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Predicting Individual Differences in Learning to Read

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Any complete theory of learning to read must explain individual differences in reading development. Studies of individual differences in early reading achievement point to key processes and abilities that may underpin reading success and failure that may ultimately help us to optimize instruction. Such studies have a long history and have attracted a huge amount of research. This review must of necessity be selective and will focus on key research areas in relation to the first few years of alphabetic reading.

Methodological Issues

Assessing the predictors of individual differences in learning to read involves longitudinal studies where a predictor variable (or variables) at one point in time (t_1) is related to reading at a later time (t_2). Where reading ability is unstable, key measures assessed at school entry will predict less variance. Predictive studies from small groups, such as single classes and perhaps even single schools, may be unreliable and, at worst, biased by the effects of particular instructional contexts. Studies of single classes and of fewer than 50 children have thus generally been excluded from this review.

The ultimate goal of reading is to understand continuous text. The higher-level processing required for this is interrupted when attention is diverted to lower-level word identification processes. Indeed, even when reading is accurate, if it is effortful, the higher-order processes involved in reading comprehension will be affected. Therefore, predictive studies of children learning to read English have typically used word reading accuracy (rather than reading rate) as a criterion measure.

Phonological recoding refers to the ability to pronounce unfamiliar printed words. In alphabetic scripts letters symbolize phonemes, so that skilled readers can decode newly encountered regular words. About 80% of English words can be considered regular for reading purposes (Woodcock, 1987) and, apart from strange words like *aisle* and *choir*, even exception words like *prove* and *break* contain regularities. To a considerable extent, therefore, learning to read regular and exception words involves common processes, particularly given that context and vocabulary can supplement partial phonological recoding in identifying unfamiliar words. Mastery of alphabetic reading thus entails the ability to use letter-sound correspondences to pronounce unfamiliar items *de novo* and provides the learner with what has been called a "*self-teaching device*" (Share, 1995). Phonological recoding is typically studied experimentally by asking children to read aloud nonwords, which are by definition unfamiliar. Nonword reading and word reading accuracy share 66–77% of variance in beginning readers (Bowey, 2000).

The fact that word reading is the usual criterion in predictive studies is not especially problematic when studying beginning readers who typically read simple texts containing vocabulary that is easily understood. At this stage of development, word identification and reading comprehension share 61–81% of variance (Bowey, 2000). As texts become conceptually more demanding, the variance shared by word identification and reading comprehension decreases (to 45–66% from fourth grade on; Bowey, 2000) and listening comprehension accounts for increasing variance in reading comprehension (Curtis, 1980). In addition, general cognitive and language abilities may strongly predict reading comprehension in older readers (Flynn & Rahbar, 1998).

A particular methodological issue posed by predictive studies is that of autoregressive effects – the tendency of a variable measured at t_1 to predict itself at t_2. On a philosophical level, it may be argued that abilities cannot cause themselves, and thus that it makes no sense to control the effects of t_1 reading within predictive studies. Such a view ignores the fact that *reading as a construct changes over time* (see Cronbach & Furby, 1970). Even when measured by the same test (e.g., word identification), reading does not necessarily represent the same cognitive process at different points in development; different processes contribute to performance as proficiency increases. Some cognitive processes drop out and are replaced by qualitatively different processes (Stuart & Coltheart, 1988). For instance, children may reconceptualize their way of thinking about spoken words once they have begun to read and they have begun to attend to phonemes (Morais & Kolinsky, this volume). When t_1 reading effects are ignored, abilities that are the product of early reading at t_1 may show inflated contributions to t_2 reading. Controlling t_1 reading effects also minimizes the possibility that predictive associations reflect the contribution of any third variable(s).

Autoregressive reading effects are far from trivial. Torgesen and Burgess (1998) found that word reading, tested early in US kindergarten, predicted 42% of variance in early first-grade word reading. This in turn predicted 58% of variance at the beginning of second grade (n = 201). Even in school entrants not yet exposed to reading instruction, early reading predicts considerable variance in later reading skill (e.g., Lundberg, Olofsson, & Wall, 1980; Wimmer, Landerl, Linortner, & Hummer, 1991).

A related issue, frequently overlooked, is that the prediction of reading from t_1 to t_2 depends on the starting level at t_1 even when growth from t_1 to t_2 is linear. Ideally, the prediction of reading skill should be examined by modeling both individual differences in starting levels and individual differences in growth using a number of time intervals (Rogosa & Willett, 1985). However, t_1–t_2 designs are a useful first step, provided that t_1

reading effects are controlled and that it is acknowledged that findings may not generalize to other values of t_1 and t_2. Testing words that are common in beginning reading materials provides more sensitive measures of early reading ability (Bowey, 1994a, 1995; Ehri & Wilce, 1985; Johnston, Anderson, & Holligan, 1996) than standardized tests that sample very few items at the beginner levels and are subject to floor effects (e.g., Wagner, Torgesen, & Rashotte, 1994; Wagner et al., 1997).

In fact, few predictive studies have properly controlled t_1 reading effects. Studies also vary widely in their inclusion of other control variables (e.g., general cognitive ability). This chapter thus begins by examining simple correlations between key predictors, assessed in kindergarten children or school entrants, and later reading skills. Somewhat different conclusions may be reached in predictive studies that start later when children have more advanced reading skills. It should be noted that studies that do not control the effects of t_1 reading may overestimate the contribution to later reading of other variables that correlate with early reading ability.

Findings from predictive studies that include t_1 control variables (e.g., general cognitive or verbal abilities) are often overinterpreted. Suppose a study controls the effects of t_1 letter knowledge when predicting t_2 reading from t_1 phonological sensitivity in school entrants with no measurable word reading ability. Assume that t_1 letter-name knowledge and phonological sensitivity share substantial variance and that both predict substantial variance in t_2 word reading (assumptions that are completely consistent with research findings; Naslund & Schneider, 1996). Now assume that, with t_1 letter-name knowledge effects controlled, t_1 phonological sensitivity predicts no independent variance in t_2 word reading. This finding only implies that the variance in t_2 word reading predicted by t_1 phonological sensitivity covaries with that explained by t_1 letter-name knowledge. It does *not* indicate that t_1 phonological sensitivity makes no contribution to t_2 word reading. The effects of t_1 phonological sensitivity on t_2 word reading may be mediated by t_1 letter-name knowledge (see Baron & Kenny, 1986). However, this conclusion is also premature. Assume that further analysis suggests that the effects of t_1 letter-name knowledge on t_2 word reading may be partly or wholly mediated by t_1 phonological sensitivity. Because letter-name knowledge and phonological sensitivity were measured at the same time, even findings that only t_1 letter-name knowledge predicts unique variance in t_2 word reading cannot be causally interpreted. Note that the example above is hypothetical; Naslund and Schneider (1996) found that results varied in predictive analyses of this type, depending how phonological sensitivity was assessed ($n = 89$).

