Cognitive prerequisites of reading and spelling

A longitudinal approach

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Longitudinal research on the preschool prediction of academic achievement has accumulated over the last three decades. This research has been fuelled by the concern about high rates of school children with learning problems. As a consequence, there has been an increasing interest in the early identification and treatment of learning problems in order to facilitate school learning and prevent or minimize learning problems (see Bryant and Bradley 1985).

Horn and Packard (1985) presented one of the first meta-analyses (i.e., a quantitative review and statistical synthesis of the published literature; see Hedges and Olkin 1982) based on fifty-eight correlational longitudinal studies conducted mainly between 1960 and 1980. The studies summarized and analysed by Horn and Packard all dealt with the relation of measures administered in kindergarten or first grade and reading achievement later in elementary school. Overall, behavioural measures, language measures, and intelligence appeared to be the best single predictors of reading achievement in grades one to three.

A more concise quantitative review of the research in this area was undertaken by Tramontana, Hooper, and Selzer (1988). In the meta-analysis by Tramontana *et al.*, a total of seventy-four studies published from 1973 to 1986 were included, the majority of these studies focusing on reading skills as the criterion variable. Major differences between the Horn and Packard (1985) and Tramontana *et al.* (1988) meta-analyses concerned the inclusion criteria relevant to the type of predictor relationship among criterion measures and the timing of predictor assessment. That is, the focus in the Horn and Packard review was on univariate prediction, whereas Tramontana *et al.* also considered approaches where various measures were combined in order to maximize predictive accuracy. Further, unlike the Horn and Packard review, Tramontana *et al.* selected only those studies in which predictor measures were assessed *prior* to first grade. Despite these differences in design, the findings obtained by Tramontana *et al.* (1988) very much resembled those reported by Horn and Packard in that measures of general cognitive abilities, language, and visual-motor skills, along with measures of letter naming, were identified as good predictors of reading in the early elementary school years.

In our view, there are at least two general problems with the numerous longitudinal studies summarized by Horn and Packard and Tramontana *et al.* and dealing with the early prediction of reading skills: (1) The selection of predictor measures was not guided by and derived from theoretical considerations concerning reading, in particular. It is obvious from the review by Tramontana *et al.* (1988) that a vast array of (mostly psychometric) measures were used that, in most cases, were not proximal to reading processes (e.g., motor skills, behavioural-emotional functioning, general cognitive ability). Interestingly enough, many of these measures predicted later reading performance surprisingly well, particularly when the focus was on univariate prediction. Needless to say, such an outcome does not facilitate the task of researchers trying to come up with a diagnostic screening instrument consisting of a few, effective predictor variables.

(2) Another, related problem concerns the fact that discriminant or differential validity of predictor variables was either not assessed at all or found to be low. In the latter case, measures important for the prediction of reading were equally powerful in predicting maths achievement in elementary school. In general, most attempts to identify a differential pattern of predictors for later achievement in reading versus maths were relatively unsuccessful.

Given these problems, approaches that derive predictor measures from theoretical assumptions concerning possible prerequisites of reading seem preferable to the basically a-theoretical approach dominating longitudinal research on this issue in the 1960s and 1970s. Such studies have indeed been successfully carried out within the last decade and will be summarized in the subsequent section.

PHONOLOGICAL PROCESSING ABILITIES AND READING

Most longitudinal studies on causal relations between the early development of phonological processing abilities and the acquisition of reading skills are based on assumptions derived from the information-processing paradigm. The term phonological processing refers to the use of phonological information (i.e., the sounds of one's language) in processing written and oral language (cf. Wagner 1988; Wagner and Torgesen 1987). Although a generally accepted taxonomy of phonological processing abilities does not exist, the following components are frequently distinguished (cf. also Torgesen *et al.* 1989): (1) *Phonological awareness*, that is, the awareness of and access to the phonology or sound structure of one's language. This ability includes aspects of analysis (i.e., segmenting a word into units) as well as aspects of synthesis (i.e., combining the constituent segments of a word into a whole word, as realized in the common sound-blending task). The relation of these phonological awareness components to early reading seems evident: processes of analysis are involved when the beginning reader is confronted with a new word and tries to break apart the string of visually presented letters, and processes of synthesis are activated when it comes to putting the sounds of the letters together to form a word.

(2) *Phonological recoding in lexical access*, that is, accessing the referent of a word in a semantic lexicon or internal dictionary. This component implies the retrieval of the phonological codes associated with an object from long-term memory. As noted by Wagner (1988), the objects for which phonological codes are retrieved in actual reading are letters or letter pairs. Tasks typically used to assess this ability involve the rapid naming of colours or objects and deciding whether a string of letters represents a word or a non-word.

