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Assessing phonological processing abilities for the prediction of future reading skills: a meta-analysis

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Assessing phonological processing abilities for the prediction of future reading skills: A meta-analysis

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Signatures have been redacted for privacy

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

Early identification of and intervention with children who are at risk for reading difficulties is crucial to the prevention of future reading problems. For accurate identification and effective intervention with these children, we need to determine what early reading skills should be measured and be taught before children actually begin to learn to read. Although the initial research in this area identified a range of early reading skills to be measured and taught, there is an emerging consensus about which early reading abilities are related to later reading achievement. Over the last three decades, many studies of the prediction of reading have placed particular emphasis on phonological processing abilities (Badian, 1998; Felton, 1992; Jorm, Share, Maclean, & Matthews, 1986; Mann, 1984; Rack, Snowling, & Olson, 1992; Shankweiler & Liberman, 1989; Siegel, 1989; Stanovich, 1988; Wagner & Torgesen, 1987; Wolf 1984).

Phonological processing refers to "an individual's mental operations that make use of the phonological or sound structure of oral language when he or she is learning how to decode written language" (Torgesen, Wagner, & Rashotte, 1994, p. 276). Ehri (1979) has mentioned two possible causal relations between phonological processing abilities and reading. First, a particular phonological ability can be a prerequisite of reading. An alphabetic writing system, such as English, represents language at the phonological level. An awareness of phonological structure of words can make learning to read words a more understandable task. Second, a particular phonological ability can act as a facilitator in the acquisition of reading skills. Children who possess phonological ability before reading instruction begins typically learn to read more easily than those without the ability (Bradley & Bryant, 1985; Felton & Wood, 1989; Stanovich, Cunningham, & Cramer, 1984).

There are at least three major phonological processing skills - phonological awareness, phonological coding in working memory, and phonological coding in lexical access. These three kinds of phonological processing skills have received the most frequent attention in studies of the prediction of reading. The studies have indicated that early assessment of these phonological skills prior to actual reading instruction could reliably predict subsequent reading achievement.

Phonological awareness[1] is defined as "one's sensitivity to or awareness of the phonological structure of words in one's language" (Torgesen et al., 1994, p. 276). Since in the case of the English language, written words are composed of sequences of letters that roughly correspond to the phonemes of spoken words, a child with phonological awareness has an advantage over a child without it in learning to read. In order for children to learn to read words they must have an understanding of how spoken language maps onto written language. A child with phonological awareness is not confused when the teacher talks about the sounds that letters stand for in a word, and thus is able to benefit from instruction. Phonological awareness is generally demonstrated by skillful performance on tasks such as tapping out the number of phonemes or syllables in a word, saying the individual phonemes or syllables of a word, and saying a word after deleting one of its phonemes or syllables (Griffith & Olson, 1992; Wagner & Torgesen, 1987).

Phonological coding in working memory refers to "coding information into a sound-based representational system that enables it to be maintained efficiently in working memory during ongoing processing" (Wagner, 1988, p. 262). Baddeley (1982) argued that in learning

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[1] Phonological awareness is also referred to as linguistic awareness and phonemic awareness (Wagner & Torgesen, 1987).

to read, a child must decode a series of visually presented letters, store the outcome of his or her decoding in some temporary systems, and subsequently blend the contents of his or her store to produce a word. Thus, a child with efficient phonological coding in working memory has an advantage in the acquisition of reading skills. Examples of representative tasks include memory-span tasks for stimuli that can be coded with verbal labels, such as letters, words, numbers, or pictures of common objects (Wagner, 1988).

Phonological coding in lexical access, "the ability to easily and rapidly access phonological information that is stored in long-term memory" (Torgesen et al., 1994, p. 277), is typically measured by rapid automatic naming tasks. The tasks require a child to name, as rapidly as possible, each set of stimuli (digits, colors, letters, or objects) printed on a page. An individual with efficient phonological coding in lexical access will use phonological information more effectively in decoding (Felton, 1992; Torgesen et al., 1994).

Purpose of the Study

The present study evaluates the ability of three phonological processing skills – phonological awareness, phonological coding in working memory, and phonological coding in lexical access – to predict future reading ability when considered simultaneously. As mentioned earlier, there is a substantial body of evidence indicating that phonological processing abilities are strong predictors of future differences in reading abilities. However, most studies have examined relations between reading and only one or two phonological processing skills. There has been little comparison of the three phonological processing skills at the same time. This study investigates which phonological ability is most closely related to the reading process and most significantly contributes to the prediction of future reading ability by comparing the three phonological processing skills at the same time.

In addition to determining the contribution of the three phonological processing skills to the prediction of later reading, the present study analyzes whether these phonological skills are related independently to reading. Torgesen et al. (1994) asked whether "these three constructs represented essentially different abilities, or whether they were simply different names for the same underlying constructs" (p. 277). In answering their question, they determined the results of the research related to this issue were "spotty and inconsistent" (p. 278). In this study, path analysis will be applied to determine the independence of the different phonological processing skills.

Research Questions

This study addresses two research questions: (1) Which of these three phonological processing skills contributes more to the prediction of risk for reading failure? (2) Are the different phonological processing skills related independently to reading?

Significance of the Study

There has been little analysis of similarities and differences among the phonological processing abilities. This lack of analysis of the phonological processing abilities may obscure potential differences in predictive power as well as interchangeability among the abilities used to measure the construct. Direct comparisons among the three different phonological abilities would help researchers and teachers focus on the most important abilities. By examining the extent to which the phonological abilities differentially predict future reading, the findings obtained from this study may contribute to making early identification of children who are at risk for reading difficulties more accurate and intervention with those children more effective.

Operational Definitions

Three phonological processing skills: Three kinds of phonological processing skills that have received the most frequent attention in studies of the prediction of reading over the last three decades. They include phonological awareness, phonological coding in working memory, and phonological coding in lexical access.

Phonological awareness: For the purpose of this study, Torgesen et al.'s (1994) definition is used. Phonological awareness is one's sensitivity to or awareness of the phonological structure of words in one's language.

Phonological coding in working memory: For the purpose of this study, Wagner's (1988) definition is used. Phonological coding in working memory refers to coding information into a sound-based representational system that enables it to be maintained efficiently in working memory during ongoing processing.

Phonological coding in lexical access: For the purpose of this study, Torgesen et al's (1994) definition is used. Phonological coding in lexical access is the ability to easily and rapidly access phonological information that is stored in long-term memory.

Future reading skills: For the purpose of this study, two kinds of reading skills after reading instruction are involved. One is word decoding. The other is reading comprehension.

Meta-analysis: A quantitative research synthesis technique to accumulate the findings from separate studies and then statistically summarize the results.

CHAPTER 2. LITERATURE REVIEW

A number of prediction studies of reading have indicated that individual differences in the three types of phonological skills prior to reading instruction are related to later differences in reading achievement measures (Badian, 1998; Bradley & Bryant, 1985; Felton, 1992; Juel, Griffith & Gough, 1986; Lundberg, Olofsson, & Wall, 1980; Mann, 1993; Mann & Liberman, 1984; Stanovich et al., 1984; Wagner, Torgesen, & Rashotte, 1994; Wolf, 1984). To test the relations between these two differences (in phonological processing skills and reading achievement), researchers have most frequently used longitudinal correlational studies. In this chapter, the findings of the existing longitudinal studies will be reviewed by type of phonological skills. Then, the meta-analysis method to be used for the purpose of simultaneously comparing different phonological processing skills will be delineated.

