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The Phonological Representations Hypothesis of Dyslexia: Consequences for the Formation of Associations

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CHAPTER 1
General Introduction

1. General Introduction

Reading acquisition

It is commonly accepted that fluent identification of words is the result of a long and complex process. Beginning readers identify words by sequentially recoding each letter into the corresponding sound and then blending these sounds together to form the word (Share, 1995). Compared to skilled readers, the manner in which beginning readers identify words is error prone, effortful, and slow.

Necessary prerequisites for the development of accurate decoding ability are phonological awareness and letter knowledge (Byrne, 1998). Letter knowledge refers to the ability to recognize the various letters (i.e., graphemes) and to the understanding that each letter represents a sound (i.e., phoneme). Phonological awareness is the awareness that spoken words can be analyzed into smaller sound units such as syllables, onsets and rimes, and phonemes (Perfetti, 1985). The recognition of the constituent sounds in a word is a difficult process as the phonemes in words are usually co-articulated. As a result, there are no clear boundaries between the sounds of the individual phonemes in a spoken word. Moreover, because of co-articulation, the sound of a particular phoneme is not constant throughout different words, but is affected by the surrounding phonemes in a word.

The ability to recognize sounds in the spoken word form and the ability to recognize letters in the written word form enable the beginning reader to learn the systematic grapheme-to-phoneme correspondences between the written and spoken form of words. Both letter knowledge and phonological awareness have been found to develop concurrently and are promoted through reading itself (e.g., Morais, Alegria, & Content, 1987). They are critical for the development of detailed orthographic representations, which, in turn, are necessary for rapid visual word recognition.

Reading by phonological recoding is especially supportive in languages with fairly consistent grapheme-to-phoneme mappings such as Dutch, German, or Spanish. The English orthography, however, is very inconsistent, especially with respect to the pronunciation of the vowel (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). For example, in Dutch the vowel *a* in the words *hand (hand), ball (bal),* and *cat (kat)* has a similar sound, whereas in English the vowel sound is different in each word (Landerl, Wimmer, & Frith, 1997). Therefore, in addition to phonological recoding, English beginning readers also tend to use strategies that exploit analogies to existing words to identify a new word (e.g., Goswami, 1993, 2002).

Phonological recoding ability provides the beginning reader with a self-teaching mechanism for the identification of new words (Share, 1995). In normal readers, after only a few successful encounters with a novel word, phonological recoding becomes less dominant because sufficient orthographic knowledge about that specific word has been acquired. In other words, a long-term representation between its written and spoken form is established (Ehri, 1992; also see Rack, Hulme, Snowling, & Wightman, 1994) that enables the reader to recognize the word more or less directly on the basis of its orthographic appearance (Perfetti, 1992; Reitsma, 1990). It remains unclear if these long-term representations contain word-specific or more general orthographic knowledge.

Ehri (1992, 1995, 1998) argued that the nature of the associations between the written and the spoken form of words differs considerably over time. Prereaders remember how to read words by forming connections between selected visual characteristics of words and their pronunciations or meanings and storing these associations in memory (Ehri & Saltmarsh, 1995; Ehri & Wilce, 1985). These visual characteristics are cues accompanying the printed word and do not involve letter-sound relations as the children are not yet aware of the systematic relations between letters and sounds. Accordingly, this phase is called the pre-alphabetic phase. Once children acquire some knowledge about the alphabetic writing system, the formation of associations involves connections between the letters in written words and the sounds in their pronunciations. At first, connections are made among some of the letters in written words and sounds detected in their pronunciations. This phase is called the partial alphabetic or phonetic cue reading phase. Subsequently, in the full alphabetic phase readers acquire full knowledge of the alphabetic system. The reader is able to form fine-grained associations between the graphemes in written and the phonemes in spoken words (Ehri, 1998). In this process spellings become amalgamated to pronunciations of words in memory (Ehri, 1992, 1998). In the final consolidated alphabetic phase readers learn to make functional use of general orthographic knowledge in the form of sensitivity to the regularities and redundancies in spellings, for example, the recognition of *'at'* in *cat, fat,* and *rat* and *'ing'* in *walking* and *running* (Vellutino, Fletcher Snowling, & Scanlon, 2004). Additionally, spelling and pronunciation become firmly connected with meaning.

Children with reading difficulties: The Phonological Representations Hypothesis

There are many children that have difficulty with the acquisition of reading. The majority of these children do not acquire enough orthographic knowledge to be able to recognize words quickly. They continually need to address a lot of attention to the decoding of words.

Research has shown that children with reading difficulties are impaired on a wide range of phonological processing abilities such as phonological awareness (Goswami & Bryant, 1990; Wagner & Torgesen, 1987), verbal short-term memory (Brady, 1991; de Jong, 1998; Jorm, 1983; McDougall, Hulme, Ellis, & Monk, 1994; Stone & Brady, 1995), the rapid retrieval of the names of familiar symbols such as objects, digits, letters, and colors (see for a review Wolf & Bowers, 1999). A phonological deficit is generally seen as the cause of these problems in phonological processing and is also considered to be the primary cause of dyslexia. The phonological deficit explanation of dyslexia states that a specific deficit in phonological processing impedes the development of the spelling-to-sound (e.g., grapheme-to-phoneme) translation. In turn, this failure to master spelling-to-sound correspondences is considered a primary source of dyslexic children's word recognition problems (Snowling, 1980; Stanovich & Siegel, 1994; Wagner & Torgesen, 1987).

More recently, the phonological deficit has been characterized as a deficit in the quality of the phonological representations of words in the mental lexicon of dyslexic children. The Phonological Representations Hypothesis states that: "dyslexic children have poorly specified phonological representations" (Snowling, 2000). Several researchers have argued that words in each individual's mental lexicon are restructured in segmental organization (Fowler, 1991; Walley, 1993). In their lexical restructuring hypothesis, Metsala and Walley (1998) state that children's initial holistic phonological representations become increasingly more segmentalized during the preschool and early school years, and eventually will be restructured to phoneme level representations (also see Studdert-Kennedy, 1987). Also, Fowler (1991) proposed that dyslexic children's phonological representations lack full segmental organization into a sequence of discrete phonemic elements. Vocabulary growth is assumed to be the driving force behind lexical restructuring, because the increase in words to be stored in long-term memory requires a more efficient storage system. According to the lexical restructuring theory, the need for segmentalized representations is most acute for words in dense neighborhoods. Such words are harder to differentiate from other lexical candidates.

Elbro (1996) has adopted the slightly different view that dyslexic children's phonological representations are less distinct from one another (1996, 1998). He argued that the quality of phonological representations varies according to their distinctness, that is, 'the magnitude of the difference between a lexical representation and its neighbors' (p. 454).

As a consequence of the assumed lower quality phonological representations of words in the mental lexicon of dyslexic children, operations on words that have lower quality phonological representations may be hampered as compared to the performance of normal reading children. Dyslexic children are known to perform poorly on phonological awareness tasks that use nonword stimuli (Wagner & Torgesen, 1987). As these nonwords do not have a phonological representation in long-term memory, dyslexic children are assumed to set up underspecified representations for novel stimuli. Accordingly, these instable representations are harder to process in phonological awareness tasks.

However, phonological awareness tasks using familiar words have also been found to pose a problem for dyslexic children (Swan & Goswami, 1997a). If not all phonological features of these words are represented adequately, deleting a specific phoneme, for example, is difficult. Accordingly, lower performance on these phonological awareness tasks is assumed to reflect inaccuracies in the phonological representations of the words that dyslexic children are asked to analyze.

Also, the shorter memory spans for verbal items observed in dyslexic children can be explained by a deficiency in the phonological representations of words. Hulme, Maughan, and Brown (1991) argued that long-term phonological representations support the retrieval of partially decayed words held in a phonological store. If these long-term representations are qualitatively inferior, this process will be disadvantaged. For reading, underspecified phonological representations might impair the temporary storage of the sequence of sounds, obtained through phonological recoding, before the full sequence can be blended into a word (de Jong, in press).

Furthermore, dyslexic children's subtle and pervasive, lexical retrieval difficulties of familiar symbols such as objects, digits, letters, and colors might also be due to, at least in part, their inferior phonological representations (see for a review Wolf & Bowers, 1999; Swan & Goswami, 1997b; Fowler & Swainson, 2004). When phonological representations are inaccurate or more difficult to distinguish from neighboring representations, this may result in slower retrieval of the correct pronunciations or in recurring pronunciation errors.

Finally, the impaired speech perception of dyslexic readers needs to be mentioned. Research in this area has shown that dyslexic children have difficulty with the identification and discrimination of stimuli on a phonetic continuum (i.e., categorical perception). Compared to normal reading children, dyslexic children have less well-defined phoneme boundaries, that is, they have more difficulty distinguishing two phonemes that sound alike, for example, /d/ and /b/ (Manis, McBride-Chang, Seidenberg, Keating, Doi, Munson, & Petersen, 1997; McBride-Chang, 1995; Mody, Studdert-Kennedy, & Brady, 1997). In contrast to the previously discussed phonological processing abilities, the speech perception findings could be seen as a cause of the formation of qualitatively underspecified phonological representations in dyslexic children rather than as manifestations of these underspecified phonological representations.

Of the above-mentioned phonological processing problems, impairments in phonological awareness, that is the sensitivity for the sound units in spoken words, are the most prominent. As stated earlier, a large body of evidence supports a relationship between phonological awareness and learning to read. Especially an awareness of phonemes is considered as a prerequisite for the discovery of the alphabetic principle (Byrne, 1998), and for the formation of fine-grained associations between the graphemes in written and the phonemes in spoken words (e.g., Ehri, 1998). Thus, a deficiency in the quality of phonological representations affects reading indirectly via problems in a range of phonological processing abilities, which, in turn, are assumed to affect reading acquisition.

The Phonological Representations Hypothesis and the formation of associations

Although dyslexic children's impairments in phonological awareness are the most prominent predictor of reading difficulties, a growing number of studies tend to suggest that dyslexic children's reading problems might depend on other phonological processing impairments (Mayringer & Wimmer, 2000; see also Landerl, Wimmer, & Frith, 1997; Vellutino et. al., 2004). In the more transparent orthographies, such as Greek, German or Dutch, phonological awareness problems have been found to be less pervasive than in English with its opaque orthography (de Jong & van der Leij, 2003; Landerl & Wimmer, 2000;

Wimmer, 1996). As a result, in transparent orthographies even dyslexic children learn to read accurately. Nevertheless, their reading speed remains very slow (van der Leij & van Daal, 1999).

Reading speed is, in part, dependent on the proportion of words read by sight (de Jong, 2000; Torgesen, 2001). For sight words, the view of the written form immediately activates its pronunciation and meaning in memory, because detailed connections between the spoken and the written form of the word have been developed (Ehri, 1998). The ease with which printed words are recognized and pronounced is dependent on the quality and number of connections between the spelling and the pronunciation (Booth, Perfetti & MacWhinney, 1999; Ehri, 1992). Accordingly, the question becomes whether impoverished phonological representations might affect the formation and storage of connections between spoken and written forms of words, that is, the acquisition of orthographic knowledge.

There is ample evidence that dyslexic children have problems with the formation of associations. Many studies investigating visual-verbal paired associate learning have found that especially associating new, phonologically unfamiliar words with pictures was more difficult for dyslexic children than for children without reading problems (Aguiar & Brady, 1991; Vellutino & Scanlon, 1989; Vellutino et al., 1995). In some studies, however, dyslexic children were also found to have more difficulty learning to associate familiar words with pictures (Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983). Nonetheless, the evidence here remains equivocal (compare Vellutino & Scanlon, 1989; Vellutino et al. 1995). Visual-visual (e.g., nonverbal) paired associate learning is not impaired in dyslexic children (Liberman, Mann, Shankweiler, & Werfman, 1982; Nelson & Warrington, 1980; Rapala & Brady, 1990; Vellutino, Steger, & Pruzek, 1973).

The paired associate learning problems of dyslexic children seem to be confined to the verbal domain, which suggests that they are part of the phonological processing impairments characteristic for dyslexia. Hence, both paired associate learning difficulties and phonological awareness problems of dyslexic children could be seen as manifestations of a deficiency of the quality of the phonological representations (see also Snowling, 2000).

However, unlike phonological awareness, paired associate learning might reflect a direct consequence of underspecified phonological representations for the formation of associations between the written and spoken forms of words.

Research questions and outline of this thesis

The Phonological Representations Hypothesis can be seen as an explanation for the well-documented phonological processing difficulties shown by dyslexic children. Though a major part of the research done in the last decade has focused on the quality of phonological representations as an underlying deficit of reading related difficulties in dyslexia, little research has been done on the consequences of these assumed underspecified phonological representations, for example, for the formation of visual-verbal associations as required in vocabulary and reading acquisition. The research presented in this thesis tried to explore these consequences. We first addressed the question whether dyslexic children have problems with the formation of visual-verbal associations. In addition, we investigated if these problems are manifestations of the phonological deficit characteristic for dyslexia. Second, we investigated whether dyslexic children have problems with the formation of associations between the spoken and written forms of words, that is, when learning to read.

In the study described in *Chapter 2* we investigated the paired associate learning performance of dyslexic and age-matched and younger normal reading children. Both word and nonword learning were addressed to examine whether dyslexic children had problems with the formation of associations between pictures and unfamiliar words as well as between pictures and familiar words. We further examined if the problems with the formation of associations could be considered as manifestations of a phonological deficit.

The study reported in *Chapter 3* was, in part, a replication of the study reported in Chapter 2. The paired associate learning performance of dyslexic children was compared to the performance of age-matched and younger normal readers. In addition to verbal learning, however, we also addressed nonverbal learning to investigate whether dyslexic children's paired associate learning problems were confined to the verbal learning domain or extended to nonverbal learning as well. Additionally, the relationship between phonological awareness problems and verbal paired associate learning problems was examined. Finally, we also considered the long-term retention of the learned associations to examine whether underspecified phonological representations primarily affect the establishment of associations or also their long-term retention.

In *Chapter 4* a series of three experiments is reported that aimed to test the phonological representations hypothesis in the context of visual-verbal learning. Phonological representations of words in the mental lexicons of dyslexic children are assumed to be less well specified. The implication of this hypothesis is that underspecified phonological representations are more similar than fully specified phonological representations. Accordingly, it follows that for dyslexic children, having underspecified representations, words from the same neighborhood (i.e., words that differ on one phoneme) are relatively more similar than for normal readers. From this assumption, it was hypothesized that for dyslexic children the visual-verbal paired associate learning of a set of words with many neighbors would be more difficult than the learning of a set of words that are phonologically distinct as compared to normal reading peers. For example, in the indistinct context, children had to associate *knip*, *knik*, *klip*, and *klik* with four pictures. In the distinct context, *knip*, *staaf*, *brom*, and *sloot* had to be associated with pictures.

Furthermore, the effect of visual distinctness on paired associate learning performance of dyslexic and age-matched normal readers was examined as well. One of the reasons was that in transparent orthographies phonologically similar words are also orthographically similar, which makes it very difficult to examine the separate effects of visual and phonological effects on reading performance. In paired associate learning, however, the effects of phonological and visual distinctness can be dissociated. Analogue to the manipulation of the distinct and indistinct word sets, sets of distinct and indistinct black and white pictures were constructed. From the phonological representations hypothesis it follows that dyslexic and normal readers should be equally affected by the visual distinctness of pictures.

In *Chapter 5*, a study is reported in which the effects of phonological and visual distinctness in reading were examined. The main aim of this study was to investigate the consequences of impaired phonological representations for the acquisition of orthographic knowledge. From the assumption that dyslexic children have underspecified phonological representations of words, we hypothesized that learning to read words in a context of orthographically and phonologically similar words might pose specific problems as compared to learning to read words in an orthographically and phonologically distinct context. Dyslexic children and groups of reading and age-matched normal readers repeatedly read lists of nonwords presented in a distinct (*kwog* with *kwes, snar*, and *skal*) or an indistinct context (*kwog* with *kwos, knos*, and *knog*). Both reading speed and accuracy were registered.

Finally, in the concluding *Chapter 6* the main results of the presented studies in this thesis are reviewed. Links and inconsistencies across the studies are subsequently discussed leading to an overall conclusion.

CHAPTER 2

Manifestations of phonological deficits in dyslexia: Evidence from Dutch children

2. Manifestations of phonological deficits in dyslexia: Evidence from Dutch children

In this study we extended the existing findings on phonological processing problems of dyslexics into the Dutch language. In addition, we studied whether these phonological processing problems are accompanied by problems in the formation of phonological representations of new words. Twenty dyslexic children, 20 chronological-age controls, and 20 reading-age controls were administered three phonological processing tasks: sound deletion, verbal short-term memory and rapid automatic naming (RAN). To assess the formation of new phonological representations two verbal learning tasks were administered, one with phonologically unfamiliar words and one with familiar words. The results indicate that Dutch dyslexic children indeed have deficits in phonological awareness and RAN. The performance of the dyslexic children on these tasks was related to reading grade. No differences were found between the dyslexic children and their chronological-age controls on the verbal short-term memory task. The results on the verbal learning tasks revealed that dyslexic children had more difficulty with the acquisition of new, unfamiliar words than their chronological-age controls. Unexpectedly, the dyslexics had more difficulty with the acquisition of familiar words as well. Again, the performance of the dyslexics on both tasks was related to reading grade. Additionally, the dyslexic children were found to make more phonological errors than their peers without reading problems in both verbal learning tasks.

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Introduction

Phonological processing problems

In the past few decades, much research has been done on dyslexic children's problems with phonological information processing. This research has yielded much evidence that dyslexic children have difficulty with phonological awareness, i.e. awareness of sound units in words (Goswami & Bryant, 1990; Wagner & Torgesen, 1987). Phonological awareness enables a child to gain access to the phonological structure of words. Words can be segmented in large phonological units such as rhymes and syllables but also in smaller phonological units such as phonemes. Access to the phonemes in words has been assumed to play a critical role in learning to read where written letter strings must be accurately translated into strings of phonemes. Dyslexic children, however, are less sensitive to the sound segments in spoken words and are found to have sustaining problems with the detection and manipulation of phonemes in words. An underlying factor giving rise to these phonological awareness problems could be the quality of the phonological representations in the lexicon (Elbro, 1996; Fowler, 1991). Both the completeness and accuracy of the phonological representations of words in long-term memory are considered to be lower in dyslexics (Elbro, 1998).

In addition to problems with phonological awareness, many studies have found evidence that dyslexic children have shorter memory spans for phonological material compared to children without reading problems (Brady, 1991; de Jong, 1998; Jorm, 1983; McDougall, Hulme, Ellis, & Monk, 1994; Stone & Brady, 1995; Wagner & Torgesen, 1987). Compared to children without reading problems dyslexic children have more difficulty to reproduce a sequence of verbal items (words or digits) in the order they were presented. Memory for nonverbal material, however, is not inferior in poor readers (Steger, Vellutino, & Meshoulam, 1972; Vellutino, Steger, Harding, & Phillips, 1975; Vellutino, Steger, & Pruzek, 1973). Both Jorm (1983) and Brady (1991) conclude that the inferior verbal memory span of poor readers is primarily due to inefficient phonological coding in short-term memory. This inefficient phonological coding may be the result of inaccurate phonological representations in long-term memory. Hulme, Maughan, and Brown (1991) have argued that long-term memory representations of the phonological form of words is important in supporting the retrieval of partially decayed words held in a rehearsal loop during memory tasks. When phonological representations are inaccurate this will result in slower retrieval and may in turn lead to less efficient rehearsal in short-term memory, resulting in inferior recall performance.