Thus, when different predictors correlate with each other, we must be wary of ever concluding that only one predictor explains independent variance when the effects of other predictors are controlled. Such conclusions may be especially unreliable in studies using single tests of each construct and with relatively small participant-to-test ratios in which outcomes may be influenced by a range of extraneous factors (including the heterogeneity of the group tested, test sensitivity, and method variance; see also Anthony et al., 2002).

Latent variables are sometimes used to avoid the measurement error associated with the use of a single test to assess a particular construct. Latent variables comprise the common variance among measures of a particular construct, thus excluding variance that is unique to a single variable, such as measurement error, unique method variance, and the unique contributions of other abilities. However, latent variables are not free of the common contribution of general cognitive ability. Furthermore, latent variables are not necessarily pure measures of a construct. When derived from a small number of fairly similar tasks, they include method variance. For instance, Wagner et al.'s (1994) treatment of phonological analysis and blending as highly correlated but different constructs may reflect failure to consider common method variance within some of the tasks defining them (Schatschneider, Francis, Foorman, Fletcher, & Mehta, 1999). In subsequent analyses, these two latent variables were combined into a second-order phonological sensitivity latent variable, "to acknowledge that analysis and synthesis represent the same construct of phonological awareness" (Wagner et al., 1997, p. 472).

Even when latent variables are used, findings that only one t_1 skill uniquely predicts t_2 reading should be interpreted conservatively. If t_1 predictors assess common abilities, these findings may simply indicate that the measures explain redundant variance in reading. Furthermore, findings that any given predictor does or does not explain unique variance are *relative* to a particular analysis, and may depend on the relationships among the variables included within a given study. Uniqueness cannot be compared across studies that assess constructs differently or use different combinations of control variables. It may thus be useful to perform commonality analyses, which partition variance in t_2 reading that can be attributed uniquely to each t_1 predictor and variance that can be attributed to various combinations of t_1 predictors (see Pedhazur, 1982).

A common misconception is that variables that predict large amounts of variance in t_2 reading can accurately identify poor readers at t_2. However, predictors that are salient at the upper end of the reading continuum may exert little influence at the lower end. For instance, even if they explain considerable variance in t_2 reading, t_1 tasks like phoneme segmentation that are extremely difficult for substantial numbers of school entrants are not likely to identify future poor readers accurately. Often children scoring at floor on phoneme segmentation become successful readers (e.g., Perfetti, Beck, Bell, & Hughes, 1987; Wagner et al., 1994).

To determine whether t_1 performance accurately identifies poor readers at t_2 requires a quite different form of analysis (see Gredler, 1997). Torgesen and Wagner (1995, cited in Torgesen & Burgess, 1998) combined three measures taken at the beginning of kindergarten (phoneme deletion, letter-name knowledge, and continuous digit naming speed) to predict the children in the bottom 10% in word reading at the beginning of second grade. Using logistic regression techniques, 23 children of 240 children were predicted to be poor readers by second grade. Of these 23 children, 14 were indeed in the bottom 10% at the beginning of second grade. Of the 217 predicted to be reading above the bottom 10% at the beginning of second grade, 207 were. Predictive outcome analyses (Gredler, 1997) indicate that this procedure was poor at predicting poor readers.

Although rarely performed, predictive outcome analyses reveal the danger of placing high levels of confidence in screening or readiness tests. Accurate early prediction of future poor readers may be doomed to failure, as it cannot account for subsequent variance in other critical factors such as the quality of instruction that the child receives, the frequency of school changes, school attendance, and so on. It is probably more appropriate to investigate how to optimize reading instruction for all children, and for teachers to keep a firm eye on children who are falling behind so that, wherever possible, directly relevant instruction can be focused on difficulties as they occur.

Key Predictors of Early Reading Ability

General cognitive ability

General cognitive ability typically predicts success best early in skill acquisition, before more specific skills required for efficient processing have been learned or mastered (Sternberg, 1981). Many of the earliest attempts children make to read comprise associating distinctive graphemic cues with whole words (Seymour & Elder, 1986) and may depend on general cognitive ability (Stuart & Coltheart, 1988). In kindergarten children without even informal reading instruction, Bowey (1995) found that general cognitive ability predicted 15–22% of variance in first-grade reading (n = 116; see also de Jong & van der Leij, 1999).

As the beginner is faced with graphemically similar words, the strategy of rote memorization using distinctive graphemic cues becomes ineffective, and specific abilities and mechanisms become increasingly important. Thus, with time, abilities contributing to both phonological recoding and "back-up" strategies (e.g., the use of context) better predict word reading, although these may be mediated by general cognitive ability.

All tests of specific abilities incorporate extraneous task-specific cognitive demands. For example, phoneme reversal requires children to analyze spoken words into their constituent phonemes, hold the phonemes in phonological memory, reverse them in working memory, and then say them back in the reverse order. Phoneme reversal is not a "clean" test (Calfee, 1977); it probably taps general cognitive abilities as well as phoneme manipulation.

Controlling t_1 general cognitive ability allows an assessment of whether t_1 experimental measures predict variance in t_2 reading independently of extraneous task-specific requirements. Without such controls, findings are ambiguous. A t_1 ability may predict t_2 reading only by virtue of its shared variance with other cognitive abilities. Nevertheless, findings that t_1 general cognitive ability predicts t_2 word reading are not particularly informative about the underlying basis of reading achievement (see Sternberg, 1981).