(3) *Phonetic recoding to maintain information in working memory*, that is, recoding information into a sound-based representational system that enables it to be maintained in working memory during ongoing processing (Baddeley 1986; Wagner and Torgesen 1987). Examples of tasks assessing this ability include memory-span tasks which include both storage and processing components for stimuli that can be coded with verbal labels, such as numbers, letters, words, or sentences. Efficient recoding in working memory seems important for early reading because beginning readers have to accomplish several tasks when confronted with a new word. First, they have to retrieve the sounds of the letters. Next, the initial sounds must be stored while subsequent sounds are being retrieved, and all of the sounds must be kept in working memory for subsequent processing. Third, the entire set of sounds in working memory has to be blended together to form a word (cf. Wagner 1988).

Research on the relevance of these three components of phonological processing for the acquisition of subsequent reading skill generally yielded impressive results. As indicated by a meta-analysis conducted by Wagner (1988) based on nine correlational longitudinal studies and seven training studies, reliable causal relations between phonological processing abilities and subsequent reading skills were obtained for both types of studies, with median correlations of .38 and .70 for the correlational and training studies, respectively. A path analysis carried out on the correlations aggregated across the two types of studies revealed that about 75 per cent of the variance in the dependent variable (i.e., word analysis) was explained by the three phonological processing abilities described above.

All in all, these findings indicate that metalinguistic abilities assessed during the preschool and kindergarten years strongly influence subsequent reading skills (cf. also Maclean, Bryant, and Bradley 1987; Vellutino and Scanlon 1987, for similar results; these more recent studies were not included in Wagner's meta-analysis). Moreover, it was repeatedly shown that the close relationship between metalinguistic predictors and reading skills did not generalize to theoretically unrelated domains like arithmetic (cf. Bryant and Bradley 1985; Maclean *et al.* 1987).

Given these impressive findings, it is no longer sufficient to ask whether phonological skills play a causal role in the acquisition of reading skills. The question now is which aspects of phonological processing skills (e.g., phonological awareness, recoding in lexical access, recoding in working memory) are most important for the prediction of which aspects of reading (e.g., word recognition, word analysis, sentence comprehension). It was the major goal of the present study to explore this issue in more detail.

MAJOR GOALS OF THE PRESENT STUDY

One basic characteristic of many longitudinal studies exploring the relationship between early phonological processing skills and subsequent reading skill was that only a few components of phonological skills were simultaneously considered as predictors of reading (e.g., Bryant and Bradley 1985; Maclean *et al.* 1987; Perfetti *et al.* 1987; Tunmer, Herriman, and Nesdale 1988). From these studies, it is difficult to tell how and to what extent the inclusion of additional components would have changed the overall pattern of results. Other studies including comprehensive batteries of phonological predictor variables were not longitudinal in nature (e.g., Wagner *et al.* 1987). While such models are informative concerning the factorial structure of preschoolers' phonological processing abilities, they do not allow any conclusions regarding the relative importance of the various components for subsequent reading acquisition. Even those few studies based on both large sample sizes and multiple preschool predictors of reading achievement (e.g., Butler *et al.* 1985; Share *et al.* 1984; Vellutino and Scanlon 1987) were not without problems when estimating predictor qualities via traditional regression analyses or path analysis techniques based on observed variables. Due to the usually large number of predictors and the significant interrelationships among these predictors, the problem of multicollinearity could not be adequately dealt with in these studies, probably resulting in biased parameter estimates and overestimation of 'true' explained criterion variance.

To cope with these problems, a latent variable causal modelling approach (LISREL; cf. Jöreskog and Sörbom 1984) was chosen in our study. In short, the major advantage of this approach is that it distinguishes between a measurement model representing the relationships among observed variables and latent, theoretical constructs, on the one hand, and a structural model representing the interrelations among the latent constructs, on the other hand. As structural/causal relationships are estimated at the level of theoretical constructs and not at the level of fallible observed variables, the number of variables included in the path model is comparably small. The distinction between a measurement model and a structural model also allows for a separate estimation of measurement errors in the observed variables and specification errors in the structural part of the model: large specification errors usually indicate that the causal model was not completely specified, that is, that important predictors were obviously missing. Another advantage of this causal modelling approach is that several so-called goodness-of-fit tests exist that detect the degree of fit between the causal model and the data set to which it is applied. Causal models are said to be 'confirmed' when the goodness-of-fit parameter indicates better-than-chance fit between the model and the data.

Based on this methodological approach, we explored the following questions: (1) How do the three components of phonological processing assessed during the kindergarten years affect reading skill as measured in second grade? (2) What is the relative impact of verbal intelligence and early literacy on the prediction of reading comprehension in second grade, and (3) how specific are the structural patterns, that is, does the causal model specified to explain reading comprehension also generalize to the prediction of spelling in second grade?

