in phonological processing abilities in Table 9. Influences of individual differences in letter-name knowledge were found for subsequent individual differences in both phonological awareness and naming. The absence of an influence of letter-name knowledge on subsequent phonological memory appears to reflect the greater stability of individual differences in phonological memory relative to phonological awareness and naming (see Table 6). The proportion of total variance in phonological processing abilities accounted for by letter-name knowledge and the control variables was considerable.

The results of comparable analyses of the influences of individual differences in word-level reading are presented in Table 10. Unlike those found for letter-name knowledge, these results did not support an influence of individual differences in word-level reading on subsequent phonological processing abilities for any phonological ability for any time period. Although two structure coefficients for word-level reading as predictors of subsequent naming were significant with a two-tailed test, the signs of these coefficients were in the wrong direction. These appear to be suppression effects as the structure coefficients were opposite in sign from the simple correlations.

General Discussion

The present results provide further evidence of relations between individual differences in phonological processing abilities and in word-level reading, and an indication of how these relations change as children develop from beginning to skilled readers. Individual differences in phonological awareness, naming, and vocabulary influence the subsequent development of individual differences in word-level reading. Individual differences in letter-name knowledge—but not in word-level reading—influence the subsequent development of individual differences in phonological awareness and naming.

Beginning with results that were relatively constant across the developmental period that were examined, we found that individual differences in phonological awareness substantially influenced subsequent individual differences in word-level read-

Table 7
Factor Loadings and Model-Fit Statistics for Influences of Individual Differences in Phonological Processing Abilities on Subsequent Individual Differences in Word-Level Reading

Latent or observed variable	Factor loading: K to 2nd grade	1st to 3rd grade	2nd to 4th grade
Phonological-processing predictor variables			
Awareness			
Analysis[a]	1.000	.999	1.000
Phoneme elision	.782	.791	.814
Sound categorization	.502	.640	.526
Phoneme segmentation	.741	.719	.618
Synthesis[a]	.812	.904	.967
Blending phonemes: Words	.894	.922	.879
Blending phonemes: Nonwords	.918	.896	.863
Memory			
Memory for sentences	.780	.943	.963
Digit span	.603	.590	.612
Naming			
Naming digits serially	.871	.895	.856
Naming letters serially	.921	1.000	1.000
Control predictor variables			
Autoregressor: Word-level reading			
Word identification	1.00	.951	.963
Word analysis	.854	.854	.896
Vocabulary[b]	—	—	—
Criterion variables			
Word-level reading			
Word identification	.919	.923	.889
Word analysis	.940	.902	.889
Model-fit statistics			
χ^2 (61, N = 216)	125.21	116.75	122.30
CFI	.963	.974	.972

Note. Latent variables are italicized; observed variables are not. For all values, $p < .001$. K = kindergarten; CFI = comparative-fit index.
[a] Loadings for the latent variables analysis and synthesis are for the second-order latent variable of analysis. [b] Vocabulary has no loading because it was an observed variable.

ing at each time period examined. The importance of this finding is that it indicates that the influence of individual differences in phonological awareness is not developmentally limited to beginning reading but in fact extends at least through fourth grade. An implication of this result for improving growth in reading is that some children may profit from a continuation of phonological awareness training through the elementary school grades. However, rather than providing this training in the context of oral language activities that might be appropriate for kindergarten and first-grade, a more efficient approach might involve code-oriented reading instruction in which the connections between print and speech are made explicit.

A second constancy in results is the remarkable stability of individual differences in phonological processing abilities through fourth grade. The present results add to a growing body of evidence in favor of viewing phonological processing abilities as stable and coherent individual difference variables akin to other cognitive abilities, as opposed to more ephemeral by-products of reading instruction that might vary considerably from year to year (Byrne et al., 1992; Wagner et al., 1993, 1994). The existence of stable individual differences in language abilities that influence the acquisition of reading skills supports the feasibility of early screening of phonological processing abilities to identify children who are at risk for reading failure. If such children can be identified early, intervention efforts may be more effective and some concomitants of reading failure (e.g., dislike of school, poor academic self-concept) might be avoided or at least mitigated.

Turning to results that varied across level of development, individual differences in phonological naming and vocabulary independently influenced subsequent individual differences in word-level reading initially, but in contrast to the results for phonological awareness, these influences faded with development as more of the variance of subsequent word-level reading was accounted for by previous word-level reading (i.e., the autoregressive effect). This does not negate the importance of these influences but merely suggests that they are time limited. Early influences of naming and vocabulary become encapsulated in individual differences in word-level reading and fail to exert independent subsequent influences.