Naming studies have also provided evidence that dyslexic children have inaccurate or underspecified phonological representations in long-term memory. They have consistently found that the majority of poor readers has subtle and pervasive, lexical retrieval difficulties for familiar symbols such as objects, digits, letters, and colors (see for a review Wolf & Bowers, 1999). These difficulties are most clearly manifested in dyslexic readers by their performance on continuous naming or naming-speed tasks, in which they are required to provide names for common, serially presented stimuli under time constraints. Denckla and Rudel (1974; 1976 a, b) found that the speed with which names were retrieved, rather than accuracy in naming itself, differentiated dyslexic readers from others. Later research on the source of the naming differences between dyslexic readers and controls has ruled out differences in articulation rate, short-term memory difficulties, and visual scanning problems (Obregón, 1994; Wimmer, 1993). The slower naming speed of poor readers compared to normal readers of the same age has been considered to reflect the lower accuracy and distinctness of their phonological representations. Phonologically related words with underspecified representations tend to overlap each other to a great extent which makes lexical access more difficult and, hence, slower (Korhonen, 1995; Manis, Seidenberg, & Doi, 1999).

Virtually all studies on rapid naming (RAN) are based upon the performance of dyslexics and normal readers of the same age. The studies including a reading-age control group to examine whether naming speed differentiates dyslexic readers from these younger normal readers are scarce and the results are mixed (Ackerman & Dykman, 1993; Badian, 1996; Olson, 1995).

Acquisition of new phonological representations

The research mentioned above indicates that dyslexic children have deficits in phonological awareness, verbal short-term memory, and rapid naming (Frith, 1997). These deficits are assumed to be caused by less accurate or underspecified phonological representations of words in long-term memory. But what if new, phonologically unfamiliar words are encountered in language? Are dyslexic children hampered to a greater extent than normal children in setting up representations of new words?

A number of studies support a relationship between problems in phonological processing abilities and the acquisition of new phonological representations. Gathercole and Baddeley (1990a) found that 5-year-old children with poor phonological memory skills were slower at learning phonologically unfamiliar words compared to children with good phonological memory skills. In addition, the two groups also differed one day later in their retention of the new words, suggesting that immediate memory processes are directly involved in the learning of new vocabulary items in young children. No differences were found between the two groups in learning phonologically familiar words.

Michas and Henry (1994) also reported that the ability to accurately produce a new word was strongly related to phonological memory. They also found that 5-year-old children with better phonological memory skills were better at producing the names of new words. The authors concluded that the construction of a stable representation of the phonological structure of the sounds of new words depends critically on the adequacy of the temporary representations of the items in phonological short-term memory.

More recently, de Jong, Seveke, and van Veen (2000) have reported two studies, which examined the relationship between phonological awareness and the acquisition of new words. The first study revealed that phonological awareness of 5-year-old kindergartners was related to the paired associate learning of phonologically unfamiliar words, but not to the learning of familiar words. In the second study a group of non-reading 5-year-old children received a phonological awareness training. After this training the children appeared to learn phonologically unfamiliar words more easily compared to children who had received no training. These findings suggest that phonological awareness can support the acquisition of novel words.

In contrast to the influences of verbal memory and phonological awareness on the acquisition of new phonological representations, to our knowledge, nothing is known about the relationship between RAN and learning new phonological representations.

On account of the phonological processing problems of dyslexic children it can only be inferred from the studies just mentioned that poor readers might have difficulty with the acquisition of new phonological representations. More direct evidence on this relationship is provided by a study by Aguiar and Brady (1991). They hypothesized that the vocabulary deficits often reported in disabled readers are not likely to be merely the consequence of less reading experience because differences in vocabulary knowledge have been observed in very young poor readers, raising questions about other factors in vocabulary acquisition. They argued that since poor readers have been found to have difficulties in accurate perception, storage, and retrieval of words "they might be expected to demonstrate difficulties in vocabulary acquisition, even when words are encountered outside of text, or aurally" (Aguiar & Brady, p. 226). Aguiar and Brady developed a vocabulary learning task of six new words in order to examine if poor readers have more difficulty acquiring auditorily presented words. Indeed, poor readers were found to need more trials to learn the new, phonologically unfamiliar words, and to make a greater number of phonological errors compared to chronological age-controls. No differences between the groups were found in the ability to learn the semantic attributes of words.

More recently, Windfuhr and Snowling (2001) found a relationship between reading ability and paired associate learning performance in 6-11-year-old children. Poor readers were found to have more difficulty with learning to pair nonwords to abstract figures than good readers. These differences could only partially be accounted for by phonological awareness skills.

Vellutino and colleagues have reported results similar to those of Aguiar and Brady and Windfuhr and Snowling previously. In several studies they compared the performance of poor and normal readers on verbal and non-verbal paired associate learning tasks (Vellutino, Steger, Harding, & Phillips 1975; Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983; Vellutino & Scanlon, 1989; Vellutino, Scanlon, & Spearning, 1995). In all instances poor and normal readers were differentiated only on measures involving a verbal component. Poor readers were found to have more difficulty with learning unfamiliar words as compared to their chronological-age controls (Vellutino et al., 1975, 1995; Vellutino & Scanlon, 1989). On learning familiar words, however, mixed results were found. Early studies revealed that poor readers made more errors than the controls in learning to pair familiar words to Chinese characters (Vellutino et al., 1978, 1983). Several later studies, however, did not differentiate poor readers from peers without reading problems on learning words, which were high in meaning. The performance of poor readers on learning familiar words approximated that of normal readers (Vellutino & Scanlon, 1989; Vellutino et al., 1995). Vellutino and colleagues suggested that poor readers rely more heavily on semantic attributes and make less use of a word's phonological attributes, i.e. phonological coding, to aid in remembering the newly learned words (Vellutino et al., 1995). In addition to paired associate learning tasks, Vellutino and colleagues administered a free recall task. The performance of the subjects on these two tasks was highly correlated. The authors reported that these results suggest that the associative learning difficulties observed in poor readers are to some extent attributable to a dysfunction in the storage and retrieval of word names.

Finally, Wimmer, Mayringer, and Landerl (1998) administered a paired associate learning task to German dyslexic children and chronological-age controls. A significant difference was found between the reading groups. The dyslexic children needed more trials to learn the three new words than their chronological-age controls. This result indicates that poor readers have difficulty with learning unfamiliar words in languages with regular orthographies as well.

Aims and general design of the study

The scope of the present study is twofold. First, we wanted to extend the existing findings on phonological processing problems of dyslexics into the Dutch language, which is a language with more straightforward grapheme-phoneme correspondences compared to the English language. In Dutch only a few studies on the manifestations of dyslexia have been performed, which included both a chronological-age control group and a reading-age control group. With respect to phonological awareness de Gelder and Vroomen (1991) found that Dutch retarded readers performed poorer on consonant deletion than both normal readers of the same age and reading-age controls. They also found that better readers are more sensitive to common phoneme relations between word stimuli than poor readers. These differences in (the manipulation of) phonological representations were found to persist into adulthood (de Gelder & Vroomen, 1991).

In a study on working memory, de Jong (1998) found that Dutch reading disabled children performed worse on several measures of working memory capacity in both the language and the numerical domain. Finally, van Bon and van der Pijl (1997) reported that Dutch dyslexic children have deficits in nonword repetition and nonword recall.

To our knowledge, no Dutch studies are available on the rapid naming performance of dyslexic children as compared to their peers without reading problems and their reading-age controls. In addition, the various aspects of phonological processing have not yet been included in one study. To examine a broader range of phonological processing problems in Dutch dyslexic children, we administered in the present study tasks for phonological awareness, verbal short-term memory and rapid naming. The performance of the dyslexic children was compared to both a chronological-age control group and a reading-age control group. Sound deletion was used to assess phonological awareness. The prediction was that the dyslexic children would perform worse than both their chronological-age controls without reading problems and their reading-age controls (de Gelder & Vroomen, 1991).

Verbal short-term memory was assessed with a nonword span task. The dyslexic children were expected to maintain less phonological material in verbal short-term memory. As a result their scores on the nonword memory task would be considerably lower than their chronological-age controls. Besides, extra attention is needed for the processing of unfamiliar phonological information, which yields an extra demand to the task. Therefore, the dyslexic children were also expected to perform worse than their reading-age controls on this task. Finally, rapid automatic naming was included to measure the retrieval of phonological representations from long-term memory. Dyslexic children were expected to have a lower naming speed for objects, digits, and letters than their chronological-age controls (for a review, see Wolf & Bowers, 1999). No predictions were made here for the performances of dyslexic children versus their reading-age controls because mixed results have been reported in literature.

The second aim of this study was to examine the acquisition of new phonological representations in dyslexic and normal readers. If dyslexic children have poorer phonological abilities than their peers without reading problems, does this hamper them to a greater extent in the establishment of new phonological representations?

In line with the study by Aguiar and Brady (1991) a verbal learning task was administered. The prediction was that dyslexic children have more difficulty with learning phonologically unfamiliar words than their peers without reading problems. As an extension to the study by Aguiar and Brady we included a reading-age control group. On the basis of the results of Vellutino and colleagues (Vellutino & Scanlon, 1989; Vellutino et al., 1995) it was expected that dyslexic children performed similar to their reading-age matched controls on the verbal learning of unfamiliar words.

Unlike most previous studies, we also examined the types of errors made in the verbal learning task. Because of the phonological processing difficulties of the dyslexic children, we expected that they would make relatively more phonologically based errors than the other two groups.

In addition to a learning task with unfamiliar words, we incorporated a verbal learning task with familiar words to examine if dyslexic children also experience difficulty on this task. As discussed earlier, learning well-known words is less dependent on phonological processing. The findings of the studies by Vellutino et al. (1978, 1983, 1995; Vellutino & Scanlon, 1989) on differences between dyslexic children and controls in learning familiar words, however, are mixed. Based on their latest findings where poor readers were found to approximate peers without reading problems in learning familiar words, we expected the dyslexic children to perform similar to their chronological-age controls on the verbal learning of familiar words.

Vellutino and colleagues also regularly incorporated a reading-age control group in their design and found that poor readers performed similar to this control group of younger children with the same reading level on learning familiar words (Vellutino et al., 1978, 1983, 1995; Vellutino & Scanlon, 1989). Hence, the dyslexic children were expected to perform similar to their reading-age controls on learning phonologically familiar words as well.

Method

Participants

Three groups of 20 children each participated in this study: a group of dyslexic children (DYS), a group of reading-age (RA) controls, and a group of chronological-age (CA) controls. Each group consisted of 12 boys and 8 girls. The dyslexic children were individually matched with the reading-age control group on reading ability and with the chronological-age control group on vocabulary and age.

All participants were administered the *Een-Minuut-Test [One-Minute-Test]* (Brus & Voeten, 1979), a Dutch standardized test of single word reading. This test is commonly used to determine the reading level of children in primary school. The test consists of 116 unrelated words of increasing difficulty. The participants are required to read the words aloud as quickly as possible, and without making mistakes. The score was the number of correctly read words within one minute. A reading lag of at least two years compared to their chronological-age was used as an indication of dyslexia.

Receptive vocabulary was assessed by means of the Passive Vocabulary Test, a standardized subtest of the Dutch *Taaltest voor Kinderen [Language Test for Children]* (Van Bon & Hoekstra, 1982). The construction of the test corresponds with the Peabody Picture Vocabulary Test. The participants had to choose the correct picture from a selection of four, which matched the given word best. The test consisted of 40 items. The vocabulary score is the number of correctly chosen pictures. Children with a vocabulary score beneath the 50th percentile according to the age-norms were excluded from the study.

The 20 children in the DYS-group were selected from a lager group of 30 children ranging in age from 8.8 to 10.8 years. All except three children, who attended primary schools, were dyslexic children who attended schools for primary learning disabled children. The IQ of these children was 85 or above. Children with hearing or articulatory problems, neurological deficits, or children for whom Dutch was not their native language were excluded from the study. In addition, children who had been diagnosed as ADHD were omitted from the study. The teachers of the children had access to the school records of the children and were asked to register which child met one or more of the above exclusion criteria.

The children assigned to the two control groups all attended primary schools. The children in the CA-group were selected from a larger group of 72 children ranging in age from 9.3 to 11.3 years. The children in the RA-group were also selected from a larger group of 86 children ranging in age from 5.4 to 8.10 years. The characteristics of the groups are presented in Table 1.

Instruments

Phonological information processing

Phoneme awareness. A sound deletion task was used to assess phoneme awareness. This task was based on the principle outlined by McDougall et al. (1994). The test consisted of 24 CCVC and CVCC nonwords that were derived from the nonwords used by van Bon and van der Pijl (1997). The nonwords were presented one by one by the experimenter. The child was asked to repeat the nonword to make sure the child had perceived it correctly and could pronounce the nonword accurately. The child was then asked to delete a sound indicated by the experimenter. The initial, middle or final sound had to be deleted on alternate trials. The nonwords used in this task consist of so-called wordlike and nonwordlike nonwords. Six examples preceded the test. Correct deletion never resulted in a word. No corrective feedback was given. The maximum score was 24.

Verbal short-term memory. A nonword memory task was constructed using 12 monosyllabic nonwords derived from the nonword repetition test (de Jong & van der Leij, 1999). None of these nonwords were already used in the sound deletion task. With these nonwords 28 lists were formed varying in length from two to eight nonwords. Four trials of each list length were presented on audio-tape. The participants had to repeat the nonword lists presented in the correct order and without making pronunciation errors. The test was stopped when three or more trials of the same length were incorrectly repeated. For each correctly repeated list of nonwords one point was awarded. The maximum score was 28.

Table 1

Characteristics of the Dyslexic children (DYS), the Reading-Age (RA) control, and the Chronological-Age control (CA) group

	DYS		RA		CA	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (in months)	122.95	3.63	96.70	6.10	121.95	3.03
Word decoding (EMT)	30.20	7.33	32.10	7.81	68.65	9.55
Reading Grade	2.4		2.5		4.5	
Vocabulary (raw score)	34.75	4.68	30.65	3.05	35.60	2.48

Rapid Automatic Naming. This test measured the naming speed of symbols, which is an indication for the rapidity at which phonological information is retrieved from long-term memory. The test consisted of three parts: objects, digits and letters. The participants were shown two cards with 32 and 28 objects respectively (knife, eye, book, door, and jacket) (de Jong & van der Leij, 1999), 24 digits, or 24 letters. The children were required to name the symbols as fast as they could without making mistakes. The naming times on both cards were added for each task and subsequently divided by the total number of symbols, resulting in the naming time per symbol. A low naming score per symbol on these tests represents a high naming speed.

Verbal Learning. Two verbal learning tasks were administered. The tasks measured the ease and accuracy with which children are able to learn to pair words to pictures. On one task, the participants had to learn phonologically familiar words and on the other task unfamiliar words paired to pictures. Hence, a set of four boy-names and a set of four girl-names were composed. The familiar boy-names were Thomas, Stefan, Martin, and Robbert. The unfamiliar names were constructed by rearranging the phoneme sequences across these names in such a way that the new sound strings were not current in Dutch language, yet easily pronounceable. The resulting non-names were Sarne, Tamro, Stomes (pronounced as 'Stomus'), and Rafin. The familiar girl-names were Karin, Hester, Laura, and Judith. The unfamiliar names derived from these names were Itnau, Juttar, Tudil, and Haske. Half of the participants in each group were taught the boy-names and their corresponding non-names, the other half learned the girl-names and non-names.

The verbal learning tasks were administered in two sessions. To avoid sequence effects, half of the participants learned the phonologically familiar words in the first session and the phonologically unfamiliar words in the second session. The remaining participants learned the words in the other order. The (non-) words had to be paired with pictures of cats or dogs.

Each verbal learning task started with a presentation-trial. The child was asked to listen carefully and to try to remember the (non-) name of each animal. One by one, the experimenter showed the four pictures of the cats or dogs, and named them aloud. After each (non-) name the child was asked to repeat the name to make sure the child had perceived it correctly and could pronounce the (non-) name accurately. Subsequently, a recall-trial took place in which the child was asked to pronounce the (non-) name corresponding to the picture shown. Of the child's verbal response a written transcription was made by the test-assistant. Next, another presentation-trial took place, followed by five successive recall-trials. Corrective feedback was given after each response. The maximum score was 24 (4 names x 6 trials).

General Procedure

Each participant was tested individually in his/her school setting in two sessions in a quiet room. The first session took about 15 minutes and started with the administration of the rapid automatic naming tests of objects and digits, followed by the first verbal learning task and the rapid automatic naming of letters. The second session consisted of the sound deletion task, the second verbal learning task, and finally, the nonword memory task. This session took about 35 minutes.

Results

First, the results of the phonological processing tests are presented. Then, the results of the verbal learning tasks are given.

Phonological information processing

In Table 2 the means and standard deviations are presented of the scores of the three reading groups on the tests of sound deletion, verbal short-term memory, and rapid automatic naming.

The scores on the sound deletion task were subjected to an ANOVA. This analysis revealed a significant effect of reading group (F (2, 57) = 4.86, $p < .05$). Contrasts showed that the mean score of the CA group was significantly higher than the mean score of the DYS group (t (57) = 3.11, $p < .01$). No significant mean score differences were found between the DYS group and the RA group.

The scores of the participants on nonword memory were also subjected to an ANOVA. No significant effect of reading group was obtained ($F < 1$). All three groups performed similar on this task.

Table 2

Means and Standard deviations on the phonological processing tests for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group

	DYS		RA		CA	
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sound deletion	17.00	6.17	18.90	4.36	21.45	2.11
Nonword memory	6.00	3.39	6.70	2.54	7.10	3.14
Rapid Automatic Naming [a]						
Objects	.75	.10	.78	.12	.70	.12
Digits	.49	.08	.57	.14	.42	.06
Letters	.62	.16	.62	.11	.44	.08

[a] Naming time per symbol (objects, digits, and letters) in seconds.

The scores on the three RAN-tests were subjected to a multivariate analysis of variance (MANOVA) with objects, digits, and letters as dependent variables and reading group (DYS, RA, and CA) as a between-subjects factor. Subsequently, two orthogonal contrasts were specified: one comparing the CA and DYS group, and the other comparing the DYS and RA group. If the multivariate statistics indicated significant overall differences, then the univariate statistics were considered.

A significant effect of reading group on RAN was found (F (6, 110) = 6.70, $p < .001$). Univariate statistics revealed a significant effect of reading group on digits (F (2, 57) = 12.17, $p < .001$), and on letters (F (2, 57) = 15.21, $p < .001$). The effect of reading group on naming speed of objects approached significance (F (2, 57) = 2.94, $p = .06$). Contrasts showed that the mean naming speed for digits of the DYS group was significantly lower compared to the mean naming speed of the CA group (F (1, 57) = 5.13, $p < .05$), but significantly higher compared to the mean naming speed of the RA group (F (1, 57) = 7.09, $p = .01$). Thus, the dyslexic children needed significantly more time to name digits than their peers without reading problems. Compared to their reading-age controls, however, dyslexic children named digits faster.

Furthermore, group contrasts showed that the mean naming speed for letters of the DYS group was significantly lower than the mean naming speed of the CA group (F (1,57) = 22.81, $p < .001$). Unlike the results for digits, no differences were found between the DYS and RA group.

Finally, contrasts showed that naming speed of objects did not differentiate between the DYS and RA group ($F < 1$). The group contrast between the CA and DYS group (F (1, 57) = 2.61, $p = .06$ one-tailed) approached significance.