The data used in the present study were taken from part of the Munich Longitudinal Study of the Genesis of Individual Competencies (LOGIC; see Weinert and Schneider 1987, for a more detailed description of the longitudinal study). In the LOGIC study, children's intellectual and social competencies were first assessed in 1984 when they were about 4 years old, and have been followed up annually since then.

DESCRIPTION OF SAMPLE AND TEST INSTRUMENTS

The models predicting reading comprehension and spelling were based on different sample sizes. Complete data sets from 185 children were available for the analyses focusing on spelling. As only a subsample of children participated in the reading comprehension tests, the analyses concentrating on this variable were based on only 121 subjects.

All tests, except for the reading comprehension measures, were taken individually. Reading comprehension measures were administered to all children in the classrooms in which they attended. Most measures included in this analysis can be easily linked to the three components of phonological processing described above.

Phonological awareness

Four different measures were used to represent phonological awareness. First, a German version of Bryant and Bradley's (1985) phonological oddity task was used to assess children's understanding of *rhyming*. In this task, children were instructed that they would hear four words from a tape recorder, and that one of the four words would not sound like the others. In the middle sound oddity condition, the target word always shared the last phone with the other three words but differed regarding the middle sound. In the end sound oddity condition, the target word always shared the same middle phone as the other three words but differed concerning the end sound. Finally, in the first sound condition, children had to detect the one out of four words with a first sound differing from that of the three other words. Correct answers were given one point. There was a total of twenty-seven trials, yielding a maximum score of 27.

The second subtest assessing children's phonological awareness was adapted from the Bielefeld Longitudinal Study on Early Risk Identification (Skowronek and Marx 1989). This test consisted of ten word pairs. For each pair, children had to indicate whether the items sounded alike. Again, correct responses were given one point, yielding a maximum score of 10.

A *syllable segmentation task* was also adapted from the Bielefeld Longitudinal Study (Skowronek and Marx 1989). In this task, children were instructed that they would participate in a word repetition game. When presenting the practice items, the experimenters segmented the words into syllables and clapped their hands. Children were instructed to clap their hands when repeating the words. The number of correct word segmentations was used as the dependent variable in this task (max. = 10).

The *sound-to-word-matching task* was also taken from the Bielefeld study (cf. Skowronek and Marx 1989). Children were told that they would hear a number of words, and that they had to listen very carefully. They first would have to repeat each word and then to indicate if a specific sound pronounced by the experimenter was in that particular word. As an example, the experimenter presented the word 'Auge' (eye) and asked subjects if they could hear an 'au' in it. The number of correct responses was recorded (max. = 10).

Phonological recoding in lexical access

Two rapid naming tasks were used to represent phonological recoding in lexical assess. The two rapid naming tasks were also taken from the Bielefeld study. In the first, *rapid colour naming of non-coloured objects*, eight sets of black-and-white drawings of four different objects were presented and labelled by the experimenter. The children were asked to name the correct colours of these objects as quickly as possible.

In the second rapid colour-naming task (*rapid colour naming of objects with incongruent colours*), the same stimulus materials were used. The only difference was that all objects had wrong colours in this task. The children were instructed to give the correct colours of the objects as quickly as possible. Total time needed to complete the tasks and the number of errors were taken as dependent measures in both rapid naming tasks.

Phonetic recoding in working memory

Two verbal memory-span tests were used to assess phonetic recoding in working memory. A German version of the Case, Kurland, and Goldberg (1982) word-span task tapped children's word span. The set sizes varied between three and seven one-syllable words. Beginning with sets of three words, two trials were given for each set size. Children were instructed to first listen to the entire set, then repeat the words they heard. Scores were taken from the maximum number of words repeated in the correct order. This scoring procedure was not in accordance with Case *et al.*'s suggestion of ignoring order because developmental differences in memory span should not be confounded with differences in encoding and preserving information about order. We decided to use the serial word span as dependent variable because it generally showed more predictive quality than the unconstrained word-span measure recommended by Case *et al.* (1982).

A *sentence-span* or *listening-span measure* was adapted from Daneman and Blennerhassett (1984). Seventy-five sentences (at maximum), ranging in length from three to seven words, were read to each child. Sentences were grouped in five sets each of one, two, three, four, and five sentences. Children were presented the one-sentence sets first, followed by the two-sentence sets, etc. With the exception of the one-sentence sets, sentences within each set were read in quick succession. Children were asked to repeat the sentences in each set verbatim. Testing terminated when the child failed to recall all five sentences at a particular level. The total number of sentences recalled correctly was chosen as the dependent variable.

Additional measures

In addition to the three components of phonological processing, two further constructs which had been referred to as important predictors of reading skill in the literature were also included in our battery of predictors. For example, as emphasized by Lomax and McGee (1987) and Share *et al.* (1984), signs of *early literacy* or young children's concepts about print seem to qualify as relevant predictors of reading skill. We thus decided to include three variables tapping this construct in our collection of predictor measures. A *letter-naming task* assessed children's grapheme–phoneme correspondence knowledge. Here, the number of letters correctly identified was chosen as the dependent variable.