One plausible alternative explanation for the early influence of individual differences in naming speed on subsequent individual differences in word-level reading deserves mention. Because the naming tasks involved naming either letters or digits, it is possible that these tasks were mere proxies for individual differences in early literacy and print exposure. Including the autoregressive effect of word-level reading in our analyses serves to rule out this alternative explanation in theory, but in practice, individual differences in word-level reading in kindergarten and, to a lesser degree, in first grade, were restricted by floor effects on the

Table 8

Simultaneous Influences of Individual Differences in Phonological-Processing Abilities, Vocabulary, and the Autoregressive Effect of Prior Reading (at Kindergarten, 1st, and 2nd Grades) on Subsequent Individual Differences in Word-Level Reading (at 2nd, 3rd, and 4th Grades)

Exogenous variable	Time period: K to 2nd grade	1st to 3rd grade	2nd to 4th grade
Phonological-processing variables			
Awareness	.37***	.29*	.27***
Memory	.12	−.03	.07
Naming	.25*	.21*	.07
Control variables			
Vocabulary	.10	.22***	−.01
Autoregressor	.02	.27*	.57***
Variance accounted for			
Phonological variables	23%	8%	4%
Control variables	25%	56%	73%
Total	48%	64%	77%

Note. K = kindergarten.
$*p < .05$. $***p < .001$.

Table 9

Influences of Individual Differences in Letter-Name Knowledge (at Kindergarten and 1st Grades) on Subsequent Individual Differences in Phonological-Processing Abilities (at 2nd and 3rd Grades)

Exogenous variable	Time period: K to 2nd grade	1st to 3rd grade
Phonological awareness		
Letter-name knowledge	.23**	.12*
Control variables		
Vocabulary	.19*	.17**
Autoregressor	.43***	.70***
Variance accounted for		
Letter-name knowledge	5%	1%
Control variables	41%	71%
Total	46%	72%
Phonological memory		
Letter-name knowledge	.05	.10
Control variables		
Vocabulary	−.06	−.14
Autoregressor	.97***	1.00***
Variance accounted for		
Letter-name knowledge	1%	0%
Control variables	92%	100%
Total	93%	100%
Phonological naming		
Letter-name knowledge	.22*	.13*
Control variables		
Vocabulary	.08	−.09**
Autoregressor	.52***	.74***
Variance accounted for		
Letter-name knowledge	3%	1%
Control variables	43%	59%
Total	46%	60%

Note. K = kindergarten.
$*p < .05$. $**p < .01$. $***p < .001$.

Table 10
Influences of Individual Differences in Word-Level Reading (at Kindergarten, 1st, and 2nd Grades) on Subsequent Individual Differences in Phonological Processing Abilities (at 2nd, 3rd, and 4th Grades)

Exogenous variable	K to 2nd grade	1st to 3rd grade	2nd to 4th grade
	Phonological awareness		
Word reading	.05	−.08	−.15
Control variables			
Vocabulary	.23**	.18**	−.05
Autoregressor	.51***	.79***	1.00***
Variance accounted for			
Word reading	1%	0%	0%
Control variables	41%	71%	100%
Total	42%	71%	100%
	Phonological memory		
Word reading	.00	−.06	.07
Control variables			
Vocabulary	−.05	−.10	−.27*
Autogressor	.98***	1.00***	1.00***
Variance accounted for			
Word reading	1%	0%	0%
Control variables	92%	100%	92%
Total	93%	100%	92%
	Phonological naming		
Word reading	−.18*	−.20*	−.12
Control variables			
Vocabulary	.16**	−.03	.01
Autoregressor	.70***	.90***	.89***
Variance accounted for			
Word reading	1%	1%	0%
Control variables	43%	59%	66%
Total	44%	60%	66%

Note. K = kindergarten.
* $p < .05$. ** $p < .01$. *** $p < .001$.

indicators of word-level reading (i.e., word identification and word analysis).

It was possible to address this issue in the present study by reestimating our kindergarten-to-second-grade and first-grade-to-third-grade models, after adding letter-name knowledge as an additional predictor. The letter-name knowledge variable ought to be a sensitive measure of differences in early literacy and print exposure at the kindergarten and first-grade levels. For the kindergarten-to-second-grade time period, the structure coefficient for naming dropped from its previous value of .245 ($p < .01$) to .141 (*ns*), with the addition of letter-name knowledge to the model as a predictor. For the first-to-third-grade time period, the structure coefficient dropped from .213 ($p < .01$) to .139 ($p < .05$) but remained significantly greater than zero. These results suggest that some but not all of the influence of individual differences in naming speed on subsequent individual differences in word-level reading can be attributed to differences in simple letter-name knowledge.