Acquisition of new phonological representations

In Table 3 the means and standard deviations of the three reading groups on the verbal learning tasks are presented. The scores on the verbal learning tasks were subjected to a repeated measures analysis of variance with reading group (DYS, RA and CA) as a between-subjects factor, and type of (non-)word learning task as a within-subjects factor.

Table 3

Means and Standard deviations on verbal learning for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group

	DYS		RA		CA	
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*
Verbal Learning						
Words	15.85	3.50	15.35	5.08	19.85	3.47
Nonwords	7.50	4.61	7.05	4.70	10.75	5.87

Subsequently, two orthogonal contrasts were specified: one comparing the CA and DYS group, and the other comparing the DYS and RA group.

A significant effect of reading group was found, $F\ (2,\ 57) = 7.22,\ p < .01$. Contrasts showed that the verbal learning scores of the CA group were significantly higher than the scores of the DYS group, $F\ (1,\ 57) = 9.43,\ p < .01$. No significant differences were found between the RA and the DYS group ($F < 1$). Verbal learning in general appeared to be more difficult for dyslexic children than for their peers without reading problems. In addition, learning phonologically unfamiliar words was significantly more difficult than learning phonologically familiar words for all reading groups ($F\ (1,\ 57) = 150.29,\ p < .001$). Finally, contrary to our prediction, the interaction between reading group and type of word learning task was not significant ($F < 1$).

Next, we considered the errors on the word learning tests. Written transcriptions had been made of the children's responses during the verbal learning tasks. Therefore, it was possible to conduct an analysis of the types of errors. Of six dyslexic children no detailed written transcriptions were obtained due to notation errors during testing. The deletion of these children hardly altered the mean scores of the dyslexic group on the control variables age, word reading and vocabulary. The data presented below are thus based on 14 dyslexic children, 20 chronological-age controls and 20 reading-age controls.

Errors could be made in the pronunciation of the word. These errors were considered as phonological errors. In addition, errors could be made in the pairing of a word to a picture, i.e. general learning errors. The combination of these error types resulted in the distinction of the following types of errors:

1) Pronunciation of the (non-) word incorrect, but paired to the correct picture (pr - / pi +);
2) Pronunciation of the (non-) word incorrect, and paired to the incorrect picture (pr - / pi -);
3) Pronunciation of the (non-) word correct, but paired to the incorrect picture (pr + / pi -);
4) Other errors, mostly "don't know" or mentioning a completely different, but existing word (other).

Each error a child had made was classified in one of the four error categories. Subsequently, for each child the percentage of the errors made within each category was calculated on the basis of the total number of errors made by that child. The mean percentage of errors per category for the three reading groups is displayed in Table 4.

To test for differences among the groups in the type of errors made two variables were considered. One variable was the overall percentage of phonological errors, which was a combination of the percentages of errors on the two phonological error categories (pr - / pi + and pr - / pi -). The other variable was the percentages of general learning errors (pr + / pi -). The category 'other errors' was not used because the scores on this variable, and accordingly the results, would be fully dependent on the scores on the other two variables.

The scores of both variables were rescaled according to an arc-sinus transformation. This was done because group means and variances of scores that reflect percentages tend to be related, which would violate the assumption of their independence underlying analysis of variance. Finally, one outlier in the CA group was excluded from the analysis.

For the learning of phonological unfamiliar words, a multivariate analysis with phonological errors and learning errors as dependent variables and reading group as a between subject factor revealed a significant effect of group (F (4, 98) = 2.67, $p < .05$). Univariate statistics revealed a significant effect of reading group on phonological errors (F (2, 50) = 4.40, $p < .05$) but not on general learning errors (F (2, 50) = 2.19, $p > .05$).

Examination of the group contrasts revealed that the dyslexic children made more phonological errors in learning the phonologically unfamiliar words as compared to both their chronological-age controls (F (1, 50) = 5.17, $p < .05$), and their reading-age controls (F (1, 50) = 8.25, $p < .01$). Although further investigation of group contrasts on general learning errors is disputable because the univariate statistics did not reveal a significant effect of reading group, we were still interested if dyslexic children differed from their reading-age controls on general learning errors. Dyslexic children were found to make a similar amount of general learning errors (i.e., correctly pronounced nonwords paired to incorrect pictures) as their peers without reading problems ($F < 1$). The difference between the dyslexic children and their reading-age controls on general learning errors, however, approached significance (F (1, 50) = 3.77, p = .06); the reading-age controls made slightly more of these general learning errors.

In the condition of learning phonologically familiar words, the dyslexic children and their reading-age controls made a negligible amount of phonological errors while the chronological-age controls made no phonological errors at all. Therefore, we only tested the differences in general learning errors between the reading groups. The ANOVA analysis revealed a significant effect of reading group (F (2, 50) = 5.22, $p < .01$).

Table 4

Error types in percentages in both verbal learning conditions for the Dyslexic (DYS), the Reading-age Control (RA), and the Chronological-age Control (CA) group

% Errors	DYS	RA	CA
Nonwords			
pr - / pi +	24.33	15.34	12.78
pr - / pi -	26.65	13.22	19.75
pr + / pi -	14.64	25.27	17.40
Other	34.39	46.17	50.06
Words			
pr - / pi +	3.88	3.59	0
pr - / pi -	3.68	1.63	0
pr + / pi -	64.14	45.67	67.70
Other	28.30	49.12	32.30

Examination of the group contrasts revealed that, again, no notable difference was found in the amount of general learning errors made by the dyslexic children and their peers without reading problems (t (50) = 0.29, p > .05). Reading-age controls, however, made less general learning errors compared to the dyslexic children (t (50) = - 2.45, p < .05).

Since a negligible amount of phonological errors was made in learning familiar words, only the incorrect pronunciations (i.e. the phonological errors) made in learning the phonologically unfamiliar words were examined in more detail. The errors were divided into three categories: errors on single phoneme level, on syllable level, and on word level could be made (based on Morais, Castro, Scliar-Cabral, Kolinsky, & Content, 1987). In Table 5 the definitions of these phonological errors are displayed.

Each phonological error a child had made was now classified in one of the three phonological error categories. Subsequently, for each child the percentage of the errors made within each category was calculated on the basis of the total number of phonological errors made by that child. In Table 6 the mean percentage of errors per category for the three reading groups are displayed.

Again, the scores of the variables were rescaled according to an arc-sinus transformation. The multivariate analysis with errors on phoneme, syllable, and word level as dependent variables and reading group as a between subject factor revealed a significant effect of group (F (6, 82) = 2.39, p < .05).

Table 5

Definitions of phonological error types, for 'Stomus': *S - T - O - M - U - S*
C1 - C2 - V1 - C3 - V2 - C4

Errors on phoneme level		
C1	changing the initial consonant only	*'S'*
C2	changing the second consonant only	*'T'*
C3	changing the third consonant only	*'M'*
C4	changing the fourth consonant only	*'S'*
V1	changing the first vowel only	*'O'*
V2	changing the second vowel only	*'U'*
Errors on syllable level		
C1V1C2	changes in the first syllable only	*' . . . mus '*
C3V2C4	changes in the last syllable only	*' sto . . . '*
Errors on word level		
C1C2C3C4	changes in the consonants of the word respecting the vowels	*' . . o . u . '*
WWI	whole word intrusions; changes in both consonants and vowels in both syllables	' . . . . . '

Note. Each error can be made in a (non-) word paired to the correct picture (pi +) or to the incorrect picture (pi -).

Univariate statistics revealed a significant effect of reading group on errors on phoneme level (F (2, 43) = 3.59, $p < .05$) but not on syllable level (F (2, 43) = 2.42, $p > .05$), and word level ($F < 1$).

Examination of the group contrasts revealed that the dyslexic children did not differ from their reading-age controls in the amount of errors made on phoneme (F (1, 43) = 1.79, $p > .05$), syllable ($F < 1$), and word level ($F < 1$). Unexpectedly, the dyslexic children also did not differ from their peers without reading problems in the amount of errors made on phoneme (F (1, 43) = 1.57, $p > .05$), and on global word level ($F < 1$). In contrast, the difference between dyslexic children and their chronological-age controls in the amount of errors made on syllable level approached significance (F (1, 43) = 3.40, $p = .07$); the dyslexic children made fewer errors on syllable level.

Discussion

The results on the phonological processing tasks indicate that Dutch dyslexic children have deficits in phonological awareness and rapid automatic naming compared to their chronological-age controls, but not compared to their reading-age controls. Concerning phonological awareness the prediction was that dyslexic children would perform worse on the sound deletion task than their peers without reading problems and their reading-age controls (de Gelder & Vroomen, 1991). In line with previous research, the dyslexic children performed significantly worse on the sound deletion task, but, contrary to our expectations, only compared to their chronological-age controls. These results implicate that dyslexic children encounter difficulties related to their reading-level in the processing of phonological information, especially in the manipulation of sound sequences. A reason for the observed difference between the present results and those of de Gelder and Vroomen (1991) might be that in the latter study the dyslexic children attended regular schools while most of the dyslexic children of the present study were in special education. Possibly, the dyslexic children attending special education received remediation programs focusing on phonological awareness, which might have had a generalization effect.

Table 6

Mean percentages of phonological error types in the nonword learning condition for the Dyslexic (DYS), the Reading-Age Control (RA) and the Chronological-Age Control (CA) Group

% Errors	DYS	RA	CA
Nonword learning			
Phoneme	36.75	43.24	17.87
Syllable	17.87	16.84	33.82
Word	45.38	39.45	48.31

With respect to RAN, the main prediction was that naming speed on all three tasks (objects, digits, and letters) would differentiate dyslexic children from their chronological-age controls and probably also from their reading-age controls. Their naming speed was expected to be considerably lower than the naming speed of the other children without reading problems. This turned out to be a far too simple assumption. Indeed, the dyslexic children had a lower naming speed for digits and letters compared to their chronological-age controls. The difference in naming speed of objects between the two groups just failed to reach significance, although there was a tendency for objects to be named slower by dyslexics than by their peers without reading problems. These results are in accordance with previous research (see Wolf & Bowers, 1999).

The differences between the dyslexic children and their reading-age controls, however, were quite diverse. The speed of naming objects and letters was similar for the dyslexics and their reading-age controls. Thus, not only letter naming speed appears to be related to reading grade, but naming speed of pictures of well known words as well. The naming speed for digits, in contrast, was higher in dyslexic children. This might be caused by the fact that the dyslexic children had more instruction in and experience with mathematics, compared to their reading-age controls. Besides, dyslexic children named digits significantly faster than letters in contrast to both their reading-age and their chronological-age controls. An explanation of this finding could be that digits, compared to letters, are additionally stored in a visuo-spatial manner in long-term memory. This extra coding component of digits might enhance retrieval speed. Although contradicting results have been reported concerning the performance of dyslexics and reading-age controls on RAN-tasks, the results of the present study are in accordance with the results of Badian (1997) and Olson (1995).

For nonword memory the prediction was that dyslexic children would have more difficulty to hold (unfamiliar) phonological material in verbal short-term memory. They were expected to obtain lower scores on this task compared to both their control groups. Unexpectedly, and in contrast with other research assessing verbal memory span (de Jong, 1998; Gathercole & Baddeley, 1990b; Stone & Brady, 1995), performance of the dyslexic children on the verbal memory task did not differ from their chronological-age controls. Also unexpected, the dyslectic children performed similar to their reading-age controls. The processing of unfamiliar phonological information did not appear to be an extra constraint for the dyslexic children. A possible explanation for the aberrant findings might be that the task was very difficult for the children without reading problems as well and therefore unable to discriminate between the groups. The total score that could be obtained was 28 correctly recalled strings of nonwords varying from two to eight nonwords per string. All reading groups obtained a mean score of six or seven correctly recalled strings. This indicates that the correctly recalled string length was maximally three nonwords. Especially for the chronological-age controls this is low (McDougall et al., 1994; Windfuhr & Snowling, 2001).

To sum up, Dutch dyslexic children were found to have deficits in phonological awareness and rapid automatic naming as compared to their peers without reading problems. In contrast, dyslexic children performed similar to their reading-age controls on these tasks, with the exception that dyslexics named digits faster than their younger reading-age controls.

The second aim of this study was to examine whether these phonological processing problems are accompanied by problems in the formation of new phonological representations in dyslexic children. Since dyslexic children have various problems with phonological processing skills that are involved in learning novel phonological material, dyslexic children were expected to have more difficulty than chronological-age controls with learning phonologically unfamiliar words. The present findings support previous research indicating that skilled and less-skilled readers differ on a task likely to approximate vocabulary learning. Dyslexic children indeed had more difficulty with the acquisition of new, phonologically unfamiliar words, in spite of similar performance of dyslexics to chronological-age controls on a verbal short-term memory task. This suggests that dyslexic children need more exposure to and rehearsal of new words to include these words in their lexicon (also see Aguiar & Brady, 1991; Kamhi, Catts, & Mauer, 1990).

Additionally, the results also suggest that poor readers encounter difficulties in the acquisition of familiar words. This result is in contrast with our expectations and partially in contrast with prior research. Vellutino and colleagues (1978, 1983, 1995; Vellutino & Scanlon, 1989) found mixed results concerning differences between older poor and normal readers on paired associate learning of familiar word stimuli. In the two latest studies of Vellutino et al. (1995) and Vellutino & Scanlon (1989) no differences were found between poor en normal readers in learning words of high familiarity and meaning. Remarkably, this was not the case in the present study. One possible explanation for this finding may be sought in the words used. The familiar words used in the present study might have been not so familiar for the participants as expected. Unlike in Vellutino's studies, no preceding check was made to insure that the familiar words were indeed familiar for each individual child. Consequently, it is possible that not all words were entirely familiar to every child.

On both verbal learning tasks dyslexic children performed similar to their reading-age controls. This is in line with the studies of Vellutino et al. (1978, 1983, 1995) and Vellutino and Scanlon (1989). Their poor readers did not perform any better than the reading-age controls on the verbal learning tasks. These outcomes provide additional support for the suggestion that poor and reading level matched normal readers are comparable in phonological processing ability and in the ability to form new phonological representations.

However, in contrast to the control groups, the dyslexic children had particular difficulty with the phonological aspects of the acquisition of the new words. Dyslexic children made more phonological errors while learning the new words than both control groups. These findings are also in line with the results reported by Vellutino and Scanlon (1989) and Vellutino et al. (1995). In addition, no differences were found between the dyslexic children and their peers without reading problems in general learning ability. Neither for the nonwords, nor for the words any differences were found between the dyslexic children and their normal reading peers in the ability to pair (non-) words to the correct pictures.

It has been suggested that dyslexic children form less specified phonological representations of words (Elbro, Nielsen, & Petersen, 1994; Elbro, 1996). As a result, poor readers would only have access to the general acoustic form of the word, and mispronunciations are made. The phonological representation is not sufficiently specific to enable them to recall the correct form. Others (e.g., Metsala & Walley, 1998) have suggested that the representations of dyslexic children did not develop into (fully) segmentalized representations at the level of phonemes. The latter would imply that during the acquisition of novel words especially global errors are to be expected. However, in the present study dyslexic children made an equal amount of phonological errors on the word level, and even less errors on the syllable level as compared to their peers without reading problems. Instead, dyslexic children made more single phoneme errors. These results suggest that the dyslexic children formed new phonological representations that are quite detailed, that is phonological representations that are segmented at the level of phonemes. However, at this level their phonological representations tended to be persistently underspecified. Thus, the results suggest that dyslexic children's relatively slow acquisition of phonological unfamiliar words might be due to phonological processing problems and in particular to the acquisition of phonological representations in which each phoneme is fully specified.

Finally, considering the paired associate learning with phonological familiar words, the evaluation of the types of errors revealed that the dyslexic children made somewhat more phonological errors than both control groups. This might indicate that the dyslexic children possessed less distinct phonological representations of these known words. However, even in the dyslexic children the percentage of phonological errors was very low. Therefore, whether differences in the distinctness of phonological representations between dyslexic children and their normal reading peers can also account for the observed differences in the paired associate learning of known words is not yet clear.

CHAPTER 3

Word, nonword, and visual paired associate learning in Dutch dyslexic children

3. Word, nonword, and visual paired associate learning in Dutch dyslexic children

Verbal and non-verbal learning were investigated in twenty-one 8-11 year-old dyslexic children and chronological-age controls, and in twenty-one 7-9 year-old reading-age controls. Tasks involved the paired associate learning of words, nonwords, or symbols with pictures. Both learning and retention of associations were examined. Results indicated that dyslexic children had difficulty with verbal learning of both words and nonwords. In addition, analysis of the errors made during nonword learning showed that both phonological errors and general learning errors were distributed similarly for the reading groups. This suggests that nonword learning in dyslexics is slower, but not qualitatively different from normal readers. Furthermore, no differences were found between the dyslexics and age-matched normal readers on non-verbal learning. Long-term retention of the learned visual-verbal associations (both words and nonwords) was not impaired in dyslexic children as compared to normal readers. Finally, phonological awareness ability was assessed. Dyslexics performed worse than age-matched normal readers, but similar to reading-age controls.

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Introduction

Word, nonword, and visual paired associate learning in Dutch dyslexic children

An extensive amount of research has yielded considerable evidence that dyslexic children have impairments in phonological processing. Dyslexics have difficulty with phonological awareness (Goswami & Bryant, 1990; Wagner & Torgesen, 1987); shorter verbal short-term memory spans (Brady, 1991; de Jong, 1998; Jorm, 1983; McDougall, Hulme, Ellis, & Monk, 1994; Stone & Brady, 1995); difficulties with the rapid retrieval of the names of familiar symbols such as objects, digits, letters, and colors (see for a review Wolf & Bowers, 1999); and visual-verbal paired associate learning problems (Vellutino & Scanlon, 1989; Vellutino, Scanlon, & Spearing, 1995). Most of these impairments in phonological processing are believed to reflect manifestations of an underlying phonological deficit, often assumed to be a deficit in the quality of phonological representations (Elbro, 1996; Fowler, 1991; Rack, Hulme, Snowling, & Whightman, 1994).

As a prime indicator of a phonological deficit in dyslexic children, phonological awareness ability has been the focus of the majority of studies on normal and deviant reading development. In the present study, however, we were concerned with paired associate learning for two reasons. First, phonological awareness problems of dyslexic children learning to read in transparent orthographies like German and Dutch seem to be restricted to the early phases of learning to read (de Jong & van der Leij, 2003; Landerl & Wimmer, 2000; van Daal & van der Leij, 1999; Wimmer, 1996). Therefore, as Mayringer and Wimmer (2000) argued, in more transparent languages like German and Dutch, support for a phonological deficit explanation of dyslexia also seems to be dependent on the manifestations of other phonological processing impairments like paired associate learning (also see Landerl, Wimmer, & Frith, 1997).

Second, learning to read can, at least to some extent, be regarded as a form of paired associate learning. For example, Ehri (1992) argued that learning to read requires the formation of associations between the written and spoken forms of words (see also Ehri, 1998; Rack et al., 1994). More recently, Snowling (2000) stated that learning to read critically depends on paired associate learning.

In several studies it was found that dyslexic children have problems with visual-verbal paired associate learning. Dyslexic children were found to have more problems associating new, phonologically unfamiliar words with pictures than children without reading problems (Aguiar & Brady, 1991; Vellutino & Scanlon, 1989; Vellutino et al., 1995). In some studies dyslexic children were also shown to have more difficulty learning to associate familiar words with pictures (Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983; c.f. Vellutino & Scanlon, 1989; Vellutino et al. 1995). However, the evidence remains equivocal.

For visual-visual (e.g., non-verbal) paired associate learning the evidence seems to be clear-cut: dyslexic children perform similarly to normal readers (Liberman, Mann, Shankweiler, & Werfman, 1982; Nelson & Warrington, 1980; Rapala & Brady, 1990; Vellutino, Steger, & Pruzek, 1973).