The second task (*sign knowledge* or *Logo task*) was originally developed by Brügelmann (1986) and later modified by the Bielefeld group (Skowronek and Marx 1989). The Logo task tapped children's knowledge of letters and words that are hidden in familiar settings. Typical examples are traffic signs (e.g., the STOP sign) and trade marks. In some trials, only the original letters were given without any graphic context. In others, only the graphic context was given and the letters were omitted. We used the number of correct responses in trials focusing on the letters (without graphic context) as the dependent variable in the present analysis.

Finally, *name writing* was chosen as another variable tapping early literacy. Children were asked to write down a word they already knew on a sheet of paper. Those children who were able to write down at least one word were told that the experimenter wanted them to write down another twelve words. The number of words correctly spelled was used as the dependent variable.

The list of predictor variables was completed by tests of *verbal intelligence.* Three verbal sub-tests (i.e., general knowledge, vocabulary, general understanding) from the Hannover-Wechsler Intelligence Test for Preschool Children (HAWIVA; Eggert 1978) were chosen to represent the verbal intelligence construct. The HAWIVA was administered twice, when children were 4 and 5 years old. Combined scores of the three verbal sub-tests were computed on both occasions and used to represent verbal intelligence in the present study.

With the exception of the verbal intelligence measures and the indicator of reading speed, all predictor variables were assessed during the last kindergarten year.

The *criterion measures,* that is, indicators of *reading comprehension* and *spelling,* were taken around the end of second grade. A thirty-item test developed by Näslund (1987) was used to measure reading comprehension and word knowledge within the context of single sentences and longer text (short stories). A total of eighteen multiple-choice items tapped *word knowledge.* They included finding synonyms and antonyms within the context of a sentence. The *text comprehension* part consisted of five short stories followed by two or three multiple choice questions. This task was designed to test children's understanding of the text, deducing answers from inferences based only on information in the stories.

Finally, the *spelling test* consisted of two partially overlapping versions, one presented at the beginning of second grade and the other shortly before the end of second grade. Each test included about twenty target words which were taken from different sources and seemed particularly suited to assess spelling competence in second grade. For all criterion measures, the number of correct items was chosen as the dependent variable.

RESULTS

The means, standard deviations, and ranges obtained for the various predictor and criterion measures are given in Table 13.1. Except for the Bielefeld rhyming task which turned out to be rather easy for most children, the measures were moderately difficult and approximately normally distributed. There were neither ceiling nor floor effects.

Table 13.1 Means, standard deviations, and range for the predictors and criterion variables included in the analyses

Construct/Variable	*Mean*	*SD*	*Minimum*	*Maximum*
1) *Verbal intelligence*				
HAWIVA 1	34.30	9.42	5.00	58.00
HAWIVA 2	46.08	9.10	8.00	64.00
2) *Phonological awareness*				
Sound oddity	22.91	1.74	18.67	27.00
Bielefeld rhyming	8.13	1.35	3.00	10.00
Sound-to-word match	6.85	2.20	0.00	10.00
3) *Phonological recoding in lexical access*				
Rapid colour naming 1	51.83	18.20	22.00	142.00
Rapid colour naming 2	84.36	29.51	32.00	220.00
4) *Recoding in working memory*				
Word span	3.47	0.97	1.00	6.00
Sentence span	14.04	6.63	2.00	38.00
5) *Early literacy*				
Letter knowledge 1	6.75	7.44	0.00	26.00
Letter knowledge 2	8.31	8.13	0.00	26.00
Sign knowledge	1.00	1.47	0.00	5.00
Written words	2.01	1.92	0.00	12.00
6) *Reading comprehension*				
Word usage in text	14.44	3.62	3.00	18.00
Text comprehension	7.42	3.31	1.00	12.00
7) *Spelling*				
Words correct 1	10.21	2.18	4.00	17.00
Words correct 2	11.03	3.99	1.00	18.00

In a second step of analysis, we calculated the intercorrelations among predictor variables and criterion measures. These are given in Table 13.2, with the reading comprehension measure and the second spelling test serving as criterion variables. As can be seen from Table 13.2, zero-order correlations among most predictors and the two criterion variables were moderately high, ranging between .15 (syllable segmentation task and reading comprehension) and .42 (sound oddity task and reading comprehension). To assess the impact of verbal intelligence on the relations among predictor and criterion variables, we additionally calculated partial correlations controlling for verbal intelligence. The partial correlations are also listed in Table 13.2. A comparison of the zero-order and partial correlations reveals that controlling for verbal intelligence generally led to a drop in correlations. The effects of verbal intelligence on the predictor–criterion relationships seem larger in the case of spelling than for the reading comprehension measures, and they affect the phonological awareness measures more than they influence recoding in lexical access and early literacy. It seems interesting to note that most relationships remained significant even after influences of verbal intelligence had been partialled out.