Studies of Phonological Awareness and Reading

There is a considerable volume of research indicating a significant relation between phonological awareness and reading. Share, Jorm, Maclean, and Matthews (1984) evaluated a group of Australian kindergartners on a number of attributes, including reading readiness, phonological awareness, and motor and language skills. They found that the best predictor of reading achievement at the end of first grade was phoneme segmentation.

Bradley and Bryant (1985) investigated the relation between skill in sound categorization in four- and five -year-olds and reading achievement measured three years later. At the beginning of the study, the children were given sound categorization tasks that required them to hear three or four words per trial and indicate which word was the odd one out. Three years later the children were given two standardized achievement tests of reading, the Neale Analysis of Reading (reading comprehension) and the Schonell Test of Reading (single word reading). Results demonstrated that initial sound categorization scores bore a consistent and significant relation to progress in reading even after the influence of intelligence had been removed. The correlations between scores on the sound categorization task and scores on achievement tests were .52 for comprehension and .57 for word reading.

Mann and Liberman (1984) examined the relations between phonological awareness, verbal short-term memory, and reading ability. To obtain a correlation between phonological awareness and reading, they administered a syllable-counting test to 62 children in May of kindergarten and the Woodcock Reading Mastery Test in May of first grade. They found phonological awareness scores were significantly correlated with reading ability ($r = .40, p < .01$). Mann (1993) examined again the relation between phoneme awareness (phoneme segmentation and invented spelling) and future reading ability. Results showed that scores on each test of phoneme awareness predicted between 30 % and 40% of the variance in first-grade reading ability.

Stanovich et al. (1984) gave ten phonological awareness tasks to 49 kindergartners whose reading ability was assessed 1 year later. The children's performance on three tasks that involved a rhyming response showed a ceiling effect, and these tasks did not correlate with subsequent reading progress. The other seven measures were all related to later reading ability; correlations ranged from .39 to .60, with a median of .45. As a set, the seven measures were a very strong predictor of reading abilities. These results provided further support for the predictive accuracy of phonological awareness tasks.

Some studies examined the relation between three phonological processing skills and reading ability. Felton (1992) evaluated 221 kindergartners' abilities in phonological awareness, phonological coding in lexical access, and phonological coding in working memory to predict third-grade reading. Phonological awareness was assessed in the spring of the kindergarten year with five measures: initial consonant not same, final consonant different, rhyme, syllable counting test, and Lindamood Auditory Conceptualization Test. Approximately three years later, vocabulary and comprehension were assessed with the California Achievement Test. Felton found beginning sound discrimination and auditory conceptualization significantly contributed to the prediction of reading outcome with correlations of .25 and .24 respectively.

Wagner, Torgesen, and Rashotte (1994) also conducted a longitudinal study of the relations between reading skills and three phonological processing abilities in young children. The correlations between kindergarten phonological awareness and first -grade word reading skill were significantly high: phonological analysis .67, $p < .001$; phonological synthesis .39, $p < .001$. Furthermore, one of their primary findings was that only phonological analysis had significant causal influence on word-reading skill when all phonological processing variables were considered simultaneously.

In addition to the published studies described above, unpublished studies such as theses, dissertations, and papers presented at professional meetings have shown that phonological awareness tasks are significant predictors of later reading. Kirby, Martinussen, and Beggs (1996) reported the results of a 2-year longitudinal study investigating the causal contributions of phonological processing to early reading competency. These results indicated that phonological analysis was the most salient predictor of Grade 1 reading, and phonological analysis depended in turn upon earlier developing skills, including phonological synthesis, naming, memory, and rhyming abilities.

A dissertation study (Floyd, 1999) produced positive correlations between the scores on tests of phonological awareness and tests of word reading and reading comprehension. Using multiple regression analysis, Floyd identified effective phonological awareness predictors of word reading and reading comprehension. The strongest predictors of word reading were the Isolation-Medial Position Subtest and the Auditory Composite score; the strongest predictors of reading comprehension were the Auditory Composite and the Deletion Subtest score.

Margolese's (1996) masters study examined the predictive validity of phonological awareness with multilingual children. Sixty-five children were tested in kindergarten with measures of phonological awareness, listening comprehension, visual-motor integration, and general cognitive ability. In Grade 1, they completed reading measures of letter, word and non-word recognition. Consistent with other results reported in the literature, phonological awareness was the best individual predictor of Grade 1 reading.

Studies of Phonological Coding in Working Memory and Reading

In contrast to phonological awareness, research evidence for phonological coding in working memory as a predictor of future reading is much less clear. Some researchers have found significant relations between working memory and later reading, while others found no general relation between the two variables. Gathercole (1990) suggested that the contribution of working memory to the acquisition of reading might be very specific in that it only contributed to reading when children have been exposed to reading instruction for between one and two years.

Mann and Liberman (1984) examined the relations between the ability to retain a string of words in short-term memory and future reading. As kindergartners, 62 subjects completed a test of memory for phonetically confusable and phonetically nonconfusable word strings. The examiner read a string of four words, after which the child was to repeat the string in the order presented. As first graders, they were given the Word Recognition and Word attack subtests of the Woodcock Reading Mastery Test. This longitudinal study showed that performance on the memory span test was significantly related to reading ability in first-grade reading. The simple correlations between these two variables were .39 for nonconfusable word strings and .26 for confusable word strings. Mann's (1984) follow-up study of 44 children replicated these results. The correlations between kindergarten memory span for nonconfusable word strings and first-grade reading was .56 ($p < .001$).

Wagner et al. (1994) administered four phonological coding in working memory tasks to 244 kindergarten children: Memory for sentences, digit span-oral presentation, digit span-visual presentation, and working memory. Results of this study supported a causal link between kindergarten children's working memory ability and later reading. The obtained correlation between working memory and word recoding was .21 ($p < .001$).

Another positive relation between memory capacity and reading achievement was revealed by German researchers. Naslund and Schneider (1991) examined the longitudinal relations between verbal ability, memory capacity, phonological awareness, and reading performance with 92 German children. Memory capacity was assessed in the children's preschool year with two word span tasks. The first task required the children to listen to ten sets of one-syllable words, and then repeat the words they heard regardless of sequence. The second task asked them to repeat lists of one-syllable words which were phonologically similar. Results of the longitudinal analyses showed that memory capacity was a significant predictor of second-grade reading ability with correlations of .38 for decoding speed and .48 for reading comprehension.

Felton and Brown (1990), however, found no relation between phonetic coding in working memory and reading. They evaluated children at risk for reading disability as kindergarteners and again as first graders to determine intercorrelations among phonological processing tasks and the relations of such tasks to word identification. They used memory span tasks for rhyming and nonrhyming word strings to assess phonetic coding in working memory were used. Results revealed that when IQ was controlled, neither of the memory tasks predicted later reading ability.