In the present study, we aimed to replicate and extend previous studies regarding paired associate learning in dyslexic children. Most of the previous studies have been conducted within the English language; the one exception is a study by Mayringer and Wimmer (2000) with children learning to read in German. Further research investigating the relation between phonological awareness, paired associate learning, and reading acquisition in transparent orthographies is necessary.

Another feature of previous studies was that most of these studies focused only on verbal (words or nonwords) or non-verbal paired associate learning. To our knowledge, none of these studies included all three types of learning tasks. The current study examined the generality of the paired associate learning deficit by assessing both verbal (words and nonwords) and non-verbal paired associate learning in dyslexic children, age-matched normal readers and reading-age controls.

Furthermore, we addressed three additional issues in the current study. The first concerned the non-verbal learning response format. Until now, the non-verbal learning tasks always involved the *recognition* of the correct answer from several alternatives, whereas verbal learning tasks required the *production* of a word or nonword. Consequently, there is the unsatisfying possibility that the absence of a difference between dyslexic and normal readers in non-verbal learning is due to this particular response format. Hence, in the current study we used a productive non-verbal learning task in which children had to draw the symbol associated with a picture.

Second, we were interested whether paired associate learning problems of dyslexics are based on quantitative or qualitative differences in learning compared to normal readers. To this end an error analysis was conducted in word, nonword, and non-verbal learning. For example, errors made in associating a (non-) word or a symbol with a picture and the phonological errors made by the participants were examined. Additionally, the phonological errors made in verbal learning were examined in more detail. Errors could be either specific (e.g., on phoneme level) or more general (e.g., on syllable level or whole word level).

A final issue addressed in the present study concerned the long-term retention of the learned associations. So far, the long-term retention of established associations has, to our knowledge, not been examined. However, it is important to distinguish if impairments in paired associate learning affect only the establishment of associations or also their long-term retention.

Theoretically, nonword learning deficits of dyslexic children can be explained by problems with the formation of phonological representations of novel sound sequences (Brady, 1997). There is ample evidence that paired associate learning of unfamiliar words is related to phonological awareness. For example, de Jong, Seveke, and van Veen (2000) found that phonological awareness training enhanced nonword learning performance in kindergartners.

Additionally, both Aguiar and Brady (1991) and Mayringer and Wimmer (2000) found that poor readers made more phonological errors in learning new words compared to normal readers. The latter results suggest that the nonword learning process in dyslexic children is qualitatively different from normal readers. As a consequence, differences in phonological awareness performance might explain differences in nonword learning.

There are, however, indications that the paired associate learning problems of dyslexic children are not confined to nonword learning, but seem to concern verbal learning in general. Although mixed results have been found, there is some evidence that word learning is also impaired in dyslexic readers (Messbauer, de Jong, & van der Leij, 2002; Vellutino et al., 1978; Vellutino et al., 1983). Contrary to the nonword learning problems, these word learning problems cannot be explained by problems with the acquisition of new phonological representations since familiar words have already established phonological representations. However, it has been suggested that the phonological representations of dyslexic children are less detailed or indistinct (e.g., Elbro, 1996; Elbro, Borstrøm, & Petersen, 1998). This implies that the phonological representations in the mental lexicon of dyslexic children are less distinct at any moment in time, with unfamiliar words being more underspecified than familiar words. Possibly, it is more difficult to associate qualitatively underspecified phonological representations with visual stimuli. In the same way, Laing and Hulme (1999) showed that visual-verbal paired associate learning performance was better when the words had a higher semantic imageability. From the assumption that visual-verbal paired associate learning is dependent on the quality of phonological representations and that dyslexic children have qualitatively less well developed representations at any point in time, it follows that dyslexic children perform worse than normal readers on both word and nonword learning. In addition, it follows that nonword learning will be more difficult than word learning.

Recently, Windfuhr and Snowling (2001) studied the effects of phonological awareness and paired associate learning on word reading. They found that both processes had partially independent effects on word reading performance. Accordingly, both processes can be separated and contribute in different ways to reading acquisition. Windfuhr and Snowling argued that paired associate learning reflects a kind of general learning parameter, whereas phonological awareness reflects the quality of the phonological representations of words. Hence, differences in phonological awareness could result in nonword learning problems, and paired associate learning problems might result in slower acquisition of associations. A direct implication is that paired associate learning problems of dyslexic children might not be restricted to nonword learning, but are more general. However, the finding that dyslexic children perform at age-equivalent levels on non-verbal learning does not support this proposition (Liberman et al., 1982; Nelson & Warrington, 1980; Rapala & Brady, 1990; Torgesen & Murphey, 1979; Vellutino, Steger, Harding, & Phillips, 1975; Vellutino et al., 1973).

Unfortunately, Windfuhr and Snowling's study only included nonword learning. Therefore, it remains unclear if the combination of phonological deficits and paired associate learning problems could also cause word learning problems in dyslexics. Although it is still unclear how phonological awareness and paired associate learning problems affect verbal learning performance, the pattern of errors made by dyslexics in word learning does not necessarily have to be qualitatively different from normal readers.

In summary, the present study examined verbal and non-verbal paired associate learning deficits in Dutch dyslexic readers. Dyslexic readers were compared to age-matched normal readers, and to reading-age controls on two visual-verbal (words and nonwords) and a visual-visual paired associate learning task. Both the learning of associations and their long-term retention were considered. In addition, we included tasks of phonological awareness and phonological memory.

Method

Participants

The study involved 21 dyslexic children, 21 reading-age controls, and 21 chronological-age controls. Each group consisted of 14 boys and 7 girls. The dyslexic children were individually matched with the reading-age control group on reading ability and with the chronological-age group on vocabulary, non-verbal intelligence and age.

All participants were administered the *Een-Minuut-Test [One-Minute-Test]* (Brus & Voeten, 1979), a Dutch standardized test of single word reading. This test is commonly used to determine the reading level of children in primary schools. The test consists of 116 words of increasing difficulty. The participants are required to read the words aloud as quickly as possible, without making mistakes. The raw score is the number of words read correctly within one minute. This score was then transformed into a standardized reading score ranging from 1 to 19, with a mean of 10 and a standard deviation of 3. Only children who had a standardized reading score within one standard deviation of the mean were selected as controls. A reading lag of at least two years compared to their chronological-age, as indicated by a standardized reading score of 2 or less, was used as an indication of dyslexia.

Receptive vocabulary was measured with the Passive Vocabulary Test, a standardized sub-test of the Dutch *Revisie Amsterdamse Kinder Intelligentie Test [Revised Amsterdam Child Intelligence Test]* (Bleichrodt, Drenth, Zaal, & Resing, 1987). The test is similar to the Peabody Picture Vocabulary Test (Dunn, 1959). The participants had to choose the correct picture from a selection of four, which matched a given word. The test consisted of 60 items. The raw vocabulary score is the number of correctly chosen pictures. Subsequently, this score was transformed into a standardized vocabulary score between 0 and 30, with a mean of 15 and a standard deviation of 5. Children with a standardized vocabulary score of one or more standard deviations below their age-norm were not included in the study.

Finally, to test non-verbal intelligence the *RAVEN Standard Progressive Matrices* (Raven, Court, & Raven, 1986) was administered. The dyslexic children and their chronological-age controls completed all of the 60 items. The reading-age controls on the other hand, completed only the first 36 items because only these items covered the range of intellectual development of these younger children. The raw score is based on the number of correct answers. Percentile points for 6-month age-ranges between 6.03 and 16.08 years of age were obtained. Children with a test score beneath the 40th percentile according to their age-norm were not included in the study.

The 21 children in the dyslexic group were selected from a larger group of 39 children ranging in age from 8.7 to 10.9 years. Except four children, who attended regular primary schools, the dyslexic children came from special schools for children with learning disabilities. The IQ of these children was 85 or above. Information from the school records of the children was used to exclude children with hearing or articulatory problems, neurological deficits, or children for whom Dutch was not their native language. In addition, children who had been diagnosed as ADHD were omitted from the study.

The children assigned to the two control groups attended regular primary schools. The children in the chronological-age control group were selected from a larger group of 114 ranging in age from 9.2 to 11.3 years. Twenty-one children from this group were individually matched with the dyslexic children on vocabulary, non-verbal intelligence and age. The children in the reading-age control group were also selected from a larger group consisting of 129 ranging in age from 7.1 to 8.9 years. Twenty-one children from this group were also individually matched with the dyslexic children on reading ability. The characteristics of the groups are presented in Table 1.

Table 1

Characteristics of the Dyslexic (DYS), the Reading-Age (RA) control, and the Chronological-Age control (CA) group

	DYS		RA		CA	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (in months)	120.52	7.05	94.19	6.15	120.29	5.33
Word decoding	29.24	7.44	29.05	7.32	68.71	8.30
Reading Grade	2.4		2.4		4.5	
Vocabulary [a]	13.52	2.84	16.05	3.34	13.57	3.09
Non-verbal intelligence [b]	57.38	25.38	45.24	13.65	55.71	24.76

[a] Standardized vocabulary score.

[b] Norm percentiles of group means.

Instruments

Phonological information processing

Phoneme deletion. This test consisted of 24 CCVC and CVCC nonwords that were derived from those used by van Bon and van der Pijl (1997). The nonwords were presented one by one by the experimenter. The child was asked to repeat each nonword to make sure the child had heard it correctly and could pronounce the nonword accurately. Then, the experimenter gave a phoneme, which had to be deleted from the nonword. The phoneme to be deleted could be either from the initial, the middle, or the final component of the nonword (after McDougall et al., 1994). Correct deletion always resulted in a nonword. Six examples preceded the test items. The maximum score was 24.

Word Completion. This test is part of a battery of language tests, the Dutch *Taaltest voor Kinderen [Language Test for Children]* (van Bon & Hoekstra, 1982). The test consists of 29 items preceded by 5 items for practice. Well-known words from which one, two or three phonemes were omitted were presented twice on audiotape. The children were asked to give the complete word. For example, in the case of --IEG-UIG, the complete word would be *VL*IEG*T*UIG ('airplane'). The maximum score was 29.

Nonword repetition. A nonword repetition test (Dutch version by de Jong & van der Leij, 1999), developed after the nonword repetition test reported by Gathercole and Baddeley (1989), was used to measure the quality of the phonological store of verbal working memory. The participants had to repeat nonwords that were presented on audiotape. Each word was presented twice before a response was required. The number of syllables per word varied from one to four. The test consisted of three practice items and 48 test items. The maximum score was 48.

Paired associate learning

Three paired associate learning tasks were administered: a word learning task, a nonword learning task, and a non-verbal learning task. In each task, four pictures of animals (cats, dogs or fish) had to be associated with four names, four nonsense names or four symbols, respectively. We made sure that no relation existed between the pictures and the various names or symbols.

Stimulus material. The familiar names used in the *word learning* task were a set of high frequency Dutch boy's names (Thomas, Stefan, Martin, and Robbert) and a set of highly frequent Dutch girl's names (Karin, Moniek, Linda, and Judith).

The unfamiliar names used in the *nonword learning* task were constructed by rearranging the phoneme sequences across the set of boy's or girl's names in such a way that the new sound strings were not a part of the Dutch language, yet were easily pronounceable. Bigram frequencies (Bakker, 1990) were used to ensure that the letter clusters within the newly formed names were of low frequency in Dutch. Hence, all nonsense names would be equally unfamiliar for the children, and, more importantly, the interference of lexical knowledge would be minimal. The resulting boy's nonsense names were Festan, Tanrim, Samot, and Bornet, and the resulting girl's nonsense names were Munik, Jidon, Tadil, and Kieran. Half of the participants in each reading group were taught the familiar boy's names and the unfamiliar girl's names; the other half learned the familiar girl's names and the unfamiliar boy's names.

In the *non-verbal learning* task, simple symbols were used (e.g., Figure 1). Each symbol consisted of four parts: four lines or three lines and a dot. In each series, the four symbols were clearly distinguishable from one another.

Procedure. Each learning task started with a presentation trial. The experimenter showed the four pictures of animals one after the other and named them aloud during the verbal learning tasks, or showed the corresponding symbol during the non-verbal learning task. The child was asked to listen or to watch carefully and try to remember the (nonsense) name or symbol corresponding to the picture. In the verbal learning tasks, the child was asked to repeat the (nonsense) name pronounced by the experimenter to ensure that the child had heard it correctly and could also pronounce the (nonsense) name accurately. With regard to the non-verbal learning task, the child was asked to draw the symbol shown in a booklet to ensure that the child could draw the symbol accurately. Subsequently, a test trial took place in which the child was asked to pronounce the (nonsense) name or to draw the symbol corresponding to the picture. Thereafter, another presentation trial took place, followed by five successive test trials. Irrespective of the response from a child, correct or incorrect, the experimenter always pronounced the correct (nonsense) name or showed the correct symbol as feedback. The maximum score was 24 (4 (nonsense) names/symbols x 6 test trials).

Scoring of errors. An audio recording of the child's verbal responses was made and transcribed after a test session. These transcriptions were then used to analyze the types of errors made in case of an incorrect response.

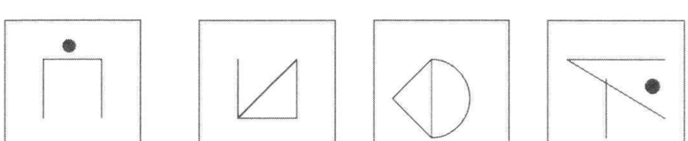

Figure 1
Example of a series of four symbols used in the visual paired associate learning task

The following error types were distinguished:

1) General learning errors: correct pronunciation of the (nonsense) name, but associated with the incorrect picture;
2) Phonological errors: incorrect pronunciation of the (nonsense) name, and associated with the correct or incorrect picture;
3) Other errors: mostly "don't know", or responding with another name or a familiar word.

To examine the errors made in the non-verbal learning task the category "phonological errors" was replaced by the category "drawing errors":

4) Drawing errors: errors made in drawing the symbols, for example orientation and mirroring errors.

Additionally, the phonological errors made in verbal learning were examined in more detail. Errors could be made either on the phoneme level (changing the initial, second, third or fourth consonant or the first or second vowel within a (non-) word), syllable level (changes in the first or second syllable, consisting of two or more phonemes), or word level (changes in the consonants of the word without affecting the vowels, and whole word intrusions, e.g. changes in both consonants and vowels in both syllables) (categories derived from the error categories used by Morais, Castro, Scliar-Cabral, Kolinsky, & Content, 1987).

Cued recall. One week after the administration of a paired associate learning task, long-term retention was assessed using a cued recall task. Before this task was administered, each child was asked to recall the names, non-names or symbols that had been learned the previous week. When a child could not recall all four items, the experimenter provided the missing ones. Next, the experimenter showed the four pictures one by one and asked the child if it could pronounce the name or non-name or could draw the symbol associated with each picture. The experimenter wrote down the verbal responses of the children. No corrective feedback was given. The maximum score was 4.

General procedure

Each participant was tested individually in three sessions in a quiet room. The first session took about 20 minutes and started with the administration of the phoneme deletion task, followed by the first paired associate learning task. The second session took about 30 minutes and consisted of the cued recall task of the first paired associate learning task, the nonword repetition test, and the second paired associate learning task. Finally, the third session started with the cued recall task of the second paired associate learning task, followed by the word completion task, and the third paired associate learning task. This last session took about 20 minutes.

The two verbal learning tasks and the non-verbal learning task were administered during three separate test sessions. To avoid sequence effects, one third of each reading group learned the familiar words in the first session, one third in the second and one third in the final. Similarly, one third of each reading group learned the unfamiliar words in one of the two remaining sessions. Finally, one third of each group learned to associate the symbols with the pictures in one of the two remaining sessions.

Results

The results are presented in three sections. First, the results of the phonological processing tasks are shown. Second, the results of the paired associate learning tasks are addressed, followed by the investigation of the relationship between phonological processing and verbal learning and an extensive analysis of the errors made in both verbal and non-verbal learning. And, finally, the results of the long-term retention of the learned associations are presented.

Phonological information processing

The mean scores and standard deviations of the groups on the three phonological processing tasks are presented in Table 2. The scores were subjected to a multivariate analysis of variance (MANOVA) with phoneme deletion, word completion, and nonword repetition as dependent variables and reading group (dyslexic readers, reading-age controls, and chronological-age controls) as a between-subjects factor.

Subsequently, two orthogonal contrasts were specified: one comparing the chronological-age control group and the dyslexic group, and the other comparing the dyslexic and the reading-age control group. If the multivariate statistics indicated significant overall differences, the univariate statistics were considered.

Table 2

Mean Scores (M) and Standard Deviations (SD) for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the Phonological Processing Tasks

	DYS		RA		CA	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*
Phoneme Deletion (max. 24)	17.67	4.81	18.00	3.77	21.33	2.59
Word Completion (max. 29)	20.48	3.59	20.29	2.45	23.81	2.09
Nonword Repetition (max. 48)	32.57	7.49	33.71	5.16	37.76	3.30

A significant effect of reading group on phonological processing was found (F (6, 116) = 5.53, $p < .001$). Univariate statistics revealed a significant effect of reading group on phoneme deletion (F (2, 60) = 5.88, $p < .01$), word completion (F (2, 60) = 10.65, $p < .001$), and nonword repetition (F (2, 60) = 5.00, $p = .01$).

Contrasts showed that the mean scores of the dyslexics on all phonological information-processing tasks were significantly lower than the mean scores of the chronological-age controls (phoneme deletion, F (1, 60) = 9.61, $p < .01$; word completion, F (1, 60) = 15.06, $p < .001$; and nonword repetition, F (1, 60) = 9.06, $p < .01$). The mean score differences between the dyslexics and the reading-age controls on the phonological processing tasks were not significant (all $F < 1$).

Verbal and non-verbal learning

In Table 3 the means and standard deviations of the reading groups on the three paired associate learning tasks are presented. The scores on the verbal and non-verbal learning tasks were subjected to a MANOVA for repeated measures with reading group (dyslexic readers, reading-age controls, and chronological-age controls) as a between-subjects factor, and type of learning task (words, nonwords, and symbols) as a within-subjects factor.

To test the hypothesis that dyslexic children perform worse than chronological-age and reading-age controls on verbal learning compared to non-verbal learning, a contrast was specified on the within-subjects factor learning task (words and nonwords, versus symbols), and two contrasts were specified on the between-subjects factor reading group (chronological-age controls versus dyslexics, and dyslexics versus reading-age controls). For each between-subjects contrast, a main effect of reading group indicated that one of the groups performed lower on both verbal and non- verbal learning. An interaction effect of reading group by learning task indicated that the difference between the two contrasted groups was dependent on the type of learning task (verbal versus non-verbal).

Table 3

Mean Scores (M) and Standard Deviations (SD) for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the Learning Tasks

	DYS		RA		CA	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*
Nonwords	8.29	4.62	7.29	5.34	11.71	5.61
Words	18.81	3.60	16.86	5.42	21.38	2.44
Symbols	19.57	3.03	15.86	5.00	18.57	4.65

Note. Maximum score on each Learning Task is 24.

This analysis, comparing verbal and non-verbal paired associate learning, revealed a significant interaction effect of reading group by learning task for chronological-age controls versus dyslexics (F (1, 60) = 8.85, $p < .01$). Dyslexic children and their chronological-age controls performed similar on non-verbal learning, but dyslexic children performed worse on verbal learning. Comparison of the verbal and non-verbal learning performance of dyslexic children and reading-age controls also revealed an interaction effect (F (1, 60) = 5.81, $p < .05$). Dyslexic children performed better than the reading-age controls on non-verbal learning, but similar on verbal learning.