Table 13.2 Zero-order and partial correlations of predictor variables with reading and spelling measures

	Reading comprehension correlations		*Spelling correlations*	
Predictor	*Zero order*	*Partial*	*Zero order*	*Partial*
Verbal intelligence	.33		.32	
Word span	.30	.29	.28	.22
Sentence span	.32	.23	.36	.20
Sound oddity task	.42	.36	.39	.27
Bielefeld rhyming	.30	.21	.38	.25
Syllable segmentation	.15	.04	.25	.10
Sound-to-word match	.28	.17	.27	.11
Rapid colour naming 1	−.29	−.29	−.35	−.25
Rapid colour naming 2	−.24	−.24	−.34	−.17
Letter knowledge 1	.37	.31	.39	.29
Letter knowledge 2	.36	.27	.39	.29
Sign knowledge	.29	.28	.25	.13
Written words	.21	.18	.25	.13

Note. Correlations larger than .15 are statistically significant at the $p = .05$ level.

STRUCTURAL EQUATION MODELLING VIA LISREL

As noted above, the computer program LISREL VI (Jöreskog and Sörbom 1984) was used to analyse the influence of the three phonological processing components, early literacy, and verbal intelligence on later reading related measures and spelling. The measurement model indicated in Table 13.1 was used for all models to be described below.

Three different structural models were specified. The first structural model represented a traditional multiple regression model based on latent variables.

By using such a model, relative direct effects of the predictor variables on the criterion can be assessed. However, nothing is known about possible indirect predictor effects because all predictor measures serve as exogenous, independent variables that are not further explained in the model.

The second structural model was specified as a path model and based on both theoretical assumptions drawn from the relevant literature and the temporal structure of data collection. In this model, verbal intelligence assessed at age 5 was considered the only independent, exogenous variable not further explained in the model. The assumption was that verbal IQ should directly influence other predictor domains but show minor direct effects on the criterion measures (i.e., reading comprehension and spelling). On the other hand, working memory (assessed about half a year later than IQ and about three months earlier than the remaining predictor measures) was assumed to have significant direct impacts on both the other predictor domains as well as the criterion measures. Furthermore, the expectation was that the working-memory construct would also have indirect effects on the criterion measures, mediated by its influence on the remaining predictors which all were assumed to show direct effects on reading comprehension or spelling. Given that the role of working memory for reading acquisition has been demonstrated in numerous studies (e.g., Daneman and Blennerhassett 1984; Mann 1984), a dominant position was reserved for this construct in our Model 2.

A third, alternative model neglected the temporal structure of the data collection process. Instead, the emphasis was solely on theoretical considerations derived from the relevant literature. In this model, verbal intelligence, phonological awareness, and working memory were considered the central explanatory constructs in the model which would influence both early literacy and phonological recoding in lexical access.

Finally, in order to assess the estimability of our causal model, given the structure of our data, we tested a model which theoretically should not fit our data; namely, the assumption that reading comprehension (or spelling) measured at age 7 should predict verbal intelligence two years earlier. From a structural point of view, this model was almost equivalent to Model 2 described above. The only exception was that the positions of the exogenous and criterion variables were exchanged. Our expectation was that such a model should not fit the data. The inclusion of such a 'nonsense' model is useful in order to justify that theoretically based models can be specified given the indicator variables included. If one can show that alternative models, which counter theoretical expectation, do not fit the data, one is in a better position to justify the significance of the causal models proposed.

PREDICTION OF READING COMPREHENSION

In a first step of analysis, a multiple regression model based on latent variables was specified and estimated via LISREL. The maximum likelihood estimates of structural (regression) parameters obtained for this model are depicted in Figure 13.1. According to this LISREL solution, reading comprehension measured at the end of second grade was best predicted by the phonological awareness variable, followed by the phonological recoding in lexical access and working memory constructs. Our regression model fitted the data (chi-square = 108.63, df = 89, p > .05).