Verbal ability

Stanovich (1991) advocated the use of verbal ability, rather than general cognitive ability, to determine which abilities make specific contributions to reading. Verbal ability may control better for the particular task requirements involved in tests of phonological processing abilities that are the focus of most current research. Indeed, it is well established that preschool language development predicts *later* reading achievement within normally developing children (Bryant, Maclean, & Bradley, 1990a; Silva, McGee, & Williams, 1985), and teachers' ratings of early language development can also predict later reading achievement well (Feshbach, Adelman, & Fuller, 1974; Lundberg, 1985). However, such findings are not helpful in determining what aspects of language development contribute to reading.

Vocabulary typically predicts early reading achievement (Bowey, 1995; Bryant et al., 1990a; Caravolas, Hulme, & Snowling, 2001; Cronin & Carver, 1998; Elbro, Borstrom,

& Petersen, 1998; Hurford et al., 1993; Hurford, Schauf, Bunce, Blaich, & Moore, 1994; Naslund & Schneider, 1996; Share, Jorm, Maclean, & Matthews, 1984; Stevenson, Parker, Wilkinson, Hegion, & Fish, 1976; Stevenson & Newman, 1986; Wagner et al., 1994; Wagner et al., 1997; Wolf & Goodglass, 1986; cf. Foorman, Francis, Novy, & Liberman, 1991). Bowey (1995) found that receptive vocabulary in kindergarten children who could not yet read predicted 20–27% of variance in end-of-first-grade reading (n = 116).

Although less commonly studied, children's grammatical development also predicts early reading achievement (Bowey, 1995; Scarborough, 1990; Share et al., 1984). For instance, Share et al. (1984) found that grammatical development at the beginning of kindergarten explained 17% of variance on a composite reading achievement factor at the end of first grade (n = 479).

Bryant et al. (1990a) asked children to correct minor grammatical errors or rearrange jumbled sentences to form coherent ones. Performance on this task, at 4:7, explained 40% of variance in word identification two years later. Sentence rearrangement is not a pure test of grammatical sensitivity and also assesses children's semantic processing and verbal working memory (Bowey, 1994b; Bryant et al. 1990a); nevertheless this task clearly assesses verbal ability.

Even when assessed in kindergarten, both vocabulary and grammatical development become increasingly important predictors as reading progresses (Flynn & Rahbar, 1998). In nonreaders, phonological processing abilities like phonological sensitivity and phonological memory probably develop concomitantly with language development and may thus account for little variance in subsequent reading that is independent of the effects of language development (see Bowey & Patel, 1988). It is not clear at the present time to what extent different facets of oral language development (including vocabulary, grammatical, and phonological skills) can be meaningfully separated and how best to conceptualize the underlying causal relationships between different constructs in this domain. For example, some have argued that tests of language development may partly reflect the contribution of underlying abilities such as phonological memory (see Baddeley, Gathercole, & Papagno, 1998; Ellis & Large, 1987) or phonological processing ability (Bowey, 2001; Elbro et al., 1998).

Phonological memory

Verbatim sentence memory reliably predicts later reading (Badian, 2000; Bruininks & Mayer, 1979; Bryant et al., 1990a; Catts, Fey, Zhang, & Tomblin, 2001; Kurdek & Sinclair, 2001; Share et al., 1984), although it may sometimes be confounded with grammatical development (but see Baddeley et al., 1998). Badian (2000) reported that verbatim sentence recall measured in kindergarten predicted 22% of variance in word reading and 25% in reading comprehension in first grade (n = 98; see also Share et al., 1984). It also predicted 40% of variance word reading and 31% in reading comprehension in fourth grade (n = 98).

Auditory word span in kindergarten children and school entrants also consistently predicts later reading (Bowey, 1995; Caravolas et al., 2001; de Jong & van der Leij, 1999;

Elbro et al., 1998; Mann & Liberman, 1984; Stevenson et al., 1976; cf. Naslund & Schneider, 1996). Nonword repetition is another measure that predicts early word and nonword reading both in children learning to read English (Baddeley & Gathercole, 1992; Bowey, 1995) and shallow orthographies (de Jong & van der Leij, 1999; Naslund & Schneider, 1996). Although nonword repetition has been proposed as a pure measure of phonological memory (Baddeley et al., 1998; Gathercole, Willis, Baddeley, & Emslie, 1994), it also incorporates substantial phonological processing (Bowey, 2001; Snowling, Chiat, & Hulme, 1991; Snowling, Goulandris, Bowlby, & Howell, 1986).

The predictive association between phonological memory and later word reading has been interpreted in several ways. Phonological memory may allow children to learn to associate letters with their names and sounds (Baddeley & Gathercole, 1992; Share et al., 1984). Alternatively, letter sounds may be held in phonological memory so that they can be blended into words. On the other hand, it could be argued that phonological memory makes no specific contribution to word reading. Rather, the predictive association between phonological memory and later reading may be mediated by verbal ability. Consistent with this view are findings that verbal span predicted later reading better than visual span (Caravolas et al., 2001; Stevenson et al., 1976) and that phonological memory predicted no variance in later word reading once earlier word reading, vocabulary, and other phonological processing abilities were controlled (n = 216; Wagner et al., 1997).

A parsimonious explanation of the predictive link between phonological memory and later word reading is the hypothesis that both skills reflect the quality of phonological representations (e.g., Brady, 1991; Wagner & Torgesen, 1987; Wagner et al., 1994; Wagner et al., 1997). Consistent with this view are findings that virtually any task that requires effortful phonological processing predicts early later word reading.

Speech perception and production

Kindergarteners' and school entrants' ability to discriminate between spoken syllables and words differing by a minimal phonemic contrast predict later reading (Bond & Dijkstra, 1967; Bruininks & Mayer, 1979; Horn & O'Donnell, 1984; Hurford et al., 1993, 1994; Stevenson & Newman, 1986; Stevenson et al., 1976). Bond and Dijkstra (1967) reported that phoneme discrimination, tested at the beginning of first grade, predicted 20–35% of variance in end-of-year word identification and 17–32% of variance in reading comprehension (n = 488–4,266). These values were higher among methods incorporating some phonics instruction (29–35% for word identification; 25–32% for reading comprehension), relative to language experience and basal reader programs (20–23% for word identification; 17–21% for reading comprehension).