Rohl and Pratt (1995) also argued that verbal working memory did not consistently predict reading across testing times. They gave 76 prereading children three verbal working memory tests - memory for letters (simple repetition, backwards repetition), memory for words, and memory for sentences - at the beginning of first grade. One year later they administered the Neale Analysis of Reading Ability. Results of multiple regression analyses, with reading as a compound criterion variable, indicated that while there was some indication that verbal working memory, especially backwards repetition, measured in first grade did predict reading in second grade, these effects were no longer evident when the individual phonological awareness variables were controlled. The evidence therefore showed that verbal working memory did not contribute to reading in Grade 2 independently of Grade 1 phonological awareness.

Studies of Phonological Coding in Lexical Access and Reading

There are markedly fewer studies of phonological coding in lexical access as a predictor of reading acquisition in comparison to studies of phonological awareness. But, several studies have identified naming speed, a task for phonological coding in lexical access, to be a strong predictor of reading.[2] Wolf (1984) conducted a three-year longitudinal study of the relations between a variety of naming tasks and reading for 115 children. The naming tasks given at the end of the kindergarten year included Rapid Automatized Naming (RAN) tests, two Rapid Alternating Stimulus (RAS) tests, Boston Naming Test, "FAS" Set Test, "Animal" Set Test, and Visual Reduction Test. A reading comprehension test, oral reading test, and word-recognition test were given at the end of the first grade and second grade years. Wolf found that scores on the naming speed tasks were significantly related to scores on the reading measures. Correlations between naming tasks and first-grade reading comprehension ranged from -.71 to .21 with a median of -.47.

Wolf, Bally, and Morris (1986) found naming speed in kindergarten to be predictive of second-grade reading. Seventy-two average and eleven severely impaired readers in kindergarten to Grade 2 received four continuous naming tests and three reading measures. Results indicated that continuous naming measures, especially naming for graphological stimuli (letters, numerals), were strong differentiators of good and poor readers and good early predictors of later reading performance. The median correlations between naming speed and Grade 2 reading tasks were -.47 for reading comprehension and .55 for word recognition.

Felton (1992) evaluated 221 kindergartners' abilities in phonological coding in lexical access along with phonological awareness and phonological coding in working memory.

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[2] The studies measured naming speed by the amount of time taken to complete the naming and the number of items named per second. In the former measure, lower scores indicated more-rapid naming. Thus, negative correlations were expected. In the latter measure, higher scores indicated more-rapid naming and positive correlations were expected.

Phonological coding in lexical access was assessed in the spring of the kindergarten year with a RAN test that asked the children to name, as rapidly as possible, items presented visually on a chart. Approximately three years later, vocabulary and comprehension were assessed with the California Achievement Test. Felton found rapid naming of letters most significantly contributed to the prediction of reading outcome. Rapid letter naming alone accounted for 20% of the variance in reading outcome.

More recently, Lefly (1997) carried out a four-year longitudinal study by comparing development in four phonological processing domains (phoneme perception, phoneme awareness, verbal short-term memory, and lexical access) in children at both high and low risk for reading disorder. One of the major findings was that high risk non-reading disabled children were significantly different from low risk non-reading disabled children on lexical access tasks (rapid naming) at years 3 and 4 of the study. Discriminant analysis results indicated that speed of naming discriminated between the two groups both at Year 1 (correct classification rate 88.2%) and Year 2 (correct classification rate 92.65%).

Badian (1998) investigated the role of preschool phonological and orthographic skills in the prediction of reading with 238 preschoolers. The children were followed through the second grade to determine whether tests of phonological awareness (syllable tapping), phonological coding in lexical access (serial naming speed) and orthographic processing (visual matching), added to a preschool battery, would improve prediction of reading proficiency. Results of correlation and regression analyses indicated that in addition to the major predictors of letter naming ($r = .51 \sim .58$) and sentence memory ($r = .45 \sim .54$), serial naming speed tasks increased prediction of later reading ability. Syllable tapping, however, was found to be an ineffectual predictor of reading in this study.

Until now a wealth of prediction studies have demonstrated a significant relation between phonological processing skills and reading. Perhaps it can be said that there are enough studies to establish the role of phonological skills as good predictors of later reading ability. Now it seems appropriate to ask which phonological processing skill contributes more significantly to predict which aspects of reading, and whether these phonological skills are independently related to reading. To answer these questions, the present study will employ meta-analysis. A description of meta-analysis is presented in the following section.

Meta-Analysis

Meta-analysis is a quantitative research synthesis technique used to accumulate findings from separate studies and then statistically summarize the results. Glass (1976) defined meta-analysis as "the analysis of analyses" and argued "the statistical analysis of a large collection of analyses results from individual studies for the purpose of integrating the findings. It connotes a rigorous alternative to casual, narrative discussions of research studies which typify our attempts to make sense of the rapidly expanding research literature" (p.3).

Wolf (1986) made mention of potential problems with more traditional methods of integrating research findings, such as narrative and vote-count research syntheses. The problems included (1) selective inclusion of studies, often based on the reviewer's own impressionistic view of the quality of the study, (2) differential subjective weighting of studies in the interpretation of a set of findings, (3) failure to examine characteristics of the studies as potential explanations for disparate or consistent results across studies, and (4) failure to examine moderating variables in relations under examination. Meta-analysis is not hampered by these problems. It (1) eliminates bias in study selection by not prejudging research quality, (2) increases objectivity by quantifying ratings on the variables of interest through calculation, (3) detects statistical interactions by examining the covariation between findings and study features identified as important characteristics, and (4) uses all information by transforming study findings into commensurable expressions describing the magnitude of experimental effect (Kavale, 1984; Sindelar & Wilson, 1984).

Particularly in an area like special education, where the sample sizes are typically small and the findings are often inconsistent, meta-analysis methods can offer an important advantage. A study carried out in a single classroom or on a single child can rarely be given much significance by itself. If such small studies are amassed by systematic and scientific methods of research synthesis, however, the accumulated data set can contribute enormously to understanding events in the real world. Meta-analysis makes it possible to handle the integration of these small studies as if they were a single larger study. Another advantage of the meta-analysis technique in special education is that it helps to reduce the confusion of heterogeneous research literature. Research in special education often produces inconsistent results. Can better conclusions be made if new additional studies are conducted using new samples, new designs, and new measures? Probably not, since the studies remain as isolated data points, and results are still diverse (Guskin, 1984; Kavale, 1984; Mostert, 1996).

In relation to the present research questions, Wagner (1988) suggested that meta-analysis could provide a quantitative evaluation of the magnitudes of causal relations between different phonological processing skills and future reading abilities. The population correlation (*rho*) between the variables obtained by calculating an n-weighted mean correlation coefficient across studies can tell which phonological processing skill is more predictive of reading achievement; the larger estimate of *rho* forecasts better prediction of future reading failure. Another advantage in using meta-analysis in the present study is that it enables the three phonological processing skills to be compared simultaneously, even though most prediction studies of reading have investigated relations between reading and only one or two phonological skills. Estimates of *rho* for the set of phonological abilities and subsequent reading skills can be obtained from the assembled data. Path analysis[3] of these estimates of *rho* can determine whether the three different phonological processing skills are related independently to reading (Wagner, 1988).