Regarding influences of individual differences in literacy on subsequent individual differences in phonological processing abilities, the results indicate that such influences are limited to letter-name knowledge and do not extend to individual differences in word-level reading. To answer a question raised by our previous report, the absence of an influence of individual differences in word-level reading is not an artifact of limited variability in word-level reading in kindergarten and first grade. The present results suggest no influence of individual differences in word-level reading for any time period, including that from second to fourth grade.

We have two hypotheses about why the effects of individual differences in literacy on subsequent individual differences in phonological processing abilities are limited to letter-name knowledge. First, the names of most letters provide information about their sounds, so a child who knows letter names would seem to be at an advantage in further development of phonological abilities (Adams, 1990; Foorman, Francis, Novy, & Liberman, 1991). Phonemes are abstract linguistic units, which make them difficult for young children to identify and manipulate. Letters roughly correspond to phonemes, thereby providing a useful concrete referent for them. Second, and orthogonal to the first hypothesis, the fact that the influence is limited to letter-name knowledge may be a by-product of the timing of their development. Substantial individual differences in letter-name knowledge exist at the time when individual differences in phonological processing abilities have not yet become highly stable (i.e., kindergarten). However, by the time substantial individual differences in word-level reading exist (i.e., first or second grade), phonological processing abilities are characterized by remarkable stability. In these grades, it simply may be too late for individual differences in word-level reading to have much of an impact on individual differences in phonological processing abilities. Finally, our analyses do not provide information about possible origins of individual differences in predictors such as letter-name knowledge (e.g., individual differences in visual–perceptual development).

In general, our results suggest that the influence of individual differences in phonological processing abilities on subsequent reading skills is developmentally limited for naming and is less so for phonological awareness. We did not find evidence of a change in the predominant direction of such influences as reading skill develops, as might have been expected if children begin to diverge in their reading experience and skill as they move through the early elementary grades. We did not find evidence of marked divergence in levels of performance between high and low performers with development. In fact, the standard deviations of the phonological and reading measures were roughly comparable from second through fourth grade, as opposed to increasing uniformly.

We do not necessarily consider the absence of an influence of individual differences in word-level reading on subsequent individual differences in phonological processing abilities to be inconsistent with previous reports of the use of spelling strategies on phonological tasks, as when miscounting five phonemes in the four-phoneme, five-letter word *pitch* (Bruck, 1992; Ehri & Wilce, 1980; Tunmer & Nesdale, 1985). Such evidence has been used to support the view that individual differences in word-level reading influence subsequent individual differences in phonological processing abilities. We do not consider our results to be inconsistent with previous reports of the use of spelling strategies on phonological tasks because such strategies are likely to be task specific. The latent variables that we have modeled capture the common variance among their indicators and exclude or minimize variance attributable to task-specific strategies. Although a spelling strategy might have been useful for phoneme elision, one of our phonological awareness indicators, it is less likely that such a strategy would have been useful for other indicators such as sound categorization. Consequently, spelling strategies are unlikely to have influenced our latent measures of phonological processing to the same degree than they may have influenced performance on the individual phonological tasks that were used in studies reporting spelling strategies on phonological tasks. However, it is possible that spelling knowledge is useful more uniformly across tasks at a deeper level below that of covert strategy usage.

One potential limitation of our results deserves mention. Our results are likely to be limited to alphabetic languages such as English in which phonological processing abilities are more likely to play a role in learning to read because of the rough correspondence of letters and phonemes, rather than to nonalphabetic languages such as Chinese (Huang & Hanley, 1994; Share, 1995). Even within alphabetic languages, the importance of phonological processing abilities may vary as a function of the regularity of the correspondence between print and pronunciation. English is less regular in this regard than, say, German, for which the mapping between graphemes and phonemes is consistent, particularly for vowels (Wimmer & Goswami, 1994; Wolf et al., 1994). The method of reading instruction received by participants was an eclectic, whole-language approach for the most part, with some phonics instruction mixed in. Whether the results would have come out differently had the reading instruction been primarily an explicit phonics program is unknown, particularly with respect to the absence of an influence of individual differences in word-level reading on subsequent individual differences in phonological processing abilities.

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