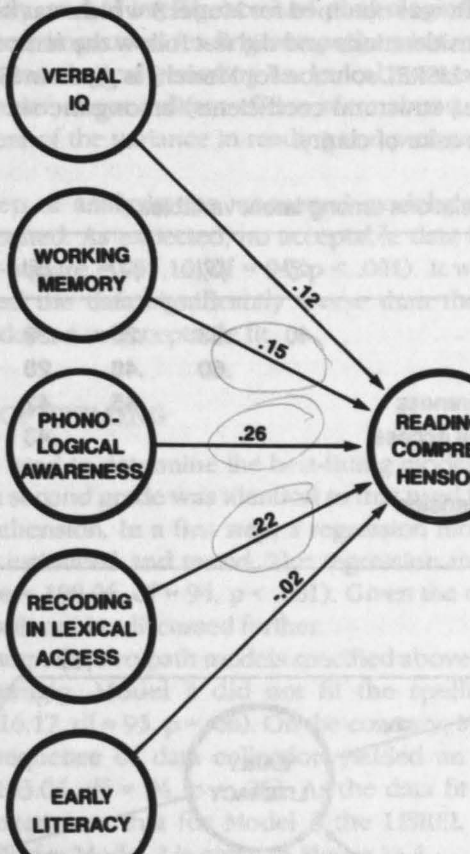

Figure 13.1 **Relative contributions of the three phonological processing components, verbal intelligence, and early literacy to the prediction of reading comprehension in second grade**

One obvious shortcoming of such a traditional regression approach is that the covariance among the predictor variables is not accounted for by the model. As can be seen from Table 13.3, the intercorrelations among the various predictor variables in our model were indeed considerable. The causal modelling approaches specified above all have in common that they make use of this information. Both causal models specified above yielded chi-square values indicating acceptable data fit (chi-square = 110.49, df = 94 for Model 2, chi-square = 89.39, df = 93 for Model 3, all p's > .05). To determine the best-fitting model, the differences in chi-square values can be compared. These differences form again chi-square statistics that can be used to evaluate the importance of the parameters that differentiate between competing models. A comparison of the two models revealed that significantly better data fit was obtained for Model 3 which was basically derived from theoretical considerations and did not follow the temporal structure of data collection. The LISREL solution for Model 3 is given in Figure 13.2. Only the causal links (i.e., structural coefficients) among the six latent variables are included for the sake of clarity.

Table 13.3 Intercorrelations among latent variables

Variables	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
1) Verbal IQ	.40	.53	.25	.38	.38	.36
2) Working memory		.60	.46	.28	.36	.41
3) Phonological awareness			.45	.42	.47	.50
4) Recoding in lexical access				.43	.60	.51
5) Early literacy					.39	.49
6) Reading comprehension						.41
7) Spelling						

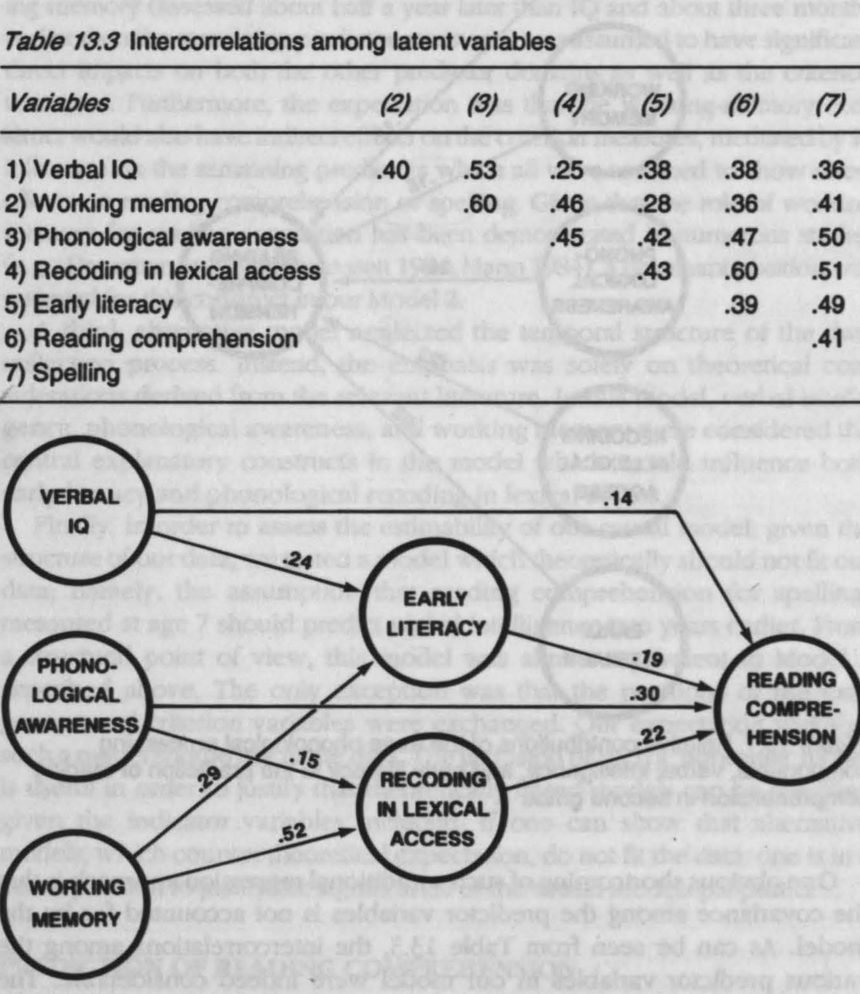

Figure 13.2 Best-fitting structural equation model for the reading comprehension construct