Like other approaches, however, meta-analysis has not been free from criticism. This approach is obviously not a panacea. Perhaps one of the biggest problems in meta-analysis is dissimilar dependent measures and variations in study features. Though a group of studies might investigate the same question with similar methods, the researchers cannot be sure to what degree the combined results are distorted due to differences in measurement procedures and study features (Bangert-Drowns, 1986). In this sense, meta-analysis has been accused of oversimplifying the results of a research domain. Wolf (1986) suggested that this issue might be dealt with empirically by coding the characteristics for each study and statistically examining whether these differences are related to the meta-analytic results. However, there has been yet to be a systematic logical procedure to identify these characteristics.

Another frequent criticism is that meta-analyses include only published studies. Glass, McGaw, and Smith (1981) noted that published research was biased in favor of significant findings because nonsignificant findings were rarely published and this in turn led to biased meta-analysis results. To avoid such a publication bias, it is necessary to include

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[3] Path analysis considers the simultaneous relations between the variables. If variables that serve as causes (exogenous variables) are independently related to variables to be explained (endogenous variables), nonzero path coefficients will be found for the exogenous variables.

unpublished studies such as theses, dissertations and papers presented at professional meetings. Other criticisms of meta-analysis include mixing results from poorly designed studies and good studies and using multiple results from the same study (Mostert, 1996; Sindelar & Wilson, 1984; Wolf, 1986). Meta-analyses, therefore, should be carefully reported. Excellent summaries of guidelines helpful in confronting the potential limitations of meta-analysis are presented in Glass et al. (1981); Hunter, Schmidt, and Jackson (1982); and Wolf (1986) and are not included here.

Despite these shortcomings, meta-analysis provides the only means by which the three phonological processing abilities can be evaluated simultaneously. The present study will contribute to the knowledge base in early reading by gathering and comparing the inconsistent findings of studies on the three phonological processing abilities to predict future reading skills.

CHAPTER 3. METHOD

Data Collection Procedures

Defining Inclusion Criteria

Prior to searching for studies to use in meta-analysis, the scope of the primary research to be included was defined. The definition of inclusion criteria limits the parameters of the conceptual base for the review (Mostert, 1996). For the present analysis, longitudinal studies of the relations between early phonological processing abilities and reading achievement were selected. Studies were included if (1) at least one of the three kinds of phonological processing abilities and one or more measures of reading skills were administered at different time periods, (2) the measures of phonological processing abilities were administered prior to actual reading instruction (i.e., at kindergarten or at the beginning of first grade), and (3) data (i.e., sample size and correlations among phonological processing abilities and reading skills) were available to calculate population correlations (*rho*) and path coefficients (β).

Locating Primary Studies

Initially, a computerized search of the Educational Resources Information Center (ERIC) database was conducted with the following keywords: longitudinal study, phonological processing, phonological awareness, lexical access, working memory, rapid naming, short-term memory, and meta-analysis. Following the computer search, reference lists in books and articles were examined. To locate unpublished studies, particularly theses or dissertations, a computer generated search of the dissertation database was carried out. Theses or dissertations not owned by Iowa State University Library were requested through interlibrary loan.

In addition to these approaches, this author contacted leading researchers in the area to identify any published or unpublished studies appropriate for inclusion in this meta-analysis. Roland Good, Rollanda O'Connor, and Joseph Torgesen gave positive responses. They suggested research included in the National Reading Panel report, a hand search of relevant journals, and provided a couple of additional references, respectively.

Of the 141 studies produced through the above searching 33 met the inclusion criteria.[4] Table 1 presents a summary of the participants, measures (phonological processing abilities, reading skills, and IQ), and publication status of the 33 primary studies included in this meta-analysis. All participants were young children who had not received formal reading instruction when the phonological processing measures were administered (Generally, one or two years later they were given the reading achievement tests). Their mean age ranged from 3.9 years to 6.5 years. Some groups were non-English-speakers including Chinese, Dutch and German. The majority of the studies included the phonological awareness measures (n = 29). In contrast, the measures of phonological coding in working memory (n = 19) and lexical access (n = 16) were included less frequently. The number of studies including the measures of word decoding, reading comprehension, and IQ was 27, 18, and 21, respectively. Most of the studies including IQ measures were published studies; only two were unpublished studies. Twenty-three studies were published and ten were unpublished theses, dissertations, or papers presented at professional meetings.

Coding Study Features

Coding study features is a subjective but pivotal feature of meta-analysis (Mostert, 1996). As mentioned in the meta-analysis section of Chapter 2, problems due to variations in

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[4] The studies used in the meta-analysis are marked by asterisks in the References list.

Table 1. Summary of Studies Included in Meta-Analyses

Study	Participants		Measures						Published
	N	Grade / Mean age (yrs)	PA	PCWM	PCLA	WD	RC	IQ	
Badian (1998)	238	Preschooler s / 5.0	✓	✓	✓	✓	✓	✓	✓
Beggs (1996)	161	Kindergarteners / 5.7	✓	✓	✓	✓			
Blachman (1984)	34	Kindergarteners	✓		✓		✓		✓
Bradley and Bryant (1985)	104 264	Nursery / 4.9 and Primary group / 5.5	✓			✓	✓	✓	✓
Carson (1998)	72	First graders in fall / 6.4	✓			✓	✓		
Cohen (1981, March)	100	Kindergarteners		✓		✓	✓		
Cronin and Carver (1998)	95	Primary group / 5.6	✓		✓	✓	✓	✓	✓
Doi (1996)	81	First graders in fall / 6.5	✓		✓	✓	✓		
Felton (1992)	221	Kindergarteners / 6.1	✓	✓	✓		✓	✓	✓
Felton and Brown (1990)	81	Kindergarteners / 6.2	✓	✓	✓	✓		✓	✓
Floyd (1999)	172	First graders at the beginning of school year	✓				✓		
Gathercole, Willis, and Emslie (1992)	80	Prereaders / 4.6		✓		✓		✓	✓

Note. PA = phonological awareness; PCWM = phonological coding in working memory; PCLA = phonological coding in lexical access; WD = word decoding; RC = reading comprehension

Table 1. (continued)

Study	Participants		Measures						Published
	N	Grade / Mean age (yrs)	PA	PCWM	PCLA	WD	RC	IQ	
Goldstein (1976)	27	Prereaders / 4.5	✓	✓				✓	✓
Ho and Bryant (1997)	100	Chinese prereaders* / 3.9	✓	✓		✓		✓	✓
James (1997)	164	First graders at the beginning of school year / 6.3	✓	✓	✓	✓			
Jong and Leij (1999)	82	Dutch kindergarteners* / 5.6	✓	✓	✓	✓		✓	✓
Juel, Griffith, and Gough (1986)	129	First graders at the beginning of school year	✓			✓	✓	✓	✓
Kirby, Martinussen, and Beggs (1996, August)	122	Kindergarteners	✓	✓	✓	✓			
Lefly (1997)	124 115	Pre-kindergarteners and Pre-first graders	✓	✓	✓	✓	✓	✓	
Lundberg, Olofsson, and Wall (1980)	143	Kindergarteners	✓			✓		✓	✓
Mann (1984)	44	Kindergarteners / 5.9	✓	✓	✓	✓		✓	✓
Mann (1993)	100	Kindergarteners / 5.9	✓			✓	✓	✓	✓
Mann and Liberman (1984)	62	Kindergarteners / 5.9	✓	✓		✓		✓	✓