Tallal (1980) suggested that poor readers show more general auditory processing deficits and that they perform poorly on temporal order judgment tasks. However, temporal order judgment is arguably not an auditory perception task (Studdert-Kennedy & Mody, 1995). Regardless, Share et al. (1984) found kindergarten temporal order judgment to predict only 6% of variance in reading at the end of first grade (n = 479).

Articulation errors reflect speech production difficulties, although in a developmental context a child's articulation errors might be traced to faulty speech perception.

Scarborough (1990) found that consonant errors in spontaneous speech at 30 months predicted reading in grade 2, even after controlling IQ. Silva and colleagues (1985) found that 9-year-old boys with general word reading backwardness had scored lower than average on articulation when tested at age 5 (Silva et al., 1985). Elbro et al. (1998) found that the distinctness with which Danish children pronounced unstressed vowels within phonologically complex words at the beginning of kindergarten predicted variance in word reading at the end of first grade. This finding held even with the effects of letter knowledge, phonological sensitivity, digit span, receptive vocabulary, and family background factors controlled.

These findings, from studies of speech perception and production, like those from studies of phonological memory described earlier, are consistent with the proposal that early phonological processing skills predict later reading.

Phonological sensitivity

Many studies have demonstrated that phonological sensitivity in kindergarten children and school entrants predicts later word-reading ability. Recent work has attempted to discover what *level* of phonological sensitivity (syllable, rime, phoneme) is needed to learn to read an alphabetic script.

In the absence of controls for initial reading levels, kindergarten children's and school entrants' ability to count and manipulate syllables in spoken words predicts later reading ability (Badian, 2000; Mann & Liberman, 1984). However, findings vary with task requirements (Lundberg, Frost, & Peterson, 1988; Naslund & Schneider, 1996). Onset and rime sensitivity is a better predictor of later word reading in children learning to read English than syllabic sensitivity (Bryant, Maclean, Bradley, & Crossland, 1990b; Byrne, Fielding-Barnsley, & Ashley, 2000; Cronin & Carver, 1998; Majsterek & Ellenwood, 1995; cf. Hulme et al., 2002). Indeed, onset and rime sensitivity predicted later word reading in four cohorts of children who could not identify any words on a standardized reading test at initial assessment (Bowey, 1995; Bradley & Bryant, 1983; Maclean, Bryant, & Bradley, 1987).

At a smaller unit level, phoneme manipulation consistently predicts later word reading irrespective of whether children are exposed to formal reading instruction in kindergarten (e.g., Foorman et al., 1991; Juel, Griffith, & Gough 1986; Lundberg et al., 1980; Perfetti et al., 1987; Wimmer et al., 1991, Study 1). However, such findings may be inflated by the effects of early reading skills on phoneme manipulation. For instance, Lundberg et al. (1980) found that kindergarten phoneme manipulation tasks predicted over 20% of variance in first-grade word reading rate (n = 143) and over 16% in second-grade word reading rate (n = 133). However, when kindergarten reading effects were controlled, most tasks failed to predict later reading (Wagner & Torgesen, 1987). Moreover, some have argued that phoneme manipulation cannot be a prerequisite for alphabetic reading (Morais, Cary, Alegria, & Bertelson, 1979; Stanovich, 1992). Alphabetically illiterate adults cannot perform these tasks (Morais, Bertelson, Cary, & Alegria, 1986; Morias et al., 1979), and many school entrants who score at floor on phoneme manipulation tasks become successful readers (Perfetti et al., 1987; Wagner et al., 1994; Wimmer et al., 1991).

Rather, a key prerequisite for learning to read an alphabetic script may be the facility with which children *learn* to attend to and manipulate phonemes, usually within the context of reading instruction (Morais et al., 1979; Wimmer et al., 1991). Consistent with this suggestion is the finding that preschool children's responsiveness to phoneme identity training predicted 8–19% of variance in fifth-grade reading, even with post-training phoneme identity effects controlled (n = 56; Byrne et al., 2000). So, too, is Spector's (1992) finding that a dynamic measure of phoneme segmentation given early in kindergarten predicted 36% of variance in end-of-year word identification, while a standard measure given at the same time predicted only 14% (n = 38).

The capacity to learn to manipulate phonemes may be well predicted by an earlier ability to recognize the similarity of onsets and rimes in spoken words (Bryant et al., 1990a; Bryant et al., 1990b). Byrne et al. (2000) provided indirect evidence that children who were not responsive to their preschool phoneme identity training program scored low in rime identity. Children who became poor readers in fifth grade scored lower than other children on pre-intervention rime, but not on pre-intervention vocabulary, phoneme identity, or letter knowledge or on post-intervention phoneme identity or decoding. Further work investigating this suggestion is clearly required.

There has been considerable controversy over whether onset-rime sensitivity or phoneme sensitivity better predicts later word reading (e.g., Bryant et al., 1990b; Hulme et al., 2002; Muter, Hulme, Snowling, & Taylor, 1998). The answer to this question varies with the developmental level of the child (Bowey, 2002), since the best measure of the construct of phonological sensitivity will vary with the age of the child and especially with the level of exposure to reading instruction (Anthony et al., 2002; Schatschneider, et al., 1999). When predictive studies are carried out with school entrants with some understanding of the alphabetic principle or some reading ability, phoneme sensitivity is likely to explain more variance in later reading. The opposite may be true in younger children and in children who cannot yet read. Bowey (1995) found that, within kindergarten children who could not yet read, final phoneme identity predicted 14–19% of variance in first-grade reading but onset and rime identity predicted 24–28% (n = 116; see also Byrne et al., 2000). The strength of predictive associations between early phoneme sensitivity and later reading may also differ in children taught to read by different methods. Alegria, Pignot, and Morais (1982) found that, midway through first grade, phoneme reversal was correlated with concurrent teacher-rated reading ability in a small group of children taught to read French by phonics methods (n = 32), but not in children taught using a whole-word method (n = 32). The phonics group also scored higher on phoneme reversal, but not on syllable reversal.