A second contrast was specified on the within-subjects factor learning task to test whether dyslexic children performed worse than chronological-age and reading-age controls on nonword learning as compared to word learning. With this contrast on the learning task factor, a main effect of reading group indicated that one of the contrasted groups performed lower on both word and nonword learning. An interaction effect of reading group by learning task indicated that the difference between the two contrasted groups was dependent on the type of learning task (words versus nonwords).

For the dyslexics and chronological-age controls we did not find an interaction of reading group by learning task ($F < 1$). However, a main effect of reading group was found (F (1, 60) = 6.21, $p < .05$). The dyslexic children performed significantly worse than their chronological-age controls on both word and nonword learning. Dyslexic children were found to perform similar to their reading-age controls on both verbal learning tasks (F (1, 60) = 1.50, $p > .20$).

Relationships between phonological processing and verbal learning

The word and nonword learning problems of dyslexic children could be due to their phonological processing problems. Accordingly, if phonological processing ability is taken into account the differences between dyslexic and age-matched normal readers on verbal learning performance should disappear.

To test this possibility, we first conducted a principal component analysis on the data from the three phonological variables. This analysis yielded one factor with an eigenvalue of more than one. This phonological processing factor accounted for 48.61% of the variance and received similar loadings from phoneme deletion (.74), word completion (.72), and nonword repetition (.64).

Next, for each participant phonological processing factor scores were derived on the basis of this principal component analysis. To test if phonological processing could account for differences in verbal learning between dyslexic and normal readers, the scores on the verbal learning tasks were subjected to a MANCOVA for repeated measures with reading group (dyslexic readers, reading-age controls, and chronological-age controls) as a between-subjects factor, and type of learning task (words and nonwords) as a within-subjects factor, and phonological processing as a covariate. The phonological processing factor score of one dyslexic participant qualified as an outlier and was excluded from the analysis.

The analysis revealed a significant effect of the phonological processing factor score on verbal learning (F (1, 58) = 6.53, $p < .05$). The performance differences between dyslexics and chronological-age controls on word and nonword learning disappeared (F (1, 58) = 0.65, $p > .40$). These results suggest that both phonological awareness and verbal learning problems of dyslexic children may reflect the same underlying difficulty.

Analysis of the errors made in paired associate learning

We were particularly interested in the nature of the difficulties encountered during word and nonword learning, and during non-verbal learning. In verbal learning, we examined the written transcriptions that were made of the children's responses during the two tasks. Each error was classified in one of three error categories (see the Method section for a detailed description of the error categories). Subsequently, for each child the percentage of errors within each category was calculated on the basis of the total number of errors.

The mean percentages of errors per category for the three reading groups are presented in Table 4. The dyslexic children made more errors in an absolute sense than the chronological-age controls in both word and nonword learning. However, the distribution (relative percentages) of the errors made was similar for both groups.

Table 4

Error percentages for the Dyslexic (DYS), the Reading-age Control (RA), and the Chronological-age Control (CA) group on the Learning Tasks

Task/Type of error	DYS	RA	CA
Nonwords			
Phonological errors	40.38	32.99	43.52
General learning errors	22.86	25.35	20.10
Other errors	36.77	41.67	36.38
Words			
Phonological errors	1.25	0	0
General learning errors	52.63	47.12	57.22
Other errors	46.12	52.88	42.78
Symbols			
Drawing errors	34.37	34.24	34.20
General learning errors	51.72	54.62	43.21
Other errors	13.92	11.14	22.59

Note. All percentages are calculated relative to the total number of errors made by the individual participants in each reading group.

Differences in error types between the reading groups were analyzed per learning task. This approach was used for two reasons. First, the errors made in non-verbal learning are qualitatively different from the errors made in verbal learning and could therefore not be compared in one analysis. Second, because a negligible amount of phonological errors was made in word learning the distribution of the errors made was quite different for word and nonword learning. Simultaneous analysis of the errors made in both verbal learning tasks would therefore affect the results negatively.

To test for group differences in error types in verbal learning, two variables were considered: the phonological errors and the general learning errors. The category 'other errors' was not used because the scores on this variable, and accordingly the results, would be fully dependent on the scores on the other two variables.

Before a MANOVA was performed for each learning task with phonological or drawing errors, and learning errors as dependent variables and reading group (dyslexic readers, reading-age controls, and chronological-age controls) as a between-subject factor, the scores on the error categories were rescaled according to an arc-sinus transformation. This was done because group means and variances of scores that reflect percentages tend to be related, which would violate the assumption of their independence underlying analysis of variance.

For learning nonwords, no significant effect of reading group was found ($F < 1$). The phonological and general learning errors were distributed similarly over these error categories across all three reading groups.

For learning words, a negligible amount of phonological errors was made. Therefore, only the differences between the groups in general learning errors were tested using an ANOVA. No significant effect of reading group was found ($F(2, 56) = 1.05$, $p > .30$).

For non-verbal learning the error percentages seemed to vary more across reading groups. However, no significant effect of reading group was found ($F < 1$).

Phonological error investigation

Finally, the phonological errors made in verbal learning were examined in more detail. This only concerned the phonological errors made in nonword learning. Investigation of the phonological errors made in learning familiar words was superfluous, because a negligible amount of phonological errors was made in this condition.

Errors could be made either on the phoneme level (changing *one* phoneme within a (non-) word), syllable level (changes in the first or second syllable, consisting of two or more phonemes), or word level (changes in the consonants of the word, and whole word intrusions, e.g., changes in both consonants and vowels in both syllables). Each error was classified in one of these three phonological error categories. Subsequently, for each child the percentage of errors within each category was calculated on the basis of the total number of phonological errors.

In Table 5 the mean percentage of errors per category for the three reading groups are displayed. Once more, it can be seen that the distribution (relative percentages) of the phonological errors in nonword learning was quite similar for all the reading groups.

Again, the scores of the variables were rescaled according to an arc-sinus transformation. The multivariate analysis with errors on the phoneme, syllable, and word level as dependent variables and reading group as a between-subjects factor revealed no significant effect of reading group ($F < 1$). The phonological errors in nonword learning were distributed similarly across the various error categories for all three reading groups.

Long-term retention of verbal and non-verbal associations

One week after the administration of a paired associate learning task, long-term retention was assessed using a cued recall task. As mentioned before, for each child only two long-term retention scores were obtained because the retention task was administered only during the second and the third test sessions. Therefore, random groups of 14 of the 21 children per reading group were available for each retention task (words, nonwords, and non-verbal). In Table 6 the mean scores on the last learning trial of the paired associate learning task and on the retention trial are presented for each of the reading groups.

We were interested in differences across the reading groups in *long-term retention* of the learned visual-verbal and visual-visual associations, and especially in the degree of decline in performance between the last learning trial and the long-term retention trial. Because the reading groups consisted of different groups of subjects for each learning and retention task, the mean reading group scores were analyzed for each paired associate learning task separately. The scores of the reading groups on the tasks were subjected to a repeated measures analysis with reading group as a between-subjects factor, and type of trial (last learning trial and retention trial) as a within-subjects factor.

Table 5

Type of phonological error in percentages for the Dyslexic (DYS), the Reading-age Control (RA), and the Chronological-age Control (CA) group on the Nonword Learning Task

Type of error	DYS	RA	CA
Phoneme level	36.76	30.42	31.23
Syllable level	30.43	27.39	24.59
Word level	32.81	42.20	44.18

Note. All percentages are calculated relative to the number of phonological errors made by the individual participants in each reading group.

Furthermore, two contrasts were specified on the between-subjects factor reading group (chronological-age controls versus dyslexics, and dyslexics versus reading-age controls). With this specification, a main effect of reading group indicated that one of the groups performed lower on both the last learning trial and on the retention trial. An interaction effect of reading group by type of trial indicated that the difference between the two contrasted groups was dependent on the type of trial (last learning trial versus retention trial).

For *nonword learning* there was no significant difference between the last learning trial and the retention trial (F (1, 30) = 1.07, $p > .30$). The dyslexic children, however, performed significantly worse than the chronological-age controls on both the last learning trial and the retention trial (F (1, 39) = 9.86, $p < .01$). Additionally, the dyslexic children performed similarly to their reading-age controls on both the last learning trial and the retention trial of non-names ($F < 1$). The reading group by type of trial (last or retention) interactions were not significant.

With respect to *word learning*, all reading groups performed significantly worse on the retention trial compared to their score on the last word learning trial (F (1, 39) = 16.96, $p < .001$). Again, the reading group by type of trial (last or retention) interactions were not significant (all $F < 1$).

Finally, with respect to *non-verbal learning*, all three reading groups scored significantly lower on the retention trial (F (1, 38) = 17.17, $p < .001$). Interactions were found between reading group and type of trial. The decline in performance of the dyslexic children was significantly larger than the decline in performance of both the chronological-age controls (F (1, 38) = 4.77, $p < .05$), and the reading-age controls (F (1, 38) = 4.03, $p = .05$).

Table 6

Mean Scores (M) and Standard Deviations (SD) on the Last Learning Trial and the Retention Trial of each Learning Task for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group

	DYS		RA		CA	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*
Nonwords						
Last learning trial	1.64	1.28	1.57	1.50	2.93	1.07
Retention trial	1.93	1.07	1.86	1.10	3.00	1.11
Words						
Last learning trial	3.57	0.76	3.57	1.09	3.79	0.58
Retention trial	3.07	0.62	2.86	0.86	2.86	1.10
Symbols						
Last learning trial	3.69	0.63	2.57	1.09	3.43	0.76
Retention trial	2.46	0.88	2.14	1.03	3.07	1.07

Note. Maximum score per trial is 4.

Discussion

In the current study dyslexic children were found to perform worse than age-matched normal readers on several phonological processing tasks, which are generally assumed to reflect manifestations of a core phonological deficit. The main findings of the study concerned verbal and non-verbal paired associate learning performance of both dyslexics and normal reading children. Before discussing the findings on this matter, the findings on the phonological processing tasks will be addressed.

As expected, the dyslexic children had more difficulty with both phonological awareness and phonological memory than their chronological-age matched controls. As found more often in Dutch studies, the dyslexic children performed similar to their reading-age matched controls (e.g., de Jong, 1998; Messbauer et al., 2002). On average, the dyslexic children answered 68% to 74% of the items on the tasks correctly. Therefore, their performance could be qualified as high, especially in view of the fact that nonwords had to be processed which gave the tasks a relatively high level of difficulty. The finding that the dyslexic children performed relatively well on the phonological processing tasks is in accordance with the idea that learning to read in a transparent language helps even dyslexic children to gain relatively high levels of phonological awareness. This is probably the reason that we did not find a difference in phonological awareness and phonological memory between the dyslexic children and the reading-age controls. Consequently, at this age a causal nature of the relationship between phonological skills and reading is not supported. In a transparent language, for example Dutch or German, support for such a relationship has only been found at the very early stages of learning to read (de Jong & van der Leij, 1999; Wimmer, 1996). At the end of primary school, even the difference between dyslexic and normal reading children tends to decrease (Landerl & Wimmer, 2000; van Daal & van der Leij, 1999), and only shows up when task demands are heavily increased (de Jong & van der Leij, 2003).

Concerning paired associate learning, it was found, like in several previous studies (Messbauer et al., 2002; Vellutino et al., 1978; Vellutino et al., 1983), that the dyslexic children performed worse than age-matched normal readers on both word and nonword learning. Dyslexic children were found to perform similarly to reading-age matched controls on verbal learning. The latter result implies that, in principle, a conclusion about the causal nature of the relationship between verbal learning and reading is not warranted. Finally, we found for non-verbal learning that dyslexics performed similarly to age-matched normal readers, but better than their reading-age controls.

The current findings are not in accordance with the hypothesis that dyslexic children have specific difficulties with the acquisition of new phonological representations (Aguiar & Brady, 1991; Mayringer & Wimmer, 2000). The dyslexic children also had word learning problems. In addition, the dyslexic children were found to make a similar percentage of phonological errors during nonword learning as both the chronological-age and the reading-age controls. Thus, this suggests that dyslexic children's problems with the acquisition of new phonological representations are not specifically phonological. However, it should be noted that this result is not in accordance with the results of a similar, but smaller study by Messbauer et al. (2002), in which dyslexic children were found to make more phonological errors. We have no ready explanation for this difference, except that in the study of Messbauer et al. only some of the dyslexic children were used for the analysis of the phonological errors.

In this study, like Messbauer et al. (2002), we found that the phonological errors of the dyslexic children made during nonword learning concerned both global errors, on the syllable and the whole word level, and quite specific errors at the phoneme level (compare Metsala & Walley, 1998). In fact, the phonological errors made by the dyslexics were distributed evenly over these error categories and were comparable to the distribution of the age-matched normal readers. These results suggest that the acquisition of new phonological representations in dyslexic children is slower, but not qualitatively different from their normal reading peers.

The finding of both word and nonword learning difficulties in dyslexic children suggests a more general verbal learning problem. However, the nature of this problem seems to be phonological. When phonological awareness was taken into account, the differences between dyslexics and age-matched normal readers on both word and nonword learning disappeared. This result suggests that phonological awareness and visual-verbal learning are both dependent on the quality of phonological representations. For verbal learning, we hypothesize that the more distinct the phonological representations of words and nonwords are the better they can be associated with visual stimuli. This hypothesis explains why dyslexic children, having a deficiency in the quality of phonological representations, were found to have problems with both word and nonword learning, but not with visual-visual learning, and why paired associate learning for nonwords is more difficult than for words. In addition, one might speculate that in a transparent orthography the quality of phonological representations, like phonological awareness, is enhanced by learning to read. This can explain the absence of a difference between dyslexic children and their reading-age controls in verbal paired associate learning.

Our findings are not in accordance with the hypothesis, suggested by Windfuhr and Snowling (2001), that paired associate learning reflects a general ability for the formation of associations. Windfuhr and Snowling found in a group of normal readers, that paired associate learning of nonwords to pictures remained to have an effect on reading ability when phonological awareness was taken into account. In the current study differences between dyslexic and normal readers disappeared when phonological awareness was controlled for. However, it should be noted that verbal learning and phonological awareness in the Windfuhr and Snowling study were substantially related, suggesting that both abilities might depend, at least to some part, on the quality of phonological representations. At least two differences between the present study and the study of Windfuhr and Snowling are noteworthy. First, Windfuhr and Snowling used the full range of reading abilities, whereas we made a comparison between groups of differing reading abilities. Secondly, the dyslexic children in the present study read words and nonwords accurately but not fluently. In the Windfuhr and Snowling study the main reading measure concerned accuracy. Possibly, phonological awareness and verbal learning have independent effects on accuracy, whereas their effects on fluency might be interchangeable. Evidently, more research is needed to show that visual-verbal paired associate learning also reflects a general kind of learning parameter. The results of the current study strongly suggest that such a parameter is tied to verbal learning because the dyslexic children did not show any non-verbal learning deficiencies. In addition, in the error analysis we did not find that dyslexic children made more general learning errors, defined as the association of a correct word, nonword or symbol with the wrong picture.

In the current study we also considered the long-term retention of learned associations. With regard to verbal learning (both words and nonwords) the problem of dyslexic children seems to lie in the acquisition of the correct associations and not in their long-term retention (compare Gathercole & Baddeley, 1990). The dyslexic children learned less word and nonwords, although they had improved on both from trial one to six. But, compared to the other groups, they did not forget relatively more. It therefore appears that dyslexic children need more exposure or rehearsal in verbal learning (also see Aguiar & Brady, 1991; Kamhi, Catts, & Mauer, 1990), but they do not seem to have impaired long-term recall of the verbal labels. Translated to reading, these findings suggest that dyslexic children's problem with the acquisition of orthographic knowledge primarily concerns the build-up of associations between the orthographic and the spoken forms of words. Given the current results, we hypothesize that dyslexic children are not specifically susceptible to the loss of established associations.

In contrast, however, for non-verbal learning, dyslexic children and age-matched normal readers do not differ in the acquisition of the associations, but rather in their long-term retention. These findings are difficult to explain, certainly in light of the strong research findings on this matter that dyslexic children do not have problems in non-verbal learning at all (Vellutino et al., 1975; Vellutino et al., 1978; Vellutino et al., 1983; Vellutino & Scanlon, 1989; Vellutino et al., 1995). Additional research is necessary to replicate and subsequently interpret these findings about non-verbal retention.

In conclusion, we found that Dutch dyslexic children have difficulty with verbal learning of both phonologically familiar and unfamiliar words. In addition, an analysis of the errors in nonword learning showed that the phonological and general learning errors were distributed similarly across the reading groups. This suggests that nonword learning, though slower in dyslexic readers, is not qualitatively different from normal readers. Furthermore, we found no differences between the dyslexics and normal readers on non-verbal learning. Thus, paired associate learning problems of dyslexic children are confined to verbal learning.

Chapter 4

Effects of visual and phonological distinctness on visual-verbal paired associate learning in Dutch dyslexic and normal readers

4. Effects of visual and phonological distinctness on visual-verbal paired associate learning in Dutch dyslexic and normal readers

In three studies, the effects of visual and phonological distinctness on the visual-verbal paired associate learning of dyslexic and normal readers in the age of 10 to 12 were examined. We hypothesized that both groups would be equally affected by the visual distinctness of the pictures, whereas the learning performance of the dyslexic children would be more susceptible to the phonological distinctness of the verbal stimuli (words). As expected, in Study 1 we found that the visual distinctness of pictures had a similar effect on both groups. However, the results of Studies 2 and 3 on the effect of phonological distinctness did not support the hypothesis. Both reader groups were equally affected by the phonological distinctness of the words. In addition, we found that, although not consistently, dyslexic children tended to be worse in verbal learning, which could to a large extent be explained by their problems with phonological processing.

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Introduction

Effects of visual and phonological distinctness on visual-verbal paired associate learning in Dutch dyslexic and normal readers

A problem in the phonological representation of spoken words in long-term memory is generally believed to be a core deficit in developmental dyslexia (Elbro, 1996; Fowler, 1991; Metsala & Walley, 1998; Snowling & Hulme, 1994). Phonological representations of dyslexics have been described as poor, less segmentalized, underspecified and indistinct (Dietrich & Brady, 2001; Elbro, 1996; Metsala & Walley, 1998). Such underspecified phonological representations have been hypothesized to have direct and indirect effects on the development of accurate and fluent reading (e.g., Vellutino, Fletcher, Snowling, & Scanlon, 2004).

Indirect effects of a deficiency in the quality of phonological representations on reading concern problems in a range of phonological processing abilities, which, in turn, are assumed to affect reading acquisition. Phonological processing problems encompass speech perception, speech production, phonological awareness, verbal short-term memory, and visual-verbal paired-associate learning (e.g., Snowling, 2000). Of these problems, impairments in phonological awareness, that is the sensitivity for the sound units in spoken words, are the most prominent. A large body of evidence supports a relationship between phonological awareness and learning to read. Especially an awareness of phonemes is considered as a prerequisite for the discovery of the alphabetic principle (Byrne, 1998), and for the formation of fine-grained associations between the graphemes in written and the phonemes in spoken words (e.g., Ehri, 1998).

However, a growing number of studies tend to suggest that the severity of dyslexic children's problems in phonological awareness might depend on the transparency of the orthography in which children learn to read. In the more transparent orthographies, like Greek, German or Dutch, these problems have been found to be less pervasive than in English with its opaque orthography (de Jong & van der Leij, 2003; Landerl & Wimmer, 2000; Wimmer, 1996). As argued by Mayringer and Wimmer (2000; see also Vellutino et. al., 2004), to examine the consequences of underspecified phonological representations in learning to read a transparent orthography, other phonological processing abilities are also of interest. In the present study, we were concerned with the effects of impaired phonological representations on visual-verbal paired associate learning (PAL).