* Non-English-speakers

Table 1. (continued)

Study	Participants		Measures						Published
	N	Grade / Mean age (yrs)	PA	PCWM	PCLA	WD	RC	IQ	
Margolese (1996)	71	Kindergarteners / 5.8	✓			✓		✓	
Muter, Hulme, Snowling, and Taylor (1997)	38	Children in nursery school / 4.3	✓			✓	✓	✓	✓
Naslund and Schneider (1991)	92	German kindergarteners* / 6.1	✓	✓			✓		✓
Naslund and Schneider (1996)	134	German kindergarteners* / 6.0	✓	✓			✓	✓	✓
Rohl and Pratt (1995)	83	First graders at the beginning of school year / 5.7	✓	✓		✓	✓	✓	✓
Simmons (1991)	95	Kindergarteners / 5.11	✓	✓	✓	✓			
Stanovich, Cunningham, and Cramer (1984)	49	Kindergarteners in May of the school year / 6.2	✓			✓		✓	✓
Wagner, Torgesen, and Rashotte (1994)	244	Kindergarteners / 5.7	✓	✓	✓	✓			✓
Wolf (1984)	115	Kindergarteners			✓	✓	✓		✓
Wolf, Bally, and Morris (1986)	83	Kindergarteners / 5-6			✓	✓	✓	✓	✓

study features may be solved by coding the characteristics for each study and examining relations between coded variables and experimental outcomes. It helps to identify which study features might mediate the relation of interest. Possible study features include sample characteristics, research design characteristics, source of study, (e.g., published, dissertation, or paper presented at professional meetings), and date of study (Wolf, 1986). In this study, IQ and study source were included as potential mediating variables.

Collecting Primary Study Outcomes

After coding the study features as independent variables, individual study outcomes (effect sizes [ESs]), were calculated. In correlational studies, the ES is the correlation itself (Carlberg & Walberg, 1984). Therefore, the correlations among the three kinds of phonological processing ability (phonological awareness, phonological coding in working memory, and phonological processing in lexical access) and two kinds of reading skill (word decoding and reading comprehension) were obtained from each primary study for later analysis. In the process, a number of decisions were made regarding how to handle various circumstances. The following is a list of decision-making rules used when collecting primary study outcomes.[5]

1. When multiple correlations between one of the kinds of phonological processing ability and one of the kinds of reading skill were reported in a single study, the median of the correlations was used in the analysis.

2. When reading measures were administered at more than two time periods and children were nonreaders[6] at Time 1, the correlations with the reading measures

[5] These decisions were based on criteria established by Wagner (1988).
[6] They were children who had not received formal reading instruction.

administered at the first time period when formal literacy instruction was introduced were used in the analysis.

3. When the children were not nonreaders at Time 1, the correlations with Time 1 reading measures were used in the analysis.

4. When the reading measure was a combination of word decoding and reading comprehension, the correlation was used both for word decoding and reading comprehension.

5. When correlations between several kinds of phonological processing skills and reading were reported in a single study, each correlation was used in the analysis.

Data Analysis

Population Correlations (*rho*)

Two kinds of population correlation coefficients between the three phonological processing abilities and reading skills were computed: unweighted correlations and n-weighted correlations. Unweighted correlations[7] were obtained by dividing the sum of the correlations from each study by the number of studies. N-weighted correlations[8] were obtained by dividing the sum of correlation multiplied by the number of persons in each study by total sample size (Hunter, Schmidt, & Jackson, 1982). Wolf (1986) recommended reporting both correlations in the meta-analysis to reduce bias due to equal weight. He argued that giving very small or unrepresentative samples of subjects equal weight could lead to the less representative studies contributing just as much weight to the results of the meta-analysis as the more well-designed studies.

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[7] $rho = \Sigma r_i / K$ r_i is the correlation in study i; K is the number of studies

[8] $rho = \Sigma[N_i r_i] / \Sigma N_i$ r_i is the correlation in study i; N_i is the number of persons in study i

Mediating Variables

To identify potential mediating factors in the relations between phonological processing abilities and reading, the variances of population correlations were calculated. These variances reflect variabilities in population correlations other than those due to sampling error. If the variances in population correlations were just sampling error, the estimates of the variances would be zero. The variances of population correlations were obtained by subtracting the sampling error variance from the observed variance in sample correlation coefficients (Hunter et al., 1982; Wagner, 1988).[9]

Next, the impact of the potential mediating variable categories (IQ and study source) on the relations of interest was examined by testing the significance of the differences between two independent correlations.[10] For IQ, the differences between zero-order correlations and first-order correlations with IQ held constant were tested and for the source of studies, the differences between the correlations in published studies and the correlations in unpublished studies were tested.

Path Analyses

Finally, this study explored whether three different phonological processing abilities were related independently to subsequent reading skills. To answer this question, a path analysis that takes into account the simultaneous relations between the variables was carried out. Using two kinds of data (i.e., zero-order correlations and first-order correlations with IQ

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[9] $\sigma_p^2 = s_r^2 - [(1\text{-}rho^2)\ K / N$ s_r^2 is the observed variance; K is the number of studies; N is the total sample size

[10] This was done by using the formula: $Z = Z_{rho1} - Z_{rho2} / \surd\ [(1/(N_1 - 3) + (1/(N_2 - 3)]$

Z_{rho1} and Z_{rho2} are Fisher's r to Z transformation for the two *rho*s; N_1 and N_2 are sample size that the two *rho*s are based on.

removed), the path coefficients were calculated. In this process, the Statistical Analysis System (SAS, 1999) was used to make the calculation of the path coefficients easier.

The path coefficient indicates the amount of expected change in the dependent variable as a result of a unit change in the independent variables (Pedhazur, 1982). If the three phonological processing skills were related independently to reading, nonzero path coefficients would be found for those abilities.

CHAPTER 4. RESULTS

Correlations between Phonological Processing Abilities and Reading Skills

The population correlations (*rho*) between three kinds of phonological processing ability and two kinds of reading skill are shown in Table 2. Both unweighted correlations and n-weighted correlations are included in this table. All phonological processing abilities were moderately related to subsequent reading skills with correlations ranging from -.35 to .50. Of the three phonological skills, phonological awareness was most predictive of word decoding (unweighted *rho* = .49; n-weighted *rho* = .50) and phonological coding in lexical access1[11] was most predictive of reading comprehension (unweighted *rho* = -.48; n-weighted *rho* = -.45).

The differences between unweighted correlations and n-weighted correlations were not significant. Results of significance tests revealed that n-weighted correlations for both kinds of reading skill were not significantly different from unweighted correlations: for word decoding, phonological awareness, $Z = .04, p > .05$; phonological coding in working memory, $Z = .03, p > .05$; phonological coding in lexical access1, $Z = .00, p > .05$; phonological coding in lexical access2, $Z = .07, p > .05$; for reading comprehension, phonological awareness, $Z = .04, p > .05$; phonological coding in working memory, $Z = .02$, $p > .05$; phonological coding in lexical access1, $Z = 1.18$, $p > .05$.