As can be seen from Figure 13.2, only the phonological awareness and phonological recoding in lexical access constructs showed a significant direct impact on reading comprehension. The effect of early literacy was not reliable, and the direct effect of verbal intelligence was very small. The working-memory construct had a strong direct influence on phonological recoding in lexical access, thereby indirectly affecting reading comprehension. Similarly, verbal intelligence and phonological awareness had an additional indirect impact on reading comprehension via their direct influence on the phonological recoding in lexical access and early literacy variables. However, these indirect effects were almost negligible. In total, about 47 per cent of the variance in reading comprehension was explained by Model 3.

In a final step of analysis, the 'nonsense' model described above was estimated and tested. As expected, no acceptable data fit was obtained for this model (chi-square = 155.10, df = 94, $p < .001$). It was good to see that this model fitted the data significantly worse than the regression model which also yielded an unacceptable fit.

PREDICTION OF SPELLING

The procedure used to determine the best-fitting model predicting spelling performance in second grade was identical to that used for the prediction of reading comprehension. In a first step, a regression model based on latent predictors was estimated and tested. The regression model did not fit the data (chi-square = 198.96, df = 94, $p < .001$). Given the extremely poor data fit, this model will not be discussed further.

In a second step, the two path models specified above were estimated and tested. Interestingly, Model 3 did not fit the spelling data very well (chi-square = 116.17, df = 95, p = .06). On the contrary, Model 2 representing the temporal sequence of data collection yielded an acceptable data fit (chi-square = 103.04, df = 94, p = .25). As the data fit for this model was significantly better than that for Model 3 the LISREL solution (structural coefficients only) for Model 2 is given in Figure 13.3.

As can be seen from Figure 13.3, the structural pattern describing and explaining spelling performance differs considerably from that describing and explaining the reading-comprehension variable. A certain advantage of Model 2 over Model 3 is that working memory and phonological awareness serve as dependent variables and can be explained in the model. Obviously, verbal intelligence does not only have a strong direct effect on working memory but also directly influences the phonological recoding in lexical access variable. Thus, while verbal intelligence does not directly affect spelling, its indirect impact on the criterion variable is essential. There is little doubt that the total effect of verbal intelligence on spelling is at least comparable to that of verbal intelligence on reading comprehension.

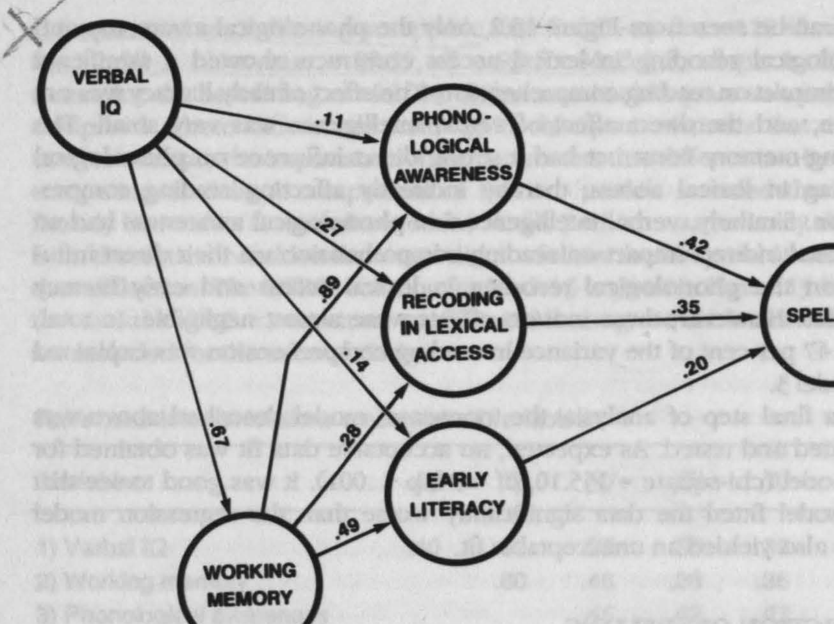

Figure 13.3 Best-fitting structural equation model for the spelling construct

Similarly, the working-memory construct plays an important role in that it strongly affects phonological awareness and early literacy. Moreover, working memory directly influences phonological recoding in lexical access. Again, no direct effect of working memory on the criterion variable was observed. Compared to the reading-comprehension model, the direct effects of phonological recoding in lexical access on spelling are larger, and the direct impacts of early literacy and phonological awareness on spelling are more pronounced. Taken together, the various predictor measures explained about 62 per cent of the variance in the criterion variable.