Visual-verbal PAL differs in two important respects from other phonological processing abilities. First, unlike abilities such as phonological awareness and verbal-short term memory, PAL is not a pure auditory task, but also involves a visual component. An association has to be established between a visual and a phonological representation, and consequently, both visual and phonological abilities could in principle be involved. Second, PAL is a learning task, and might therefore give a view on development, albeit in a small time window. These aspects of visual-verbal PAL are of interest, because they are also involved in learning to read. As argued for example by Ehri (1992), reading acquisition entails the learning of associations between the written and spoken form of words (see also Rack, Hulme, Snowling, & Wightman, 1994). Of course, there is an important difference between visual-verbal PAL and reading as well. In reading, associations are less arbitrary, as letters in written words are connected to the sounds in spoken words, whereas this is not the case in visual-verbal PAL. Nevertheless, Snowling (2000; Windfuhr & Snowling, 2001) suggested that paired associate learning as such might be critically involved in reading acquisition.

There is already a fair amount of evidence to suggest that dyslexic children are impaired in visual-verbal PAL. Most studies have been concerned with the learning of associations between pictures and phonological unfamiliar (nonwords) or familiar words. For nonword learning, dyslexic children have been consistently found to be slower in the acquisition of novel phonological representations than normal readers (Aguiar & Brady, 1991; Messbauer & de Jong, 2003; Vellutino & Scanlon, 1989; Vellutino, Scanlon, & Spearing, 1995). The results of several studies also suggest that dyslexic children have problems in word learning, although the evidence on word learning is less consistent (Messbauer, de Jong, & van der Leij, 2002; Messbauer & de Jong, 2003; Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983). As the present study was concerned with the effects of the quality of phonological representations of spoken words on visual-verbal PAL, it seemed logical to confine the study to word learning. More in particular, we examined the effects of the phonological distinctness of words and the visual distinctness of pictures on word learning in dyslexic and normal readers.

Distinctness of a phonological representation has been defined by Elbro (1996) as 'the magnitude of the difference between a lexical representation and its neighbors' (p. 454). In dyslexic children, having less distinct representations, differences among neighbors are presumed to be smaller than in normal readers. Consequently, word learning of a set of words that are neighbors might pose a specific problem for dyslexic readers. For example, phonological differences among a set of words such as *sting*, *sling* and *slink* are minimal. A detailed representation of the phonological features of these words seems critical in a word learning task that involves these words. If not all phonological features of these words are represented adequately, there will be relatively more overlap among their phonological representations and, consequently, the possibility of confusion in the word learning task will increase. In contrast, words like *sling*, *hand* and *stop* are phonologically more distinct as they are not neighbors. Performance in a word learning task with this set of words will probably be less dependent on the quality of their phonological representations, as there are more different phonological features to distinguish these words. Thus, following Elbro's definition, we hypothesized that the word learning performance of dyslexic children would be more affected by the phonological distinctness among the words to be learned, than word learning in normal readers.

Instead of being less distinct, Metsala and Walley (1998; see also Fowler, 1991) have adopted the slightly different view that dyslexic children's phonological representations are less segmentalized. According to their lexical restructuring theory, children's initial holistic phonological representations become increasingly more segmentalized during the preschool and early school years, and eventually will be restructured to phoneme level representations. Vocabulary growth is assumed to be the driving force behind lexical restructuring, because the increase in words to be stored in long-term memory requires a more efficient storage system. According to the lexical restructuring theory, the need for segmentalized representations is most acute for words in dense neighborhoods. Such words are harder to differentiate from other lexical candidates. The underlying assumption here is that holistic representations are more similar (or in Elbro's conception less distinct) than segmentalized representations. It follows that for dyslexic readers, having less segmentalized representations, neighbors are relatively more similar than for normal readers. Accordingly, the lexical restructuring theory on the development of phonological representations leads to the same hypothesis about the effects of phonological distinctness on word learning as the distinctness account.

There are a number of studies on the differential effect of phonological distinctness on the phonological processing abilities of normal and dyslexic readers. Most of these studies concerned verbal short-term memory. In an early study, Shankweiler, Liberman, Mark, Fowler, and Fischer (1979) examined the effect of the phonological similarity (or distinctness) of letters (rhyming or non-rhyming) in a memory span task on the recall performance of good and poor second grade readers. Irrespective of the mode of presentation (visual or auditory) of the letters, poor readers were not influenced by the phonological similarity of the letters whereas the normal readers recalled more non-rhyming than rhyming letters. Shankweiler et al. (1979) suggested that poor readers used visual or semantic, rather than phonological, representations of the written word, due to 'poorer access to a phonetic code, or access to a degraded phonetic representation' (p. 542). However, in subsequent studies this finding was not replicated. Dyslexic and normal reader's memory span performance were equally affected by the phonological similarity of the letters (Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Johnston, 1982; Johnston, Rugg, & Scott, 1987), or words (rhyming or non-rhyming) (Swanson & Ramalgia, 1992) in a span task. Using a slightly different manipulation of phonological similarity, Palmer (2000) found the same result in a span task in which the words were presented as pictures of objects. Interestingly, in addition to the effect of phonological similarity, Palmer also examined the effect of the visual similarity of the objects to which the words in the span task referred. The recall of words by normal readers was not affected by the visual similarity of the objects in the span task. The performance of the dyslexic readers, however, was lower in the task with visually similar objects (for example, ball, cake, face, pan etc.) than in the task with visually distinct objects.

The effect of phonological distinctness on the performance of normal and dyslexic readers in tasks that require the formation of associations between visual and verbal stimuli has been hardly examined. Mauer and Kamhi (1996) considered the effects of phonological and visual similarity on the learning of associations of phonemes with novel graphemes in normal and dyslexic readers. In most studies with visual-verbal PAL tasks, the visual stimulus is given by the experimenter and the verbal stimulus has to be provided by the learner. In this study, however, the phoneme was given and the accompanying novel grapheme had to be learned. The novel graphemes were simple abstract letter-like symbols. Sets of two novel phoneme-grapheme pairs were constructed. The phonemes within a set were either phonologically similar (*b, d*) or different (*m, s*). The corresponding graphemes could be visually distinct or similar as well. Accordingly, learning performance, that is, number of trials to criterion, was examined in four conditions. Unfortunately, the effects of phonological and visual similarity could not be examined for the normal readers, because they performed at ceiling in all learning conditions, although the rate of learning of phoneme-grapheme pairs with phonologically similar phonemes and visually similar items was somewhat slower in this group. The dyslexic readers were clearly affected by both phonological and visual similarity of the phonemes and graphemes, respectively. Sets with phonologically similar phonemes were learned more slowly than sets with distinct phonemes, and also, sets with visually similar graphemes were learned more slowly than sets with visually distinct graphemes.

In sum, evidence so far suggests that the effect of the phonological distinctness of letters or words on verbal short-term memory performance is of similar magnitude for dyslexic and normal readers. With respect to the effect of phonological distinctness on visual-verbal PAL, there is some indication, although quite weak, that the performance of dyslexic readers is more strongly affected than the performance of normal readers.

In addition to the effect of phonological distinctness, we also considered the effect of visual distinctness of pictures on visual-verbal PAL. We had several reasons for this interest. First, there is some indication that dyslexic children might be somewhat more influenced by the visual distinctness of pictures (see Mauer & Kamhi (1996) and Palmer (2000) described above). However, except for the study by Mauer and Kamhi (1996), visual processing of dyslexic children has not been investigated in a visual-verbal learning task, which seems an omission given that, as said, reading also requires the formation of visual-verbal associations.

Unfortunately, in a transparent orthography, it is more or less impossible to examine the separate effects of visual and phonological effects on reading, as phonologically similar words are also orthographically, and thus visually, similar. In PAL, however, the effects of phonological and visual distinctness can be dissociated. An additional reason was that task manipulations in phonological and visual processing tasks are usually vastly different. In the present studies, phonological and visual distinctness were varied according to similar principles within the same task. Finally, as a more general reason, we think that it provides a stronger test of the hypothesis that underspecified phonological representations constitute the core problem in dyslexia, if, within the same study and task paradigm, predictions about circumstances that differentiate normal and dyslexic readers are tested simultaneously with predictions on circumstances, that are presumed to have an equal influence on both groups of readers. From the Phonological Representation Hypothesis (Snowling, 2000) it follows that normal and dyslexic readers should be equally affected by the visual distinctness of pictures (or written words) but differentially influenced by their phonological distinctness.

In the remainder of this paper three studies are reported in which the consequences of the quality of phonological representations on visual-verbal PAL were investigated in dyslexic and normal readers. In the first study, the effect of visual distinctness on the visual-verbal learning of words was examined. The second study was concerned with the effect of the phonological distinctness of words on visual-verbal PAL with visually distinct pictures. Finally, in the third study we examined the effect of phonological distinctness on visual-verbal PAL with visually indistinct pictures.

Study 1

In the first study we addressed the effect of visual distinctness on visual-verbal PAL in dyslexic and normal readers. If dyslexic children are more susceptible to visual distinctness than normal readers, than the difference in performance in a learning task with visually indistinct stimuli and a task with distinct visual stimuli should be larger in dyslexic than in normal readers.

To generalize the effects of our particular manipulation of visual distinctness (see Method section), we used visual stimuli that varied in semantic content. In several studies concrete words (i.e., words of high imageability) were found to be easier to learn than abstract words (i.e., words low in imageability) (de Groot & Keijzer, 2000; Rubin & Friendly, 1986; see also Laing & Hulme, 1999). In the present study, the visual stimuli were pictures of concrete or abstract objects. Following earlier work mentioned above, we expected that visual-verbal PAL would be easier for concrete than for abstract stimuli.

Visual-verbal PAL has been taken as an indicator of a more general phonological deficit (e.g., Snowling, 2000). In accordance with this hypothesis, Messbauer and de Jong (2003) found that differences in visual-verbal PAL between a group of normal and a group of dyslexic readers could be accounted for by differences between these groups in phonological awareness. The latter can be considered as another indicator of this phonological deficit. As an additional aim of the present study, we examined the relationship between phonological awareness and visual-verbal PAL, and in particular aimed to replicate the results of Messbauer and de Jong (2003).

Method

Participants

The study involved 44 dyslexic (29 boys and 15 girls) and 46 normal (31 boys and 15 girls) readers. The dyslexic children were individually matched with the normal readers on vocabulary, non-verbal intelligence and age. The overall majority of the children of this study, participated also in another study that was done 6 months later (see Study 3). On that occasion, we also assessed arithmetic achievement. However note that in the present study the groups were not matched on arithmetic achievement.

Reading ability was assessed with the *Een-Minuut-Test [One-Minute-Test]* (Brus & Voeten, 1979), a Dutch standardized test of single word reading. The test is commonly used to determine the reading level of children in primary schools. The test consists of 116 words of increasing difficulty. The participants are required to read the words aloud as quickly as possible, without making errors. The raw score is the number of words read correctly within one minute. Standardized scores range from 1 to 19, with a mean of 10 and a standard deviation of 3 (van den Bos, Lutje Spelberg, Scheepstra, & de Vries, 1994). Children with a standardized reading score within one standard deviation of the mean were considered as normal readers. A reading lag of at least two years compared to their chronological-age, as indicated by a standardized reading score of 2 or less, was used as an indication of dyslexia.

Receptive vocabulary was measured with the Passive Vocabulary Test, a standardized subtest of the Dutch *Revisie Amsterdamse Kinder Intelligentie Test [Revised Amsterdam Child Intelligence Test]* (Bleichrodt, Drenth, Zaal, & Resing, 1987). The participants had to choose the correct picture from a selection of four, which matched a given word. The test consisted of 60 items. The raw vocabulary score is the number of correctly chosen pictures. Subsequently, this score was transformed into a standardized vocabulary score between 0 and 30, with a mean of 15 and a standard deviation of 5. Children with a standardized vocabulary score of one or more standard deviations below their age-norm were not included in the study.

Finally, as a measure of non-verbal intelligence we administered the *RAVEN Standard Progressive Matrices* (Raven, Court, & Raven, 1986). The participants completed all of the 60 items. The raw score is based on the number of correct answers. Percentile points for 6-month age-ranges between 6.03 and 16.08 years of age were obtained. Children with a test score beneath the 40th percentile according to their age-norm were not included in the study.

Furthermore, for the selection of the dyslexic children information from the school records was used to exclude children with an IQ of 85 or below (based upon the full scale IQ obtained with the *Wechsler Intelligence Scale for Children – Revised* (WISC-R), which is generally administered at school entry). Additionally, children with hearing or articulatory problems,

Table 1

Characteristics of the dyslexic and normal readers in Studies 1 to 3

		Dyslexic		Normal	
Variable	Study	*M*	*SD*	*M*	*SD*
Age (in months)	1	132.75	7.45	131.70	7.00
	2	126.35	9.36	126.31	9.33
	3	141.88	6.97	140.88	7.16
Word decoding	1	33.57	11.22	76.00	9.56
	2	29.27	8.58	75.19	8.42
	3	38.61	11.98	80.98	10.70
Reading Grade	1	2.5		5.5	
	2	2.4		4.5	
	3	2.9		6.1	
Calculation Speed	1	[a]		[a]	
	2	[a]		[a]	
	3	52.43	14.48	81.88	12.53
Arithmetic Grade	1	[a]		[a]	
	2	[a]		[a]	
	3	3.3		6.9	
Vocabulary[b]	1	12.93	3.58	14.07	3.41
	2	14.15	3.06	15.42	3.78
	3	12.72	3.60	14.09	3.45
Raven (raw score)	1	34.09	6.90	37.27	7.30
	2	38.19	7.65	39.67	4.26
	3	34.24	7.06	37.56	7.26

Note. A reading or arithmetic grade reflects the grade at which a mean normal developing child achieves this level. (For example, a reading grade of 2.5 means that a normal child achieves this level halfway second grade.) Note also that in Study 3, the vocabulary and Raven scores were obtained nine months a year earlier (during Study 1).

[a] n.a is not available, because the test was not administered

[b] Based on the national norms the scores were transposed to standardized scores with a mean 15 of and a standard deviation of 5

neurological deficits, or who had been diagnosed as ADHD, as well as children for whom Dutch was not their native language were omitted from the study.

Of the group of dyslexic children, ten attended regular primary schools. The other 34 dyslexic children came from special schools for children with learning disabilities. All except two children assigned to the control group of normal reading children attended regular primary schools.

Finally, about 6 months after the selection of the children, we also assessed arithmetic achievement with a test for calculation speed, the *Tempo Test Rekenen [Arithmetic Tempo Test]* (de Vos, 1992). This test is regularly used in Dutch education to evaluate arithmetic achievement. Two subtests were used, requiring elementary addition and subtraction computations, respectively. Each subtest consists of 50 items of increasing difficulty. Of these items, about the first 20 items concerned arithmetic facts. For each subtest, children are required to solve as many items correct within 3 minutes. The score on each subtest is the number of computations solved correctly. Based on all participants, the scores on each subtest were converted to z-scores. Next, a total score was computed as the mean z-score over both subtests.

The characteristics of the groups are presented in Table 1. Dyslexic and normal readers did not differ in age and vocabulary knowledge (t (88) = 1.45, ns). The difference in performance on the Raven test approached significance (t (88) = 1.66, p = .10). However, in addition to a lower reading ability, the performance of the dyslexic children was significantly lower on the speeded calculation test (t (82) = 9.58, p < .001).

Phonological information processing

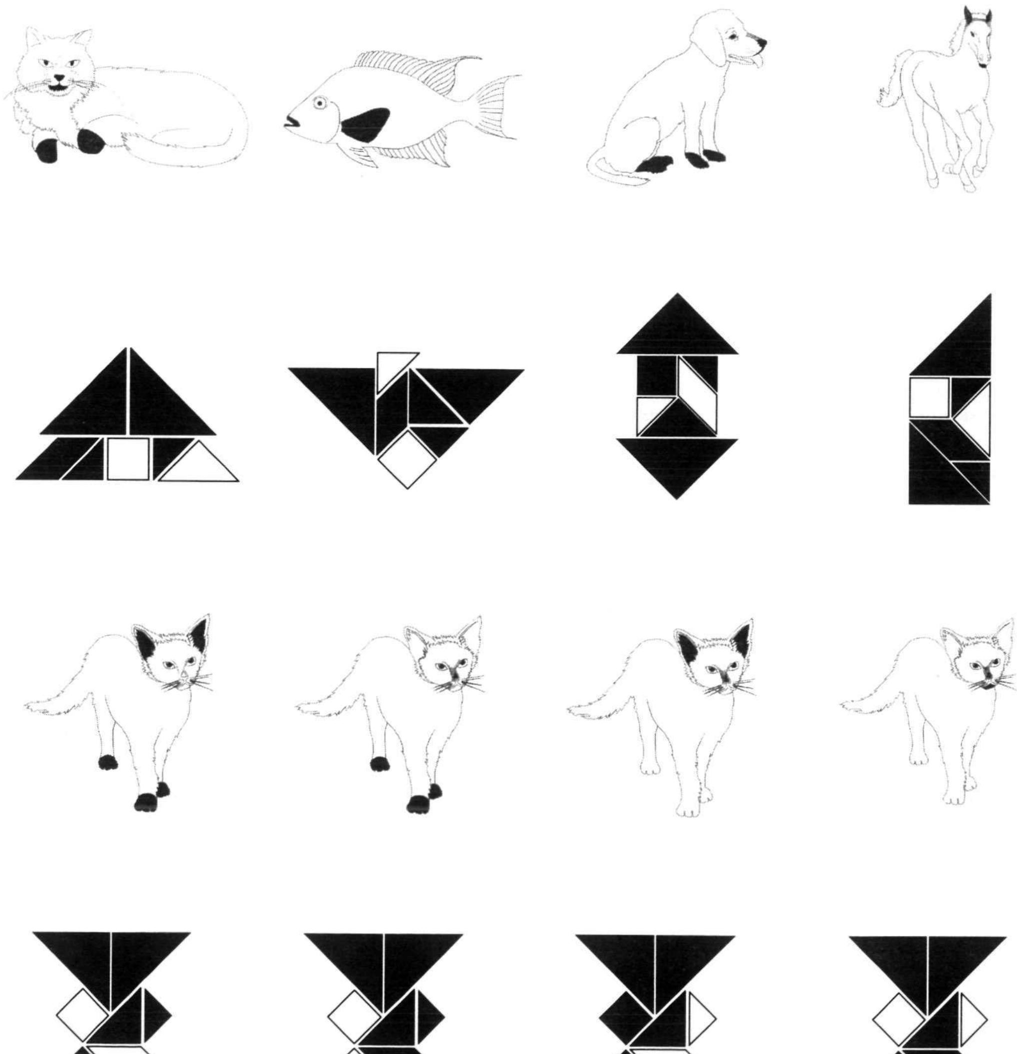
Phoneme deletion. The test required the deletion of a phoneme from a one or a two-syllable nonword (see de Jong & van der Leij, 2003). The 10 one-syllable CVCC and CCVC nonwords were selected from a test designed by Messbauer and de Jong (2003). In addition, 10 two-syllable nonwords were constructed. The first syllable of the nonword was either a CVC or CCV-syllable. The composition of the second syllable varied, but always started and ended with a consonant.