Variables Mediating the Relations between Phonological Abilities and Reading Skills

Table 3 shows the estimates of the variance in population correlations. In a significance test for whether the observed variation is greater than that expected by chance,

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[11] The negative correlations are expected because the measure of naming proficiency was the amount of time taken to complete the naming. In contrast, for phonological coding in lexical access2, the positive correlations are expected because the measure of naming proficiency was the number of items named per second.

Table 2. Population correlations (rho) between phonological processing abilities and reading skills

Phonological processing ability	WD				RC			
	Unweighted rho	N-Weighted rho	K	N	Unweighted rho	N-Weighted rho	K	N
PA	.49	.50	18	2038	.45	.44	12	1659
PCWM	.39	.40	9	1031	.39	.38	5	785
PCLA1[a]	-.35	-.35	4	301	-.48	-.45	5	595
PCLA2[b]	.39	.43	3	564	.42	.42	1	238

Reading skill: WD and RC.

Note. K = number of studies; N = total sample size; PA = phonological awareness; PCWM = phonological coding in working memory; PCLA = phonological coding in lexical access; WD = word decoding; RC = reading comprehension

[a] The measure of naming proficiency was the amount of time taken to complete the naming. Thus, lower scores indicate more-rapid naming.

[b] The measure of naming proficiency was the number of items named per second. Thus, higher scores indicate more-rapid naming.

Table 3. Estimates of the variance in rho

Phonological processing ability	Reading skill					
	WD			RC		
	Observed variance	Sampling error variance	Variance of rho	Observed variance	Sampling error variance	Variance of rho
PA	.03	.01	.02***	.02	.01	.01***
PCWM	.01	.01	.00	.03	.01	.02***
PCLA1	.02	.01	.01	.01	.01	.00
PCLA2	.01	.00	.01**	.00	.00	.00

** $p < .01$, two-tailed. ***$p < .001$, two-tailed four out of eight estimates were significant at the .01 or .001 level. This is strong evidence that there was reliable variability in the population correlation coefficients other than that due to sampling error. Thus, it was apparent that unknown mediating variables affected the relation between phonological processing abilities and reading.

In this study, two potential mediating variables were examined to determine whether they mediated the relations between phonological abilities and reading skills. The first variable was IQ. Zero-order correlations and first-order correlations with IQ held constant for phonological processing abilities and reading skills are presented in Table 4. Overall, the correlation coefficients after IQ was controlled were lower than those before IQ was controlled. When the significance of the differences between the two correlations was tested, their differences became clearer. After IQ was partialed out, all but three correlation coefficients were significantly different from what they were before IQ was partialed out. Only correlations between phonological coding in lexical access and reading skills did not differ: *rho*s between phonological coding lexical access1 and word decoding, $Z = -.46$, $p > .05$; *rho*s between phonological coding lexical access1 and reading comprehension, $Z = -1.65$, $p > .05$; *rho*s between phonological coding lexical access2 and reading comprehension, $Z = 1.62$, $p > .05$. Thus, it can be said that controlling for IQ had an impact on the strength of the relation between reading skills and phonological processing abilities except for phonological coding in lexical access.

The second potential mediating variable category was the source of studies. Table 5 shows the n-weighted population correlations for published studies and unpublished studies. Contrary to this author's expectations, the correlation coefficients for the unpublished studies

Table 4. Zero-order correlations and first-order correlations with IQ partialed out for phonological processing abilities and reading skills

	PA	PCWM	PCLA1	PCLA2	WD	RC
PA	—	.19	-.12	.11	.33	.25
PCWM	.42*	—	-.03	.16	.29	.23
PCLA1	-.41*	-.39*	—	—	-.31	-.36
PCLA2	.30*	.29*	—	—	.23	.29
WD	.50*	.40*	-.35	.43*	—	—
RC	.44*	.38*	-.45	.42	—	—

Note. Correlations below diagonal show zero-order correlations. Correlations above diagonal show first-order partial correlations.
* Correlations are significantly different than partial correlations at the .05 level.

Table 5. Correlations for the source of the studies of the relation between phonological processing abilities and reading skills

Phonological processing ability	Reading skill			
	WD		RC	
	Published	Unpublished	Published	Unpublished
PA	.48 (1773)	.64 (265)	.42 (1415)	.54 (244)
PCWM	.39 (931)	.44 (100)	.37 (685)	.44 (100)
PCLA1	-.34 (220)	-.38 (81)	-.44 (514)	-.54 (81)

Note. Numbers within parentheses indicate total sample size. Estimates of rho between PCLA2 and reading skills for unpublished studies were not available.

were higher than those for the published studies.[12] There seems to be a relation between the estimates of the correlations and the source of the studies. Results of correlation analysis indicated that the population correlations between the three phonological processing abilities and the two reading skills were significantly correlated with the source of the studies: for word decoding, phonological awareness, $r = .33, p < .001$; phonological coding in working memory, $r = .15, p < .001$; phonological coding in lexical access1, $r = -.14, p < .05$; for reading comprehension, phonological awareness, $r = .36, p < .001$; phonological coding in working memory, $r = .13, p < .001$; phonological coding in lexical access1, $r = -.45, p < .001$. That is, the higher correlations between the phonological processing abilities and two kinds of reading skill tended to be obtained from unpublished studies rather than from published studies.

[12] The correlations between PCLA2 and reading skills could not be compared because the correlation for unpublished studies was not available.

The significance test of the difference between the correlations for published and unpublished studies also indicated that the source of the studies affected the estimates of the population correlations between the phonological processing abilities and reading across studies. The correlations between phonological awareness and reading skills for the published studies were significantly different from those for the unpublished studies (word decoding, $Z = 3.61, p < .001$; reading comprehension, $Z = 2.37, p < .05$).

Path Analyses

Path analyses were carried out on the two kinds of data reported in Table 4: zero-order correlations and first-order correlations with IQ held constant. First, the results of path analyses using zero-order correlations are presented in Figure 1. The diagrams on the left use phonological coding in lexical access1 and those on the right use phonological coding lexical access2. The path coefficient (β) above each unidirectional arrow represents that particular phonological ability's impact on the mean of the reading skill, if the mean of the phonological ability were to be increased by 1. For example, if β between phonological awareness and word decoding is .40, then increasing the mean of phonological awareness by 1 would be result in a .40 increase in the mean of the word decoding. The square of multiple correlation coefficient (R^2) indicates the proportion of the variance in the reading skills that can be predicted from the phonological processing abilities.