Last not least, it should be noted that the 'nonsense' model specified for the spelling data was far away from fitting the data (chi-square = 176.87, df = 95, $p < .001$). Again, we were glad to see that the data fit obtained was significantly worse than that of all other competing models.

DISCUSSION

The major aim of the present study was to explore the relative impacts of three phonological processing components (i.e., phonological awareness, phonological recoding in lexical access, and phonetic recoding in working memory) assessed during the kindergarten years on reading comprehension and spelling as measured at the end of second grade. Further questions of main interest were whether individual differences in verbal intelligence and early literacy would contribute significantly to the prediction of both reading comprehension and spelling, and whether different causal (structural) patterns have to be specified in order to explain reading comprehension versus spelling outcomes.

Taken together, the results of the LISREL models seem straightforward in that (1) significant effects of the three phonological processing skills described above on both reading comprehension and spelling could be demonstrated; (2) both verbal intelligence and early literacy significantly contributed to the prediction of both outcome variables; and (3) the causal models showing the best data fit differed for the reading comprehension and spelling criterion measures.

Our findings seem to square well with the existing literature in several regards. First, they demonstrate that the direct effect of intelligence on reading comprehension or spelling is moderate at best when more specific indicators of metalinguistic skills are simultaneously considered (cf. also Bryant and Bradley 1985; Stanovich, Cunningham, and Feeman 1984). This does not mean, however, that the role of verbal intelligence can be neglected, as the visual inspection of the regression model depicted in Figure 13.1 would lead one to suggest. On the contrary, the LISREL solutions shown in Figures 13.2 and 13.3 demonstrate that, by influencing various phonological skills, verbal intelligence does have an indirect effect on both reading comprehension and – even more pronounced – on spelling performance.

Second, and related to this, the strong impact of working memory or memory capacity on the acquisition of literacy emphasized in many recent publications (e.g., Mann 1984; Swanson, Cochran, and Ewers 1989; Yuill, Oakhill, and Parkin 1989) was also confirmed in our study. Again, the multiple regression estimates for this variable were less impressive than the solutions obtained for the causal modelling approach which point to the importance of indirect influences of memory capacity on related phonological processing skills.

We should note here that our memory-span tasks are essentially measures of capacity. As indicated by Swanson *et al.* (1989), the sentence-span task does not separate the storage and processing components of working memory and therefore makes interpretations of performance differences between reading groups difficult. However, we agree with Swanson *et al.* in that the task is appropriate for determining the contribution of information stored in long-term memory to working-memory performance, which seemed to be essential for our theoretical frame of reference.

A comparison of data fit obtained for the traditional multiple regression model and the two theoretically plausible path models reveals that the regression model did not fit the data very well, regardless of whether the reading comprehension or spelling model was concerned. It is obvious that the basic theoretical assumption of the regression model, namely independence of predictor variables, was not met in our study. There is reason to assume that this assumption does not hold for most research in this field, and that the problem of multicollinearity may have been underestimated in many studies. As a consequence of such a bias, overestimations of explained variance in the criterion variables may result. This is at least what we found when we compared the results of multiple regression analyses based on observed variables with analyses based on the latent variable approach. While more than 70 per cent of the criterion variance could be explained in the analyses based on observed variable, not more than 45 per cent of the variance in the criterion variable was accounted for by the predictors included in our LISREL analyses. It appears to us that the latter represents a more accurate estimate of the true relationship.

Still, a few caveats regarding the status of causal modelling analyses seem in order. First, the few LISREL analyses available in the literature share the problem of small sample sizes (cf. Lomax and McGee 1987; Torneus 1984). Our study does not provide an exception, at least not with regard to the reading comprehension data. Replication studies based on independent, larger samples are therefore badly needed to validate the findings presented in this chapter.

Moreover, the question of appropriate alternative models is not trivial. In our case, this means that a number of additional conceptualizations seem intuitively plausible and can be principally tested via causal modelling procedures. For example, we could assume a causal path from phonological awareness to early literacy or reverse the relationship and postulate that the familiarity with print predicts the quality of phonological awareness (see Valtin 1984, for a detailed discussion of this point). We actually did so and estimated such models, which yielded unacceptable data fit.

To summarize, the major outcome of the present study was that components of phonological processing skills represent important prerequisites for the development of subsequent reading and spelling skills. While the strength of the interrelationship seems to vary as a function of the skill under consideration, all of these components function as reliable predictors of reading and spelling skills developed early in the schooling process. It would be premature, however, to generalize this finding across the whole period of elementary school. Recent findings by Butler *et al.* (1985) and Juel (1988) indicate that, while phonological processing skills measured in kindergarten influence reading in early primary grades, early reading achievement seems to be the major determinant of later reading performance.

ACKNOWLEDGEMENTS

We would like to thank Hans Brügelmann and Werner Zielinski for their helpful comments on an earlier version of this chapter.

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