Some studies have gone beyond the question of the level of phonological sensitivity that best predicts reading to examine different phonological sensitivity tasks. Sound blending is crucial to readers who are still acquiring phonological recoding skills. In children not taught to read until first grade, syllable blending at the end of kindergarten is associated with later word reading rate (Lundberg et al., 1980; Naslund & Schneider, 1996). Majsterek and Ellenwood (1995) found that a simplified sound blending task given before kindergarten predicted 15% of variance in second-grade nonword reading and 21% of variance in word identification (n = 76). Wagner et al. (1994) found that a latent sound blending variable, formed from onset-rime and phoneme blending tasks at the beginning of US kindergarten, predicted 35% of variance in word reading one year later (n = 244). At the beginning of first grade, sound blending predicted 61% of variance in word reading one year later (Wagner et al., 1994; see also the basal reading group studied by Perfetti et al., 1987). However, sound blending and reading shared considerable common variance at initial assessment (Wagner et al., 1994; see also Lundberg et al., 1980).

Although Wagner et al. (1994) reported that phonological analysis and blending comprised separate but very highly correlated factors in US kindergarten children (n = 244; see also Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993), it is highly likely that they constitute a single factor (Wagner et al., 1997). Well-designed factor-analytic studies suggest that there is a single phonological sensitivity factor (Anthony et al., 2002; Schatschneider et al., 1999; Stahl & Murray, 1994). With the effects of prior reading, verbal ability, and other phonological processing abilities controlled, phonological analysis and blending at the beginning of kindergarten or first grade, when treated as a single higher-order factor, predicted unique variance in word reading two years later (n = 216; Wagner et al., 1997). Similarly, studies teaching phonological sensitivity and phoneme manipulation in isolation from letter knowledge and reading instruction to kindergarten children with minimal knowledge of letters or reading definitively show that phonological sensitivity contributes directly to reading (Lundberg et al., 1988; Schneider, Kuspert, Roth, & Vise, 1997; see Ehri et al., 2001).

Recent research has increasingly questioned whether phonological sensitivity predicts early reading development in all alphabetic languages. Generally, findings have not been as strong in children learning to read shallow orthographies. Naslund and Schneider (1996) gave German kindergarten children tests of initial phoneme detection, rime detection, onset-rime oddity, and onset-rime blending. Only rime detection (16%) and onset-rime oddity (42%) predicted variance in a composite literacy measure administered at the end of second grade (n = 89). With early letter-sound knowledge effects controlled, rime detection explained 8% of independent variance in second-grade reading, and onset-rime oddity explained 27%. In Dutch children, de Jong and van der Leij (1999) found that rime oddity, tested at the beginning of kindergarten, predicted 13–16% of variance in second-grade reading rate. However, rime oddity did not predict variance in later reading independently of early letter knowledge and general cognitive ability (n = 82). The consistency of the orthography and the direct code methods frequently used to teach decoding skills in Dutch and German children may counteract the effects of individual differences in school entrants' letter knowledge and phonological sensitivity (de Jong & van der Leij, 1999; Wimmer, Mayringer, & Landerl, 2000).

Letter-name knowledge

The letter-name knowledge of school entrants strongly predicts their later reading achievement. For instance, Bond and Dijkstra (1967) reported that letter-name knowledge at the beginning of first grade predicted 26–36% of variance in end-of-year word identification and 26–35% of variance in reading comprehension (n = 488–4,266). It predicted more variance in word identification when reading instruction incorporated some phonics instruction (31–36%; n = 488–1,104), relative to language experience and basal reader programs (26–30%; n = 1431–4,266).

At its most basic level, letter knowledge implies an ability to represent in memory letters that differ from others in few distinctive ways (e.g., *n* vs. *u*, *m*, *h*, and *r*). Children who cannot discriminate and remember individual letters cannot learn to read an alphabetic script, whereas children who can effortlessly identify and name individual letters should find it easier to learn to associate sound values with them (Adams, 1990; Ehri, 1983; Share et al., 1984).

If letter-name knowledge per se makes a direct contribution to word reading, then teaching kindergarten or first-grade children letter names should enhance word reading. However, letter-name training does *not* typically transfer to early word reading (see Samuels, 1971), making it difficult to interpret at face value the predictive effects of letter-name knowledge on later reading. So, too, do suggestions that letter-name knowledge reflects other variables, such as interest in learning to read, exposure to book-reading, and informal reading instruction in the home, which may also contribute to reading success (Adams, 1990).

Some children who are surrounded by print are familiar with letters as symbols for sounds long before formal reading instruction begins (Burgess & Lonigan, 1998). For them, letter knowledge may reflect a rudimentary understanding of the alphabetic principle (Adams, 1990; Lukatela, Carello, Shankweiler, & Liberman, 1995; Morais, 1990). Ellis and Large (1988) commented that "Letter recognition is the ubiquitous entry point to the acquisition of reading, and those that have taken this step are henceforth apprentice readers" (p. 61). Bowey (1994a) found that in children not yet actually taught to read letter knowledge was associated with word reading, sharing 27% of variance, even though 79% scored at floor on the reading test (n = 96; see also Wimmer et al., 1991).

In children exposed to a range of literacy-related activities at home, letter-name knowledge may also reflect general cognitive ability, especially if letter names are not explicitly taught (Bowey, 1994a, 1995). De Jong and van der Leij (1999) found that letter knowledge and general cognitive ability, tested a year before formal reading instruction began, predicted considerable common variance in reading at the beginning of first grade (n = 166).

Given that teaching letter names does not necessarily enhance reading and the difficulties in interpreting letter-name knowledge (Adams, 1990; Calfee, 1977), letter-name knowledge is often omitted from predictive studies of early reading skill or from key analyses (e.g., Wagner et al., 1994; Wagner et al., 1997). It is not clear whether or not letter knowledge effects should be controlled within predictive studies. When they are, findings should be interpreted cautiously, as letter knowledge effects may be mediated by, or act in concert with, other variables.

Phonological sensitivity and letter knowledge co-determine early reading ability

Phonological recoding, arguably the key skill to be acquired in early alphabetic reading, presupposes comprehension of the alphabetic principle – that letters represent sound. This understanding itself presupposes some level of phonological sensitivity; the alphabetic insight is not logically possible without *some* ability to attend to sounds within spoken words. Moreover, an understanding that the initial sounds of *mat* and *mop* are equivalent (*onset identity*) is required for children to understand why the letter *m* is used in the printed form of both words (Byrne, this volume). Without this understanding, the fact that *man*, *mop*, and *mud* all begin with the letter *m* may appear coincidental.