On average, approximately one-third of the variance in subsequent reading skills was explained by the causal influence of the three phonological processing abilities (mean $R^2 = .32$) in the path analyses using zero-order correlations. Each of the phonological processing abilities contributed to the reading skills; none of the phonological processing abilities had zero path coefficients. These results showed that the three phonological processing abilities

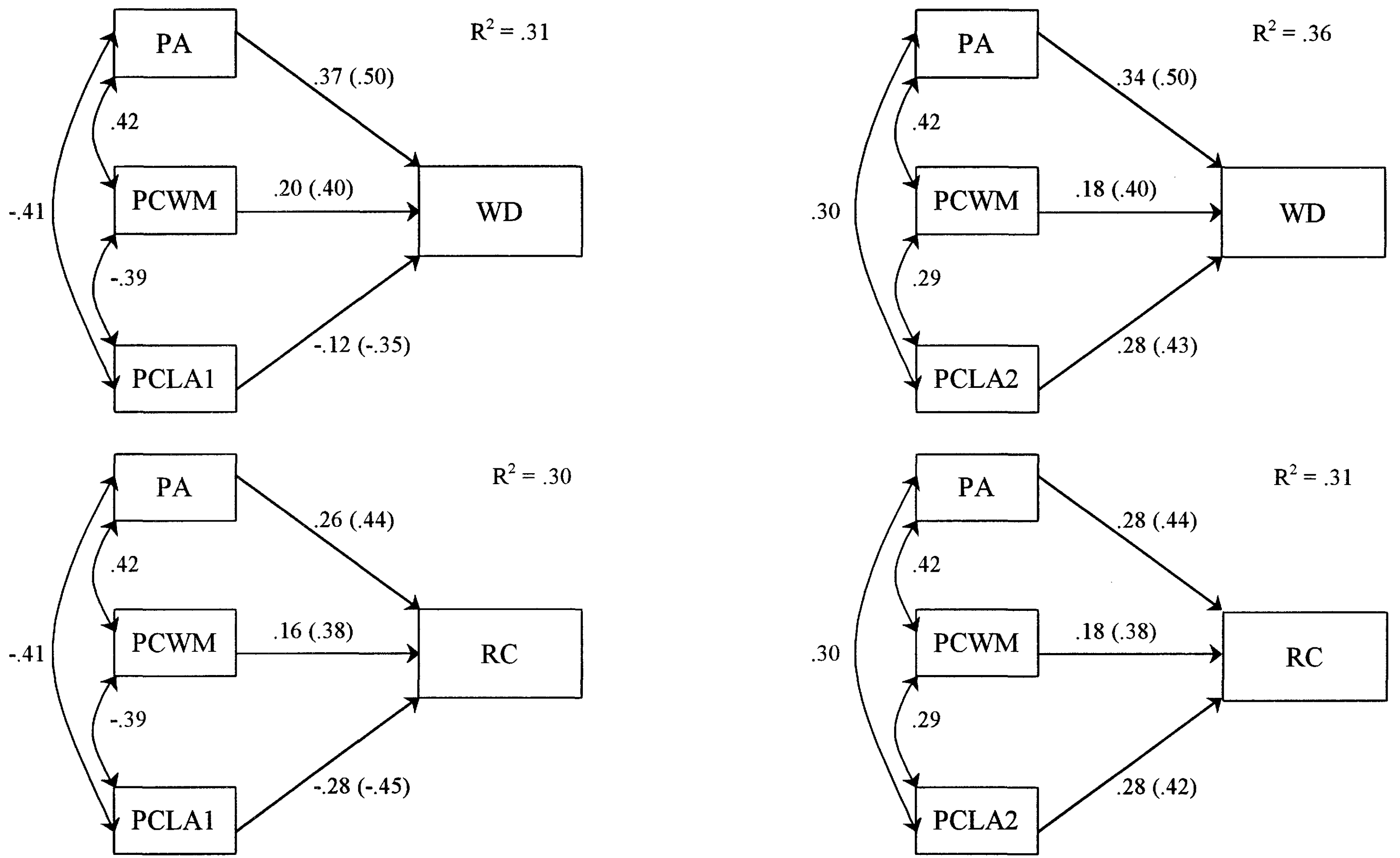

Figure 1. The results of the path analyses using zero-order correlations
Curved lines with arrowheads at both ends indicate the correlations between exogenous variables and unidirectional arrows indicate the paths leading from exogenous variables to an endogenous variable. Above each unidirectional arrow the path coefficient and within parentheses the correlations are given.

were related independently to subsequent reading performance. Of the three phonological processing abilities, phonological awareness had the greatest impact on word decoding (β = .37, .34) and phonological coding in lexical access had the greatest impact on reading comprehension (β = -.28, .28).

Figure 2 presents the results of the path analyses using IQ-partialed data. Like Figure 1, the diagrams on the left use phonological coding in lexical access1 and those on the right use phonological coding lexical access2. The proportion of the variance in subsequent reading skills that can be predicted from the three phonological processing abilities was somewhat lower than that in Figure 1 (mean R^2 = .20). This reduction indicated that some of the variance shared by IQ and reading was unrelated to variance in phonological processing abilities, but the impact of each phonological processing ability on two kinds of reading skill was similar to that of Figure 1. Furthermore, each of the phonological processing abilities still had a causal influence on the reading skills without zero path coefficients. In the IQ-partialed models, phonological awareness and phonological coding in lexical access also had the greatest impact on word decoding and reading comprehension, respectively.