Each nonword was presented by the experimenter. The child was asked to repeat the nonword to make sure that the child had heard it correctly and could pronounce the nonword accurately. Then, the experimenter gave a particular phoneme, which had to be deleted from the nonword. The particular phoneme was always a consonant. Correct deletion always resulted in a nonword. Six examples preceded the test items. The maximum score on the test was 20.

Spoonerisms. This task consisted of 10 one-syllable nonword pairs (CVC, CCVC or CVCC) derived from a nonword repetition test (de Jong & van der Leij, 1999). The nonword pairs were presented one by one by the experimenter. The child was asked to repeat each nonword pair to make sure the child had heard it correctly and could pronounce both nonwords accurately. Then, the experimenter asked the child to exchange the initial phonemes

Figure 1

Examples of the four different sets of visual stimuli used in the visual-verbal PAL tasks in Studies 1 to 3: Two sets of visually distinct stimuli (concrete and abstract) and two sets of visually indistinct stimuli (concrete and abstract)



of these nonwords. For example, *zar-rep* had to be converted into *rar-zep*. In six nonword pairs, both nonwords had a single consonant in the onset (e.g., *kum-jar*). From the remaining four nonword pairs, two pairs consisted of nonwords with initial consonant clusters (e.g., *gruit-pleek*), and two pairs consisted of an initial single consonant and an initial consonant cluster (e.g., *palt-frop*). Six examples, three word pairs and three nonword pairs, preceded the test items. For each correctly converted nonword one point was obtained. The maximum score was 20.

Paired associate learning

Stimulus material. The task required the learning of associations between words and pictures. Two sets of words were selected from a previous study on visual-verbal paired associate learning (Messbauer & de Jong, 2003). One set consisted of highly frequent Dutch boy's names (Thomas, Stefan, Martin, and Robbert). The other set had highly frequent Dutch girl's names (Karin, Moniek, Linda, and Judith).

Twelve sets of four indistinct pictures were constructed. Of these sets, six consisted of pictures of animals (birds, butterflies, cats, dogs, fish, or horses). The other six sets were abstract figures. Each abstract figure was composed of seven parts. All concrete pictures and abstract figures were in black and white.

The four concrete pictures in an indistinct set had the same contour. All pictures of the set had four features that could be either black or white. On each picture, two of these features were white and two were black, but which features were black or white varied among the pictures in the set. As a result, every two pictures in a set had features in common, that is being both black or both white, but the common features depended on the particular pair of pictures. For example in the indistinct set of cats, one cat had black ears and a black nose. The second cat in this set had a similar black nose, but a black mouth. The third cat had a similar black mouth, but black ears. And, finally, the fourth cat had similar black ears, but black feet (see Figure 1).

The abstract figures differed in a similar way from one another. In all, of the 4 figures in an indistinct set, two figures had two common features with every other figure in the set, and two figures had two features in common with two of the other three figures in the set.

Distinct sets of concrete pictures and abstract figures were paired with the indistinct sets by randomly selecting four pictures from the remaining five indistinct sets of pictures (concrete or abstract), with the restriction that only one picture or figure from a set was selected. As a result, the pictures in an indistinct set differed by contour and by many other features (see Figure 1).

Learning procedure. Each paired associate learning task started with a presentation trial. The experimenter showed the four pictures (animals or abstract figures) one after the other and named them aloud. The child was asked to listen and to watch carefully and try to remember the name corresponding to the picture. After the presentation of each picture, the child was asked to repeat the given name to ensure that it could pronounce the name correctly. Subsequently, the first test trial was given. Each picture was presented and the child was asked to provide the name corresponding to the picture. Thereafter, a second presentation trial was given, followed by another five test trials. Irrespective of the correctness of the response of the child, during the test trials the experimenter always gave the correct name as feedback. The maximum score on the paired associate learning task was 24 (4 names x 6 test trials).

General procedure

Each child was administered two paired associate learning tasks: One task with distinct and the other with indistinct pictures. Concreteness of the pictures in these tasks (concrete or abstract) was randomized over children within reader groups (normal or dyslexic readers). Also, the type of name (names of boys or names of girls) was randomized over children within each reader group. Thus, visual distinctness (distinct or indistinct) was a within-subjects factor, whereas reading group (dyslexic or normal reader), and concreteness of the visual stimuli (concrete or abstract) were between-subjects factors. Finally, to avoid sequence effects half of each reading group learned the names associated with the visually distinct pictures in the first session and the names associated with the visually indistinct pictures in the second session. The other half of each reading group made the tasks in the other order. Similarly, half of the participants in each reading group were taught the boy's names in the first condition and the girl's names in the second; the other half the other way around.

Testing was completed in two sessions. Each participant was seen individually in a quiet room at school. The first paired associate learning task was administered in the first session. The phoneme deletion task and the second paired associated learning task were administered in the second test session.

Results

One normal reading child was not included in the analyses. The child had a score of 1 on the paired associate learning task with a distinct set of pictures, which was more than 3.5 standard deviations from its group mean. This score was considered as an outlier. Omission of this child did not alter the characteristics of the reading groups. In all, 44 dyslexic and 45 normal readers were included in the analyses.

Phonological information processing

The mean score of the dyslexic children on the phoneme deletion task was lower than the mean score of the normal readers (DYS: $M = 13.43$, $SD = 4.08$; Normal: $M = 17.84$, $SD = 1.87$). A *t*-test confirmed that the mean scores of the groups differed significantly ($t\ (87) = 6.57$, $p < .001$). The dyslexic group also had a lower mean score than the normal group on the Spoonerism task (DYS: $M = 6.64$, $SD = 4.08$; Normal: $M = 13.00$, $SD = 3.55$). The mean score difference on this task was significant ($t\ (87) = 7.86$, $p < .001$).

Paired associate learning

In Table 2 the means and standard deviations of the reading groups on the paired associate learning tasks in the various conditions (visually distinct or indistinct set of pictures, and concrete or abstract pictures) are presented. The paired associate learning scores were subjected to a multivariate analysis of variance (MANOVA) for repeated measures with reading group (dyslexic and normal readers), semantic content (concrete or abstract), and the order in which the learning tasks were administered (distinct or indistinct first) as between-subjects factors, and visual distinctness (distinct or indistinct set of pictures) as a within-subjects factor.

The order in which the learning tasks were presented, did not have any significant effect (all $F < 1$). Therefore, we report the results of the analysis without the order factor. We found a significant main effect for reading group ($F\ (1, 85) = 23.81$, $p < .001$, $\eta^2 = .22$). The dyslexic children had a lower visual verbal paired associate learning score than the normal readers. In addition, a significant main effect was found for distinctness ($F\ (1, 85) = 75.65$, $p < .001$, $\eta^2 = .47$). The mean learning score for the distinct set of pictures was higher than for the set of indistinct pictures.

Table 2

Means and standard deviations on the learning tasks with visually distinct and indistinct pictures for the dyslexic and the age-matched normal reading group in Study 1

	Concrete pictures				Abstract pictures			
	Distinct		Indistinct		Distinct		Indistinct	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dyslexic	17.56	4.28	10.70	4.83	13.81	4.79	11.67	5.19
Normal	21.70	2.57	14.17	5.83	18.45	4.08	15.14	5.00

The effect of semantic content was not significant (F (1, 85) = 2.47, ns, η^2 = .03). However, we did find a significant interaction of semantic content and distinctness (F (1, 85) = 15.31, $p < .001$, $\eta^2 = .15$). With an indistinct set of pictures, paired associate learning was not affected by semantic content (concrete or abstract), but for a distinct set of pictures learning to associate words with pictures was easier with the concrete than with the abstract pictures.

We did not find an interaction of reader group and distinctness, and of reader group and semantic content. Dyslexic and normal readers were equally affected by the distinctness of the set and the semantic content of the pictures.

Explaining differences between dyslexic and normal reader's performance in verbal learning

The dyslexic readers appeared to have a lower arithmetic ability than the normal readers. Therefore, the verbal learning problems of the dyslexic children could be due to their problems in speeded calculation instead of their reading problems. Another possibility, as mentioned before, is that dyslexic children's lower performance on the learning task could be accounted for by their phonological processing problems.

To test for these possibilities, two MANCOVAs for repeated measures were done on the scores of the verbal learning tasks with, as before, reading group (dyslexic and normal readers) and semantic content (concrete and abstract) as between-subjects factors, and visual distinctness (distinct and indistinct) as a within-subjects factor. In one MANCOVA the scores on the test for calculation speed served as a covariate, whereas on the other a phonological processing score, based on the phoneme deletion and the spoonerism task, was used as a covariate.

The test for calculation speed was administered 6 months after this study (Study 1) to the children that also participated in another study (see Study 3). Of the 90 children involved in Study 1, 6 children (3 dyslexic and 3 normal readers) did not participate in Study 3. In addition, two normal readers had scores that were 2.7 and 2.4 standard deviations, respectively, below the mean score of their group. These scores were the main cause of a readers group by speeded calculation interaction effect, an interaction that is not allowed in covariance analysis (Tabachnick & Fidel, 2001). Therefore, these normal readers were also omitted, and 41 dyslexic and 41 normal readers were involved the analyses with the speeded calculation test. The decrease in the number of children did not alter the characteristic of the groups as reported in Table 1.

In the analysis with calculation speed as a covariate, we found a significant effect of calculation speed (F (1, 77) = 8.86, $p < .05$, $\eta^2 = .10$). Children with a higher score on the test for calculation speed performed better on the learning tasks. More interestingly, the effect of reader group was no longer significant ($F < 1$). Thus, the difference between the groups in calculation speed could account for the difference in verbal learning.

In a second analysis, phonological processing was used as a covariate. A score for phonological processing was obtained by the computation of a mean z-score over the scores on the phoneme deletion and the spoonerism task. The second analysis revealed a significant effect of phonological processing (F (1, 84) = 4.87, $p < .05$, $\eta^2 = .06$). There was also a significant effect of reader group (F (1, 84) = 5.07, $p < .05$, $\eta^2 = .06$). Thus, differences in phonological processing could not fully account for the difference between normal and dyslexic readers in verbal learning. Nevertheless, phonological processing did account for a substantial part of the difference as its inclusion in the analysis reduced the η^2-effect of reader group from .22 to .06.

Finally, in two additional MANCOVAs we examined the unique effects of calculation speed and phonological processing on verbal learning. In both analyses a sequential procedure (see Tabachnick & Fidel, 2001) was used. Such a procedure resembles a fixed order hierarchical regression. Semantic content was always entered as the first factor. In the first analysis, the order of entrance was phonological processing and calculation speed. The effect of speeded calculation was significant, after phonological processing was controlled (F (1, 76) = 9.57, $p < .01$). In the second analysis, the order of phonological processing and calculation speed was reversed. In this analysis, the effect of phonological processing, after calculation speed was controlled, approached significance (F (1, 76) = 3.67, $p = .056$).

Discussion

The main interest of the present study concerned the effect of visual distinctness of pictures on visual-verbal PAL. The results were straightforward. The effect of visual distinctness was similar in both groups. Both normal and dyslexic readers performed more poorly on the set of visual indistinct pictures than on the set of visual distinct pictures.

We also found, as reported before in several other studies (Messbauer et al., 2002; Messbauer & de Jong, 2003; Vellutino et al., 1978; Vellutino et al., 1983), that dyslexic readers had more difficulty with visual-verbal PAL than their normal reading peers. Note, however, that the present study concerned the association of known names to pictures. Thus, the difference between normal and dyslexic readers cannot be attributed to a slower acquisition of novel phonological representations. Instead, assuming that dyslexic children's quality of phonological representations for these known names might have been lower than in normal readers, one might hypothesize, as Messbauer and de Jong (2003) did, that underspecified phonological representations can be associated less easily with visual stimuli.

In this respect it is of interest that differences in phonological awareness between the groups, as found on the spoonerism task and on phoneme deletion, could account for a substantial part of the difference in visual-verbal PAL. It suggests that the problems of dyslexic children in visual-verbal PAL are phonological. This is in accordance with the suggestion that both phonological awareness and visual-verbal PAL are dependent on the quality of underlying phonological representations.

However, the dyslexic children had, in addition to their lag in reading achievement and phonological awareness, a similar lag in arithmetic achievement. The difference in visual-verbal PAL between the normal and dyslexic readers could also be accounted for by their difference in arithmetic achievement. In principle these findings raise the possibility that the lower performance of the dyslexic children are due to their arithmetic problems and not to their reading problems. However, arithmetic ability is known to be related to both reading ability and phonological awareness. Therefore, it might be that arithmetic ability could account for the difference between the normal and the dyslexic readers, at least in part, through its relationship to phonological awareness (e.g., Hecht, Torgesen, Wagner, & Rashotte, 2001; Leather & Henry, 1994). We will discuss these findings more extensively in the General Discussion.

Finally, manipulation of the semantic content of the visual stimuli had an effect on verbal learning when the pictures were clearly distinguishable from one another, but not when the pictures were in the indistinct set. This finding can be easily interpreted because the concrete pictures in the distinct set could be verbally labeled whereas the abstract ones could not. Thus, concreteness of visual stimuli seems to support visual-verbal learning in a similar way as imageability of words (de Groot & Keijzer, 2000; Laing & Hulme, 1999). In contrast, the separate pictures in the indistinct set of pictures of objects could not be verbally labeled, being all variations of the same object.

Study 2

In the previous study visual distinctness was found to affect visual-verbal PAL performance of both dyslexic and normal readers to a similar extent. In the second study we examined the effect of phonological distinctness on visual-verbal PAL, whereas the visual distinctness of the stimuli was controlled. Two verbal learning tasks were constructed, one in which phonologically distinct words had to be associated with visually distinct pictures, and one in which phonologically indistinct words had to be associated with different, but also visually distinct pictures. We hypothesized that if dyslexic children are more susceptible to phonological distinctness than normal readers, they are expected to perform worse on the learning task with phonologically indistinct words than on the task with phonologically distinct words as compared to their age-matched normal readers.

Because the semantic content of the visual stimuli affected visual-verbal PAL performance when the pictures were clearly distinguishable in the previous study, we used only abstract pictures in this study. In this way, the pictures used were equally unknown to the participants and so any confounding influences of verbal labeling were controlled for.

Method

Participants

The study involved 26 dyslexic and 26 normal readers. Each group consisted of 18 boys and 8 girls. The dyslexic readers were individually matched with the normal readers on vocabulary, non-verbal intelligence and age (see the Method section of Study 1 for a detailed description of the selection criteria and tasks). The characteristics of the reading groups are presented in Table 1.

Paired associate learning

Two visual-verbal paired associate learning tasks were constructed. Each task required the learning of associations between four visually distinct abstract figures and four words. In one task the set of four words was distinct. In the other paired associate learning task the set of words was indistinct.

Stimulus material. The pictures used in the learning tasks were the same abstract figures as used in the previous study. For each task, four pictures were randomly selected from a larger set of eight abstract pictures. Because the participants were given both learning tasks, we made sure that the two sets of pictures did not include similar ones.

The words used in the learning tasks were Dutch high frequent CCVC words. Six phonologically indistinct sets of four words were composed (see Appendix A for the complete sets). The words in a set differed on either the second or the final consonant from a root word in the set. For example, the root word was /klas/. The other words in this set were: /klap/, /krap/, and /kras/. As a result, each word in a phonologically indistinct set had two neighbours. Each child was administered one of the six sets of phonologically indistinct words. The sets of phonologically distinct words were formed by randomly selecting four words from the remaining five indistinct word sets, with the restriction that only one word from a phonologically indistinct set was selected, and that the words in the distinct set differed on both the vowel and the initial consonant cluster. For example, the four words in one set of phonologically distinct words were: /brom/, /slaaf/, /klik/, /stak/. Accordingly, the two words in a phonologically distinct set had at the most one sound in common.

Learning procedure. The learning procedure was identical to the procedure of the fist study. In brief, each learning task started with a presentation trial. Subsequently, a test trial was given in which the child was asked to name the word corresponding to a particular picture. Thereafter, another presentation trial was administered. After the second presentation trial five more test trials were given. Irrespective of the response of the child, correct or incorrect, the experimenter always named the correct word as feedback. The maximum score was 24 (4 words x 6 test trials).

General procedure

The two learning tasks were administered in separate sessions. Half of each reading group was given the learning task with the phonologically indistinct words in the first session and the learning task with the phonologically distinct words in the second session. To the other half of each reading group the learning tasks were administered in the reversed order. Participants were tested individually in a quiet room.

Results

For one dyslexic child the scores on the learning task with phonologically distinct words were missing. Omission of this child did not alter the characteristics of the groups. Therefore, the analysis of the learning tasks was based on 25 dyslexic and 26 normal readers.

In Table 3 the means and standard deviations of the reading groups on the two paired associate learning tasks are presented. The scores on the learning tasks were subjected to a MANOVA for repeated measures with reading group (dyslexic and normal readers) and the order in which the learning tasks were presented (distinct or indistinct first) as between-subjects factors, and phonological distinctness (distinct and indistinct) as a within-subjects factor. However, because there were no significant effects of the order, we report the results of an analysis without this factor.

The analysis revealed a significant main effect of phonological distinctness (F (1, 48) = 13.23, p = .001, η^2 = .21). The mean learning scores for the visual-verbal learning of an indistinct set of words was lower than for a phonologically distinct set of words. Unexpectedly, the effect of reader group was not significant ($F < 1$). In addition, we did not find an interaction of group and distinctness. Analysis of the scores on the last learning trial revealed virtually identical results.

Table 3

Means and standard deviations on the learning tasks with phonologically distinct and indistinct words for the dyslexic and the age-matched normal reading group in Study 2

	Distinct words		Indistinct words	
Group	*M*	*SD*	*M*	*SD*
Dyslexic	18.88	4.48	15.80	4.77
Normal	18.92	3.60	16.35	5.47

Discussion

The main finding of the present study is that the verbal learning performance of dyslexic and normal readers was equally affected by the phonological distinctness of the set of words to be associated with pictures. For both groups the paired associate learning of phonologically distinct words was easier than the learning of phonologically indistinct words.

Unexpectedly, we found that the verbal learning performance of the dyslexic children was similar to the performance of the normal readers. These results are not in accordance with our first study and earlier studies on verbal learning in which dyslexic readers were found to perform worse than normal readers on verbal paired associate learning tasks (Messbauer et al., 2002; Messbauer & de Jong, in 2003; Vellutino et al., 1978; Vellutino et al., 1983; compare Vellutino & Scanlon, 1989; Vellutino et al., 1995).

An explanation for these findings might be sought in the fact that in the present study highly frequent words were used, whereas in the first study, as in other studies (Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003), names were used. Comparison of the task with phonologically distinct words of the present study and the corresponding verbal learning task of Study 1 (the task with visually distinct abstract pictures) shows that the normal readers performed similar on the learning task with names and the task with highly frequent words ($M = 18.45$ and $M = 18.92$, respectively). In contrast, the dyslexic children performed better on the task with highly frequent words as compared to the task in which names had to be associated with pictures ($M = 13.81$ and $M = 18.88$, respectively). These results suggest that words and names might have different roles in the verbal learning of dyslexic readers. Note also that the paired associate learning of words was rather easy, as over the six trials about 80% of the stimuli were correctly named.

Although the names in most studies using PAL tasks have been supposed to be familiar to the children, this is seldom checked. Therefore, one explanation for this difference between names and high frequent words, is that, to some extent, names might act as nonwords. There is good evidence that dyslexic children have problems with the paired associate learning of nonwords.

Another possibility is that well-known words are better "anchored" in the mental lexicon than names, because they are supported by semantic connections as well (see also Ehri, 1992). This semantic support might help the dyslexic children to compensate for the effects of weaker phonological representations.