Even before formal reading instruction, some children discover for themselves the nonarbitrary, alphabetic, nature of the associations between letter names and the letters used to represent sounds within printed words, provided that they know letter names and have some phonological sensitivity. They first appear to notice similarities between letter names and parts of spoken words – this *is* phonological sensitivity. Treiman, Tincoff, and Richmond-Welty (1996) reported that two thirds of 5-year-old US preschoolers with no formal reading instruction said that the spoken word *beach* begins with the letter *b* (/bi/). One third said that *seem* begins with the letter *c* (/si/). Children also found it easier to say that *beach* begins with the letter *b* (/bi/), relative to *boat*. Byrne and Fielding-Barnsley (1989) found that 4-year-old nonreaders taught to read just two words (e.g., *mat* and *sat*) could not say which of the two printed words *mow* and *sow* corresponds to the spoken word /mou/ unless they were taught *both* to understand that *mat* and *mow* start with the same sound /m/ and the sounds of the letters *m* and *s*.

If some children who know letter names and who have some phonological sensitivity discover the alphabetic principle for themselves, prior to formal reading instruction, then children who can effortlessly name letters and who possess some understanding of at least onset identity should find it easier to understand the alphabetic principle when it is explicitly taught. Children familiar with both letter names and the alphabetic principle and with well-developed phonological sensitivity profit from reading and spelling instruction that teaches the sound values of letters and digraphs. In addition to meaningful and enjoyable reading activities, good early literacy instruction should teach children to attend to the sounds within spoken words to supplement the teaching of letter-sound correspondences and sound blending (Adams, 1990).

In English, letter names are often good clues to the names and sounds of letters within printed words (e.g., /bi/ within the word *beach* is identical to name of the letter *b*, and the sound for the letter *b* within the word *boat* is the onset of the letter *b*'s name). Once they have understood the alphabetic principle, phonological sensitivity and letter-name knowledge together help *some* children to derive letter sounds for themselves. For instance, beginners may spell words beginning with /w/ with the letter *y*, deriving the sound from the onset of the letter name /waɪ/ (Treiman, Weatherstone, & Berch, 1994). Furthermore, they frequently derive the letter sound /b/ from the letter name /bi/, saying that the first letter of a spoken CV nonsense syllable beginning with /b/ is the letter *b* (Treiman et al., 1994; see also Treiman et al., 1996). To do so, children must know letter names like /waɪ/ and /bi/ and be able to segment them into singleton onset and rime. Children also find it easier to derive letter sounds forming the singleton onset of letter names than the final phoneme of letter names, and hardest to learn the sounds of letters whose names do not include their sounds (Treiman, Tincoff, Rodriguez, Mouzaki, & Francis, 1998).

Even in children not yet exposed to reading instruction, letter-name knowledge is associated with phonological sensitivity (Bowey, 1994a, 1995; de Jong & van der Leij, 1999;

Johnston et al., 1996; Lonigan, Burgess, Anthony, & Barker, 1998; Mann & Wimmer, 2002; Wimmer et al., 1991). Both predict later word reading. Unpublished data from the study reported by Bowey (1995) showed that, in children who could not yet read, kindergarten letter-name knowledge predicted 34% of variance in a composite first-grade word and nonword reading measure (n = 161). Of this variance, 21% was shared with phonological sensitivity. Of this 21% of common variance, 13% was independent of general cognitive ability.

The argument that letter knowledge and phonological sensitivity *co-determine* the acquisition of the alphabetic principle and the development of reading proficiency circumvents attempts to separate the effects of these variables on later reading. Such attempts are likely to be fruitless until we understand what may well be a reciprocal developmental relationship between letter knowledge and phonological sensitivity. As is true for the predictive association between early phonological sensitivity and later reading, findings here are likely to depend on how phonological sensitivity is assessed.

Phonological sensitivity does predict later letter knowledge. In children who were explicitly taught letter names throughout kindergarten, Majsterek and Ellenwood (1995) found that prekindergarten phonological sensitivity predicted end-of-kindergarten letter-sound knowledge, but not letter-name knowledge (for which marked ceiling effects were observed; n = 76). Frijters, Barron, and Brunello (2000) found that in Canadian kindergarteners with limited reading skills, phonological sensitivity and letter-name and letter-sound knowledge shared 45% of variance. They suggested that phonological sensitivity mediated the concurrent association between home literacy and letter knowledge. Home literacy explained 16% of variance in phonological sensitivity and 12% of variance in letter knowledge but, with phonological sensitivity effects controlled, home literacy no longer predicted letter knowledge (n = 94). Frijters et al. did not report contrasting analyses of letter knowledge as a mediator of the home literacy-phonological sensitivity association.

Burgess and Lonigan (1998) investigated the parallel development of phonological sensitivity and letter-name and letter-sound knowledge in 5-year-old US preschool children (n = 97), 80% of whom could not identify more than one word in a test of environmental print recognition when first tested. At age 5, children were given onset and rime oddity tasks, simplified sound blending and deletion tasks, and tests of letter knowledge. With the effects of initial composite phonological sensitivity, language development, and age controlled, letter-name knowledge predicted 2% of additional variance in phonological sensitivity at age 6. Letter-sound knowledge predicted none. Phonological sensitivity at age 5 was a somewhat better predictor of subsequent letter knowledge, despite ceiling effects on these measures at age 6. With the effects of initial letter-name knowledge, language development, and age controlled, phonological sensitivity predicted 6% of additional variance in letter-name knowledge, and 4% of additional variance in letter-sound knowledge at age 6.

We have seen that the effects of literacy on phoneme manipulation begin extremely early. While letter knowledge is probably the most critical factor in the acquisition of phoneme manipulation, it is difficult to disentangle its effects from the dramatic effects of acquisition of the alphabetic insight. With autoregression and vocabulary effects controlled, Wagner et al. (1994) found that kindergarten letter-name knowledge, but not word reading, predicted phonological sensitivity, but not verbal memory, at the beginning of first grade (n = 244). However, very marked floor effects were observed for kindergarten word reading.