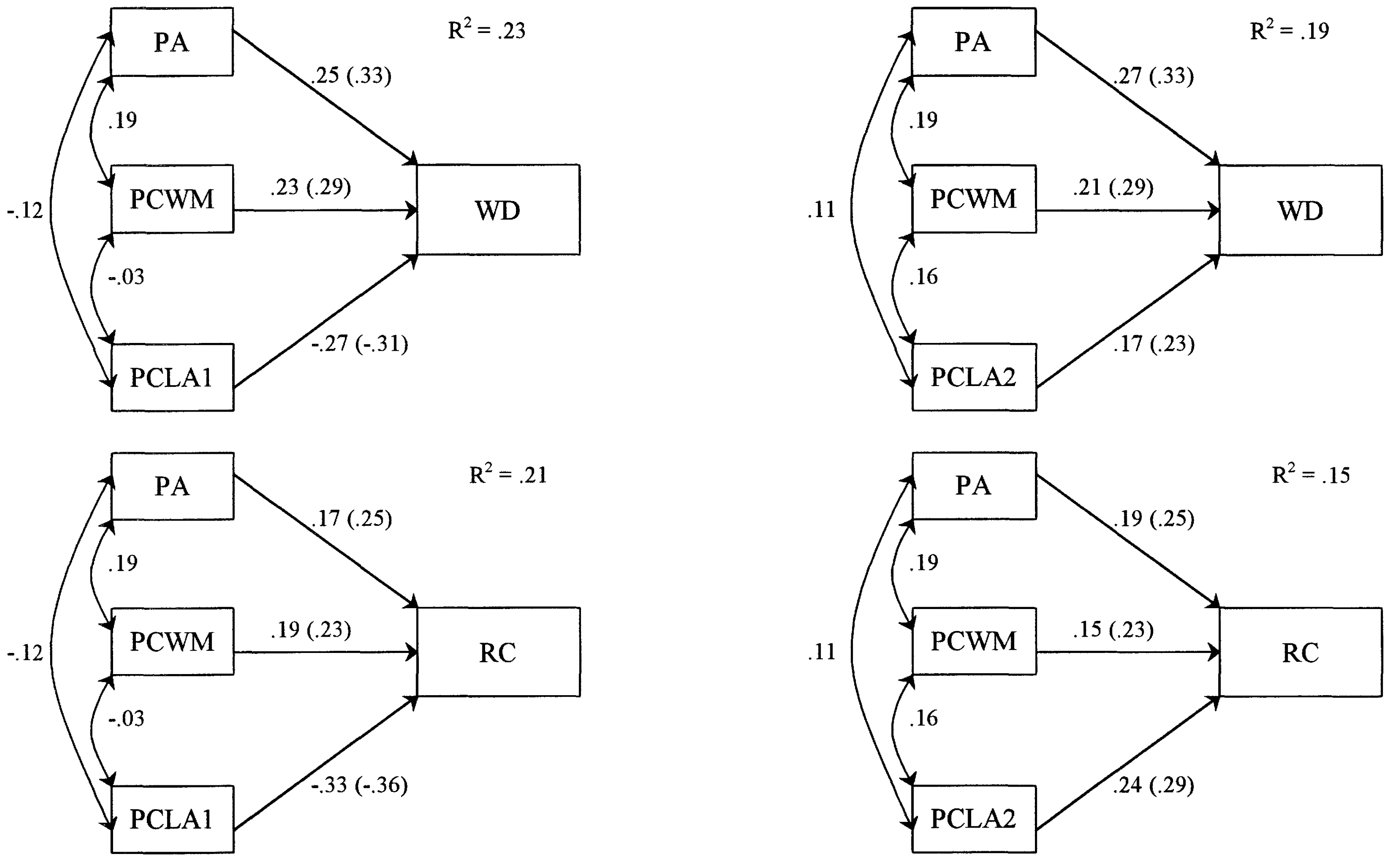

Figure 2. The results of the path analyses using IQ-partialed correlations
Curved lines with arrowheads at both ends indicate the correlations between exogenous variables and unidirectional arrows indicate the paths leading from exogenous variables to an endogenous variable. Above each unidirectional arrow the path coefficient and within parentheses the correlations are given.

CHAPTER 5. DISCUSSION AND CONCLUSIONS

The first purpose of this study was to identify which of three phonological processing abilities in young children (phonological awareness, phonological coding in working memory, and phonological coding in lexical access) more significantly contributes to the prediction of future reading skills. The correlation coefficients obtained through meta-analysis indicated that phonological awareness was most predictive of word decoding and phonological coding in lexical access was most predictive of reading comprehension.

Meta-analysis results, however, showed that there were potential mediating variables affecting the relation between phonological processing abilities and reading. Wagner (1988) argued that knowing that mediating variables exist is important in designing and interpreting future studies, because they may play a role in shaping a theoretical account of relations between phonological abilities and reading skills. IQ was one variable examined as a potential mediating variable in this study. Controlling for IQ had an impact on the strength of the relation between reading skills and phonological processing abilities. The magnitude of correlation between phonological awareness and word decoding decreased by more than 30% and the magnitude of the correlation between phonological coding in lexical access and reading comprehension decreased by 25%. However, path-analysis results indicated that causal influence of each phonological ability on subsequent reading skills was still significant after IQ was partialed out. Of the three phonological processing abilities, phonological awareness had the greatest impact on word decoding and phonological coding in lexical access had the greatest impact on reading comprehension.

These findings can have important implications for early identification and intervention with children who experience reading difficulties. First, the estimates of the magnitude of the causal relations between phonological processing abilities and subsequent reading skills suggest that the status of certain phonological abilities in young children who have not yet received formal reading instruction can predict, with a certain degree of accuracy, some specific aspects of future reading ability. Results of this study support teachers' use of certain phonological processing tests as screening measures to identify children at risk for reading failure. More specially, word-level reading abilities could be assessed more accurately with phonological awareness tests than with tests of working memory or lexical assess; comprehension-level reading is best assessed by lexical access tests. Likewise, teachers can identify potential future reading problem areas with the results of phonological tests. Low abilities in phonological awareness are more likely to predict difficulties in word decoding rather than comprehension; low abilities in phonological coding in lexical access predict difficulties in comprehension rather than word decoding.

Second, the causal influence of phonological processing abilities on reading skills suggests that phonological deficits can be a cause of early reading failure. Thus, phonological ability training prior to reading instruction may be one method to reduce the incidence of reading disabilities among young children (Torgesen et al., 1994). In fact, studies on the effects of training in phonological awareness have demonstrated relatively positive results; young children were successfully trained in phonological awareness and this training improved success in early reading. On the other hand, studies on the effects of training designed to improve phonological coding in working memory (e.g., memory span performance) or phonological coding in lexical access (e.g., rapid naming performance) have been carried out rarely. However, given knowledge of the strong relation between phonological processing abilities and the acquisition of reading skills, Torgesen and his colleagues (1994) recommended that training in phonological abilities be included in "any preventive or remedial program for children either at risk or identified with reading disabilities" (p. 285).

Another purpose of the present study was to determine whether the different phonological processing abilities were related independently to reading. Results showed that each of the phonological processing abilities contributed to subsequent reading skills with nonzero path coefficients; that is, the three phonological processing abilities exerted an independent causal influence on different types of reading skill. This finding also can have important implications for prediction and prevention of reading failure. Independence of the three phonological processing abilities suggests that it may be possible for each to predict different reading problems and provide rationale for differential intervention.

Finally, researchers and teachers must note the limitations of meta-analysis. Mostert (1996) suggested that the risk of theoretical and practical misinterpretation with meta-analysis might be somewhat higher than with other review methods because of the broad research generalizations made from meta-analytic results. The present study made every effort to overcome the potential limitations of meta-analysis by carefully defining inclusion criteria for the studies, including unpublished studies in the analysis, and coding study characteristics and statistically examining whether these differences were related to the meta-analytic results.

There are a large number of different experimental paradigms used to assess the three phonological processing abilities. For example, phonological awareness tasks include syllable counting tasks, rhyming tasks, phoneme segmentation tasks, phoneme substitution tasks, and blending tasks; phonological coding in working memory tasks include sentence memory tasks, word string memory tasks, digit memory tasks, and design memory tasks; phonological coding in lexical access tasks include naming letter tasks, naming number tasks, naming object tasks, and naming color tasks. The literature on phonological processing abilities has shown considerable convergence despite the use of a variety of paradigms (Stanovich, Cunningham, & Cramer, 1984). However, without careful comparisons between these tasks, doubts about a convergence of results from different tasks will always remain. Thus, it is necessary that an attempt be made to evaluate relations between phonological tasks and determine their degree of convergence for future research.

In summary, this study confirmed the strong relation between phonological processing abilities and reading skills and found that of the three phonological processing abilities, phonological awareness was the better predictor of word decoding and phonological coding in lexical access was the better predictor of reading comprehension. Additionally, it suggested that different aspects of reading might be predicted by the different phonological abilities. Results, however, indicated that other factors, specifically IQ, affected the acquisition of reading skills in addition to phonological processing abilities. Although phonological abilities are one important factor to identify young children who are likely to be at risk for reading failure, other factors should be taken into account for accurate identification.

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