The development of letter knowledge and phonological sensitivity appear to be inextricably linked, with both strongly influencing the development of early word reading and phonological recoding skills. It may be more useful to consider letter knowledge and phonological sensitivity as *co-determinants* of early reading development than to attempt to determine which of the two plays a stronger role.

Rapid automatized naming

Rapid automatized naming (RAN) tasks have been the subject of much research on the predictors of reading skill. Rapid naming tasks assess the speed with which children name a continuous series of common items as rapidly as possible (Wolf, Bally, & Morris, 1986). The stimuli are typically letters, digits, colors, or pictures of familiar objects, and it is assumed that the naming responses are themselves overlearned (automatized).

RAN-colors and RAN-pictures in kindergarten children and school entrants consistently predict later reading (Badian, 2000; Catts et al., 2001; Cronin & Carver, 1998; de Jong & van der Leij, 1999; Share et al., 1984; Wolf et al., 1986). Wolf et al. (1986) reported that kindergarten RAN-colors predicted 20% of variance in second-grade word identification and 22% of variance in reading comprehension (n = 83). RAN-pictures at the beginning of kindergarten predicted 13% of variance in word and nonword reading rate at the end of second grade in children learning to read a shallow orthography (n = 166; de Jong & van der Leij, 1999).

RAN-letters and RAN-digits consistently predict substantial variance in later reading, particularly word identification (Badian, McAnulty, Duffy, & Als, 1990; Cronin & Carver, 1998; Wagner et al., 1994; Wolf et al., 1986). Wolf et al. (1986) reported that kindergarten RAN-letters predicted 41% of variance in second-grade word identification and 30% in reading comprehension (n = 83). Kindergarten RAN-digits predicted 44% of variance in second-grade word identification and 26% in reading comprehension. When the effects of early reading skills were not controlled, Wagner et al. (1994) found that a latent RAN variable, derived from letter and digit naming at the beginning of kindergarten, predicted 44% of variance in word reading one year later (n = 244).

The consistently stronger predictive association with reading of RAN-letters and RAN-digits, relative to RAN-colors and RAN-objects, warns us to be very careful in interpreting RAN-letters and possibly RAN-digits in beginning readers as measures of *automatized* naming. Within kindergarten children and school entrants, naming speed is confounded with knowledge of letter names (Share, 1995; Wagner & Torgesen, 1987). Letter-name knowledge predicts 26–36% of variance in early reading (Bond & Dijkstra, 1967). Several predictive studies of RAN-letters have reported in passing that not all children can name letters and digits accurately (Blachman, 1984; Catts et al., 2001; Stanovich, Feeman, & Cunningham, 1983; Walsh, Price, & Gillingham, 1988; Wagner et al., 1994). At the beginning of kindergarten, Blachman (1984) found that only 38% of inner-city children could name more than one of the five lower-case letters (*o, a, s, d, p*) used on her RAN task ($n = 34$). Even in US first graders showing very marked ceiling effects for letter-name knowledge, Wagner et al. (1994) found that letter-name knowledge and RAN-letters shared 16% of variance ($n = 244$). This figure was higher in kindergarten children (21%). Furthermore, first-grade letter-name knowledge predicted second-grade RAN for letters and digits, even with first-grade RAN and general verbal ability effects controlled. Thus, for letters and digits, RAN does not assess *automatized* naming deficits in beginners.

The gradual automatization of letter naming with exposure to reading instruction is reflected in differential growth in RAN for letters and digits, relative to other items. Cronin and Carver (1998) gave Canadian children three RAN tasks three times over the course of the year in which reading instruction commenced ($n = 57$). At the beginning of the year, children named digits faster than letters. Neither letters nor digits were named faster than pictures. By the end of the year, speed was similar in all three tasks. By the beginning of first grade, RAN-pictures was slowest, although RAN-letters and RAN-digits were still equivalent. Neuhaus, Foorman, Francis, and Carlson (2001) reported similar findings. They suggested that articulation duration (with pauses edited out) within continuous naming tasks assesses item familiarity. Articulation duration within RAN-letters and RAN-digits tasks, but not within RAN-pictures tasks, decreased from first to second grade, as children became more familiar with alphanumeric item names. Towards the end of first grade, articulation duration within RAN-letters explained 11–14% of variance in concurrent word identification ($n = 221$; Neuhaus & Swank, 2002).

RAN-letters is clearly confounded by knowledge of letter names in kindergarten children and beginning readers. For this very reason, and because letter names may need to be overlearned before this knowledge will transfer to reading (Ehri, 1983; Walsh et al., 1988), RAN could provide a useful measure of overlearned letter-name knowledge within beginners *if* it could be confidently interpreted as a pure measure of the efficiency with which letters can be identified and named. However, RAN is not so easily interpretable. There is no consensus as to what RAN measures. It reflects several distinct processing components and it is likely to reflect these components differentially at different levels of reading proficiency.

Wolf, Bowers, and Biddle (2000; Bowers & Wolf, 1993) argued that RAN should not be conceptualized as a phonological processing measure because it incorporates processes in addition to those involved in retrieving and articulating item names, including those involved in both item identification and rapid serial processing of a continuous series of items. However, apart from item identification, the processes tapped by RAN all require phonological processing of some kind. Furthermore, if it were conceded that item identification per se were a major source of variance in RAN, then RAN-letters, for example, must be interpreted as largely reflecting letter knowledge. The argument that RAN-letters and RAN-digits primarily reflect nonphonological processes thus rests on the dubious assumption that RAN does not assess item identification or name retrieval and articulation (cf. Cronin & Carver, 1998; Neuhaus et al., 2001) but, rather, other yet-to-be-understood processes that contribute to reading skill and that can be measured independently of both phonological processing skill and word reading.

It is unlikely that the rapid serial processing component of RAN reflects only nonphonological processes. Discrete-trial and continuous rapid naming do reflect somewhat different processes, in that the speech planning and articulation processes required in continuous naming are far more demanding. Furthermore, when a continuous series of items is named, minor differences in the efficiency of the first stages of letter identification and letter-name retrieval may cascade to affect those involved in programming and executing rapid sequences of articulatory gestures (see Baron & Treiman, 1980). However, even when the serial processing component of continuous naming is eliminated by using discrete-trial naming tasks, rapid naming continues to predict later reading. Although associations are typically weaker than for continuous naming, Wagner et al. (1994) found that discrete-trial naming of letters and digits at the beginning of kindergarten explained 20% of variance in word reading one year later (n = 244). When assessed at the beginning of first grade, it explained 23% of variance in word reading one year later (n = 244).

Wolf and Bowers (1999) argued that naming speed deficits are distinct from other phonological processing deficits, such as deficits in phonological sensitivity and phonological memory. However, Wagner et al. (1997) found that, with kindergarten reading, verbal ability, and other latent phonological processing abilities controlled, a latent kindergarten alphanumeric RAN variable predicted little independent variation in word reading two years later, and this was largely mediated by letter knowledge (n = 216).

Bowers and Wolf (1993) proposed that slow naming speed primarily represents a deficit in the ability to form orthographic representations of letter names, sublexical units of print, and words. More recently, they suggested that a RAN deficit is problematic only if combined with a phonological sensitivity deficit (Wolf & Bowers, 1999; Wolf et al., 2000). This *double deficit hypothesis* predicts an *interaction* between phonological sensitivity and RAN in predicting reading. The double deficit hypothesis lacks a strong theoretical motivation. Wolf et al. (2000, p. 396) conceded that "no . . . straightforward conceptualization exists to explain how the processes underlying naming speed affect word identification and word attack" and that their attempts are "highly speculative and represent work in progress."

There is no direct published test of the hypothesis that the effects of phonological sensitivity interact with RAN in predicting reading (as follows from the double deficit hypothesis). However, unpublished data from the study described in Bowey (1995) permit such a test. In kindergarten children screened for novice reading ability, and with general cognitive ability effects controlled, phonological sensitivity and RAN-colors predicted independent variance (n = 161). However, the interaction of phonological sensitivity and RAN-colors predicted no additional variance (see Baron & Kenny, 1986).

The hypothesis that RAN predicts reading only if there is also a phonological sensitivity deficit was indirectly tested by Wimmer et al. (2000), whose data did not support the double deficit account. They found no consistent differences in third- and fourth-grade reading rates between children who had entered school with either single phonological sensitivity or single RAN deficits and those with double deficits. However, in children learning to read German (a shallow orthography), phonological sensitivity appears to be a weaker predictor of reading than in children learning to read English (see above).

In summary, the predictive association between RAN and later reading is substantially greater when RAN is assessed with letters and digits, relative to colors and pictures. When RAN is assessed using letters or digits, its predictive effects appear to be largely mediated by letter knowledge (Wagner et al., 1997; see Wagner & Torgesen, 1987). Support for a role for RAN-pictures and RAN-colors in predicting later word reading that is independent of phonological sensitivity is inconsistent (de Jong & van der Leij, 1999; cf. Wimmer, et al., 2000), and may be explicable in terms of measurement error and method variance. Moreover, there is no support yet available for the interactive prediction made by the double deficit hypothesis.

In relation to letters and perhaps digits, we are left with the conclusion that RAN in kindergarten children and school entrants is best interpreted as reflecting several components, but primarily the degree of overlearning of letter and number names and the efficiency of phonological processing. The very strong associations between continuous naming speed for letters and digits and later reading where initial word reading effects are not controlled probably reflects the dual assessment of two constructs critical to alphabetic reading success.

Conclusions

Crain-Thoreson and Dale (1992) made the interesting suggestion that "The initial stages in reading acquisition may be limited by the least advanced segment of the child's cognitive profile" (p. 427). There may be several key abilities that co-determine reading ability. Given appropriate instructional methods, children may require only threshold levels of these key abilities to find learning to read easy, but their reading progress may be held back by below-threshold levels in any of them. This plausible suggestion may partly explain why it is so hard to accurately predict future poor readers.

In the meantime, predictive studies of early reading success, when carefully considered in relation to other work on reading acquisition, are indicative of what these key abilities may be – and here overlearned letter-name knowledge and phonological sensitivity stand out. Early reading instruction should attempt to teach these skills to all children within enjoyable learning contexts. Children who are highly familiar with letter-names and easily able to detect similarities in the sounds within spoken words are likely to readily acquire the alphabetic principle and, when provided with appropriate instruction that explicitly links phonological sensitivity, letter-sound knowledge, decoding and writing, should learn phonological recoding skills with ease. It is critical that this instruction be enjoyable and be integrated with the reading of meaningful material. It should also encourage the development of a range of complementary strategies that may be helpful in decoding words in which not all letter-sound correspondences are yet known or words that contain atypical letter-sound correspondences.

This review has focused on the cognitive determinants of reading development and has examined only a limited set of predictors of early reading. It is possible that other predictors will emerge, especially in relation to subgroups of children experiencing reading difficulties. The focus on letter-name knowledge and phonological processing abilities reflects current research, but it is also motivated by consideration of the process of learning to read. Understanding the alphabetic principle and developing efficient phonological recoding skills are arguably the key competencies that the beginning reader must acquire in order for reading to become a self-teaching process, and abilities that contribute to these competencies are critical.

Nevertheless, the direct role of phonological sensitivity may be overestimated in some predictive work. Phonological sensitivity may predict reading partly because it assesses an underlying phonological processing ability that itself predicts children's ability to acquire new phonological processing skills, of which efficient phonological recoding is one par excellence, albeit one that is a component of the reading process itself. The fact that phonological sensitivity cannot be assessed without imposing some minimal extraneous task demands also means that it may partly reflect the contributions of general cognitive ability to the process of learning to read.

The current review is not exhaustive. However, it does summarize the current state of play and highlights directions for future research in this area. It is critical that researchers be aware of methodological issues and of the dangers of overinterpreting their findings. If research in this area is to be of use to practitioners, it should focus on abilities that are likely to be readily teachable and to make a direct contribution to reading development. These contributions to reading can then be assessed within studies using a training methodology. Here, too, caution must be exercised. Failure to obtain transfer effects within training studies is notoriously difficult to interpret (Schneider et al., 1997). Furthermore, it is possible that various abilities co-determine reading development. If so, then overly simple training studies may throw the baby out with the bathwater.