Study 3

In the second study, we found that the phonological distinctness of words had a similar effect on the paired associate learning performance of dyslexic and normal readers. In the second study we used a set of distinct visual stimuli. The learning task appeared to be rather easy, especially in the phonologically distinct condition. The main aim of the present study was to examine the effects of phonological distinctness on visual-verbal PAL, but now with a set of visually indistinct stimuli. The use of such a set makes the learning task more difficult. In the study of Mauer and Kamhi (1996), mentioned in the Introduction section, the learning of novel phoneme grapheme correspondences was most difficult when the phonemes were phonologically indistinct and the graphemes were visually indistinct. With a visually indistinct set, high quality phonological representations might be more critical. Note in this respect that during reading, a reader has to identify many written words that may not be very distinct from other words. The possibility remains that the association of less distinct phonological representations with a set of indistinct pictures is particularly difficult for dyslexic readers. Accordingly, as in the second study, we hypothesized that the visual-verbal PAL performance of dyslexic readers would be more affected by the phonological distinctness of the set of words than the performance of normal readers.

Method

Participants

This study involved 84 children who did also participate in Study 1, which was conducted about half a year earlier. Of the 90 children of Study 1, 3 dyslexic and 3 normal readers could not participate in the current study, because they had gone to another school after the summer. As a result, 41 dyslexic (26 boys and 15 girls) and 43 normal readers (28 boys and 15 girls) participated in the current study. The decrease in the number of children per reading group did not alter the characteristics of the groups as reported in Table 1.

Phonological Processing

A phoneme deletion and spoonerism task were administered. The description of these tasks was given in the Method section of the first study.

Paired associate learning

Two visual-verbal paired associate learning tasks were administered. In each task, four visually indistinct pictures of animals (birds, butterflies, cats, dogs, fish, or horses) or four indistinct abstract figures had to be associated with either four phonologically distinct or four indistinct words.

Stimulus material. The pictures used in the learning tasks were the same sets of visually indistinct concrete pictures and abstract figures as used in Study 1 (see Figure 1). As in the first study, half of the participants in each reading group learned to associate the words with concrete pictures, and the other half of the participants with abstract ones. For each participant, however, we changed the semantic content of the stimuli. Thus, if a child had concrete pictures in the first study, it would have to associate the words with abstract stimuli in the current study and vice versa. The words in both learning tasks were selected from the same highly frequent Dutch words as Study 2.

Learning procedure. The learning procedure was similar to the one used in the previous studies. To sum up, each learning task started with a presentation trial. Subsequently, a test trial took place in which the child was asked to pronounce the word corresponding to the picture. Thereafter, another presentation trial took place, followed by five successive test trials. Irrespective of the response from a child, correct or incorrect, the experimenter always pronounced the correct word as feedback. The maximum score was 24 (4 names x 6 test trials).

General procedure

The children were tested individually in two sessions in a quiet room. To avoid sequence effects, the order of presentation of the learning tasks was varied. Half of each reading group learned the phonologically indistinct words in the first session and the phonologically distinct words in the second session. The other half of each reading group made the tasks in the other order.

Results

In Table 4 for each order of presentation of the visual-verbal PAL tasks the means and standard deviations of the reading groups on the learning tasks are presented. The learning scores were subjected to a MANOVA for repeated measures with reading group (dyslexic and normal readers) and the order of presentation (phonologically distinct or indistinct set first) as between-subjects factors, and phonological distinctness (distinct or indistinct) as a within-subjects factor.

We found significant main effects of phonological distinctness (F (1, 80) = 7.75, p < .01, η^2 = .09) and reader group (F (1, 80) = 11.87, p < .01, η^2 = .13). The dyslexic children had a lower performance on the learning task than the normal readers. However, the effect of phonological distinctness was qualified by a significant interaction of distinctness and order of presentation (F (1, 80) = 4.70, p < .05, η^2 = .06). In addition, the interaction of distinctness and group (F (1, 80) = 3.70, p = .06, η^2 = .04) and the second order interaction of distinctness, group and order of presentation approached significance (F (1, 80) = 3.35, p = .07, η^2 = .04). The results in Table 4 show that the performance of the dyslexic children is not affected by the phonological distinctness of the set of words and the order of presentation of the learning tasks. For the normal readers, performance on the distinct and the indistinct set is similar in the first order of presentation, whereas in the second order performance on the distinct set is better than on the indistinct set. Because the interpretation of these results is complicated by the interactions with order of presentation, we also considered the scores of the last learning trial. Means and standard deviations of the scores of the groups on the last trial for each order of presentation are also given in Table 4.

A MANOVA for repeated measures with reading group and order of presentation as between-subjects factors, and phonological distinctness as a within-subjects factor did not reveal any effect of order of presentation. In a subsequent analysis without this factor a significant effect of phonological distinctness was found (F (1, 82) = 14.18, p < .01, η^2 = .15). The mean performance on the phonologically distinct set of words was higher than on the indistinct set. We also found a significant effect of group (F (1, 80) = 8.31, p < .01, η^2 = .09).

Table 4

Means and standard deviations of the total learning score and on the last trial on the learning tasks with phonologically distinct and indistinct words for the dyslexic and the age-matched normal reading group for two orders of presentation in Study 3

	Order 1				Order 2			
	Distinct		Indistinct		Distinct		Indistinct	
Group	*M*	*SD*	M	*SD*	*M*	*SD*	*M*	*SD*
				Total Score (max. 24)				
Dyslexic	11.89	5.09	11.58	4.90	12.27	4.36	11.55	4.00
Normal	15.33	4.81	14.91	5.76	17.00	4.46	11.72	4.65
				Score Last Trial (max. 4)				
Dyslexic	2.63	1.01	2.16	1.39	2.55	1.41	2.09	1.11
Normal	3.19	1.21	2.71	1.27	3.41	0.85	2.36	1.09

Note. Order 1 was first distinct and then indistinct learning task. Order 2 was first indistinct and then distinct learning task.

The mean score on the last trial of the dyslexic group was lower than the mean score of the group of normal readers. The interaction of group and phonological distinctness was not significant ($F < 1$).

As in Study 1, the dyslexic readers had a lower ability in arithmetic and phonological processing than the normal readers. Following up our analyses of the performance on the last learning trial, we examined whether differences in arithmetic and phonological processing ability could account for the observed difference in visual-verbal PAL between the normal and the dyslexic readers. In a MANCOVA for repeated measures with phonological processing as a covariate, the effect of phonological processing approached significance (F (1, 81) = 3.29, $p < .07$, $\eta^2 = .04$), whereas the effect of reader group was no longer significant ($F < 1$). For the analysis with calculation speed as a covariate, two normal reading children were excluded, as they were considered as influential outliers (see for details the Results section of Study 1). The MANCOVA with calculation speed as a covariate showed a significant effect of calculation speed (F (1, 79) = 6.55, $p < .05$, $\eta^2 = .05$), but the effect of reader group was not significant ($F < 1$).

Discussion

The results of this study are clearly not in accordance with the hypothesis that the difference in verbal learning performance between dyslexic and normal readers is larger on a learning task with a phonologically indistinct set of words than on a task with a set of phonologically distinct words. With respect to the mean task performance, computed over the six learning trials, the performance of the dyslexic children was hardly influenced by the phonological distinctness of the word set. For the normal readers, the effect of distinctness appeared to be dependent on the order of presentation of the learning tasks. In the first order, starting with the distinct task, the difference between the normal and dyslexic readers was similar on both tasks. In the second order, starting with the indistinct task, the difference in mean learning performance was even smaller on the indistinct than on the distinct task.

Considering the performance of the groups on the last learning trial, there was also no indication that the dyslexic readers were relatively more hampered on the indistinct learning task. As in the second study, both groups were equally affected by the phonological distinctness of the set of words. Performance on the indistinct set of words was lower than on the distinct set of words.

An additional finding of this study was that the visual-verbal PAL performance of the normal readers was better than the performance of the dyslexic readers. As in the first study, the difference between the groups could be accounted for by their difference in arithmetic ability, as well as their difference in phonological processing ability.

General discussion

The present studies were concerned with the consequences of dyslexic children's presumed impairment in the quality of phonological representations for visual-verbal paired associate learning. More specifically, we examined the effects of the phonological distinctness of words and the visual distinctness of pictures on visual-verbal PAL performance.

For visual distinctness we found, as expected, that normal and dyslexic readers were equally affected. Both groups of readers performed more poorly when words had to be associated with a set of visually indistinct pictures than with a set of visually distinct pictures. The similar effect of visual distinctness on the learning of normal and dyslexic readers is in accordance with the findings of previous studies in which dyslexic children were found to have no problems with the paired associate learning of non-verbal (visual) material (Liberman, Mann, Shankweiler, & Werfman, 1982; Messbauer & de Jong, 2003; Nelson & Warrington, 1980; Rapala & Brady, 1990; Vellutino, Steger, & Pruzek, 1973).

Our main hypothesis concerned the effect of phonological distinctness on visual-verbal PAL. From the assumption that dyslexic children have relatively indistinct representations of words, we hypothesized that the visual-verbal PAL of a set of words with many neighbours (words that differ on only one phoneme from one another) might pose specific problems. Accordingly, our main hypothesis was that the difference in performance between dyslexic and normal readers would be larger in learning an indistinct set of words then a distinct set of words. Although the manipulation of phonological distinctness appeared successful, indistinct sets were more difficult to learn than distinct sets, the results of Studies 2 and 3 clearly did not support our main hypothesis (for a summary of the manipulations per Study see Table 5).

In Study 2 the verbal learning performance of dyslexic and normal readers was equally affected by the phonological distinctness of the set of words. For both groups the paired associate learning of phonologically distinct words was easier than the learning of phonologically indistinct words. In Study 3, the mean learning performance even suggested that performance of the normal children was more negatively affected by the indistinctness of the set of words than the performance of the dyslexic children, whereas on the last learning trial, like in Study 2, dyslexic and normal readers appeared to be equally affected by the phonological distinctness of the set of words.

The current results on the effects of phonological distinctness on visual-verbal PAL are very much in accordance with the evidence on the influence of the phonological distinctness of verbal stimuli on verbal short-term memory performance. As mentioned in the Introduction, several studies have shown that dyslexic and normal readers' short-term memory performance is equally affected by the phonological similarity of the verbal stimuli (Hall et al., 1983; Johnston, 1982; Johnston et al., 1987; Swanson & Ramalgia, 1992).

Similar findings were reported in a recent study by McNeil and Johnston (2004), but only for verbal presentation of the items. When the verbal stimuli in the short-term memory task were presented as pictures, however, a smaller effect of phonological distinctness was found in dyslexic children as compared to age-matched normal readers. Hence, McNeil and

Johnston argued that poor readers tend to rely on visual information in verbal short-term memory tasks if verbal recoding is not obligatory (see also Palmer, 2000). Accordingly, with visual presentation the effect of phonological distinctness is smaller in dyslexic readers, but when phonological coding is unavoidable the effect is of a similar magnitude as in normal readers. Clearly, in our visual-verbal PAL tasks phonological coding of the words was obligatory.

Given the evidence for poorly specified phonological representations as a core problem in dyslexia, the question arises why dyslexic and normal readers were equally hampered by the phonological indistinctness of verbal stimuli in verbal-visual PAL (and verbal short-term memory). One possibility is that even in the dyslexic children, the representations of the words in the indistinct set were sufficiently distinct to form associations between pictures and words when these associations are of an arbitrary nature. However, the quality of phonological representations might become critical in reading acquisition that requires the formation of associations between phonological representations and written words that have systematic relationships. That is, the written forms of words contain embedded phonological information, because the graphemes of written words are systematically connected to the sounds in spoken words. Although somewhat speculative, the use of this embedded phonological information in the visual word, like McNeil and Johnston (2004) argued for with

Table 5

Summary of the manipulations examined in the Studies 1 to 3

	Learning task		
Study	Visual (VD/VI)	Verbal (PD/PI)	Main effects
1	Concrete VD	Name PD	Reading group
	Concrete VI	Name PD	Visual distinctness
	Abstract VD	Name PD	Semantic content x visual distinctness
	Abstract VI	Name PD	
2	Abstract VD	Word PD	Phonological distinctness
	Abstract VD	Word PI	
3	Concrete VI	Word PD	Reading group
	Concrete VI	Word PI	Phonological distinctness
	Abstract VI	Word PD	Distinctness x order x reading group
	Abstract VI	Word PI	

Note. VD = Visually Distinct; VI = Visually Indistinct

PD = Phonologically Distinct; PI = Phonologically Indistinct respect to verbal short-term memory, is probably not obligatory, but might be crucial in an indistinct context. Our visual-verbal PAL task using both phonologically and visually indistinct stimuli closely resembles the reading process. However, the fact that the visual stimuli in our visual-verbal PAL tasks did not contain phonological information which use could be beneficial, might be an explanation for the absence of a performance difference between dyslexic children and their normal reading peers.

The present study was deliberately confined to the learning of known phonological representations (names or words) to pictures. Whereas studies on visual-verbal PAL with novel words or nonwords have consistently shown that the performance of dyslexic children, compared to normal readers, is relatively worse, the results for word learning have been equivocal. Some studies report that word learning is also impaired in dyslexic children (Vellutino et al., 1978; Vellutino et al., 1983), but in other studies performance differences between dyslexic and normal readers have not been found (Vellutino & Scanlon, 1989; Vellutino et al., 1995). The results of the current studies were also inconsistent. In the first study, we found a substantial difference between dyslexic and normal readers, thus replicating the results of Messbauer and de Jong (2003) who used the same verbal stimuli. In the third study, in which the same children participated as in the first study, a difference between normal and dyslexic children was also found, but the magnitude of the effect was about half of the effect in the first study. Finally, in the second study we did not observe a difference in the performance of normal and dyslexic readers.

In the first study the verbal stimuli were names, whereas in the other two studies highly frequent words were given. Although the names were very common, some of them might not have been familiar to some of the participants and hence might have acted as nonwords. A study by Mayringer and Wimmer (2000) that controlled for familiarity of the highly frequent names used, reported similar visual-verbal PAL performance for dyslexic and normal readers. In a previous PAL-study by Messbauer and the Jong (2003) that used the same highly frequent names as in the first study, however, the dyslexic children mainly made errors in the association of the names with the correct picture. In contrast to nonword learning, a negligible amount of phonological errors was made in word learning. These results suggest that, although not all names might have been familiar to the participants, they did not act as nonwords. More important might have been the semantic content or good imageability of the words. In contrast, names are abstract, unless one knows somebody with the name.

Recently, Duyck, Szmalec, Kemps, and Vandierendonck (2004) showed that associative learning is enhanced when the words or nonwords in a pair are associated with a visual image. Several earlier studies have also shown that high meaning and concrete words are more easily associated with visual stimuli than low meaning and abstract words. Moreover, dyslexic children were found to perform similar to normal reading peers when high meaning and concrete words had to be associated with visual stimuli, but worse than their normal reading peers when low meaning and abstract words had to be learned (Torgesen & Murphey, 1979; Samuels & Anderson, 1973; Vellutino et al., 1989; Vellutino et al., 1995). Thus, the relatively strong difference between normal and dyslexic readers in the first study, like in the study of

Messbauer and de Jong (2003), might be due to the use of names that are usually of low imageability as compared to high frequency words. When high frequency words have to be used, differences between normal and dyslexic readers seem to be small or even absent.

Finally, we found that the lower word learning speed of the dyslexic children in the first and the third study could be attributed to their problems with phonological processing abilities for a substantial part. When phonological awareness was taken into account, the difference between the dyslexic and the normal readers on visual-verbal PAL performance decreased considerably, replicating previous findings (Messbauer & de Jong, 2003; Windfuhr & Snowling, 2001). However, the dyslexic children that participated in the first and third study also lagged behind in arithmetic ability and this difference in arithmetic ability could also account for the difference in visual-verbal PAL between the groups. This finding does not necessarily mean that the lower performance of dyslexic children on visual-verbal learning was due to their arithmetic problems. In previous studies substantial relationships have been found among reading, arithmetic and phonological processing (e.g., Bryant, MacLean, Bradley, & Crossland, 1990; Hecht et al., 2001; Leather & Henry, 1994). Hecht et al. (2001) reported that the relationship between reading and arithmetic ability almost disappeared when phonological awareness was controlled. Hecht et al. concluded that phonological processing abilities tend to influence both abilities. In this respect it is of interest that our measure of arithmetic achievement, calculation speed, mainly tested the availability of arithmetic facts. The formation of an arithmetic fact requires the formation of an association between a problem and its answer (e.g., Geary, 1994). The formation of arithmetic facts itself might therefore, at least in part, be considered as a form of visual (the written problem) verbal (the answer) PAL. In a subsequent analysis we also found that both arithmetic achievement and phonological awareness accounted for unique variance in visual-verbal PAL. Therefore, the current results tend to suggest that the lower performance of dyslexic children in visual-verbal PAL is in part a reflection of their problems in phonological awareness, and its underlying impairment of phonological representations, as well as a more general problem in the ability to form associations (see also Windfuhr & Snowling, 2001).

In conclusion, the main finding of the current studies was that the visual-verbal paired associate learning performance of dyslexic and normal readers was equally affected by the visual distinctness of the pictures and the phonological distinctness of the words. In addition, we found that the word learning performance of dyslexic children was impaired when visual-verbal learning involved names, but performance differences were less or absent if the learning concerned high frequency words. Finally, differences in word learning between normal and dyslexic children could be accounted to a large extent by their differences in phonological processing.

CHAPTER 5

Exploring the consequences of underspecified phonological representations for the acquisition of orthographic knowledge

5. Exploring the consequences of underspecified phonological representations for the acquisition of orthographic knowledge

The effect of orthographic context on learning to read new words was studied in 19 Dutch dyslexic children, 20 chronological-age and 20 reading-age controls. We assumed that dyslexic children have underspecified phonological representations of words and, as a result, that neighbour words are relatively more similar than in normal readers. Accordingly, we expected that dyslexic children would specifically have problems in the acquisition of the orthographic knowledge of words that are presented in a context of neighbor words. To test this hypothesis, dyslexic children and groups of reading- and age-matched normal readers repeatedly read series of target nonwords, presented in an indistinct (e.g., knip, knik, klip, and klik) and a distinct context (e.g., knip, staaf, brom, and sloot) during a training. At posttest, target nonwords and new nonwords, meant to study transfer, were given. The results at posttest suggest that dyslexic readers are affected by orthographic context whereas normal readers are not. This sensitivity of dyslexic children to the orthographic context can be interpreted as a direct consequence of underspecified phonological representations.

Introduction

Exploring the consequences of underspecified phonological representations

Underspecified, low quality or indistinct phonological representations are believed to be one of the main causes of dyslexia (Elbro, 1996; Fowler, 1991; Metsala & Walley, 1998; Snowling & Hulme, 1994). Such representations are assumed to hamper the development of phonological awareness, especially at the level of phonemes, which, in turn, is necessary to crack the alphabetic code and to learn to read accurately (e.g., Byrne, 1998; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Thus, according to this account, low quality phonological representations have an *indirect* effect on learning to read.

However, in transparent orthographies even dyslexic children learn to read accurately and their problems in phonological awareness tend to decrease considerably (de Jong & van der Leij, 2003; Landerl & Wimmer, 2000; Wimmer, 1996). Nevertheless, dyslexic children's reading speed remains very slow (van der Leij & van Daal, 1999). This raises the question of a *direct* link between impoverished phonological representations and the development of reading speed.

Reading speed is, in part, dependent on the proportion of words read by sight (de Jong, 2000; Torgesen, 2001). For sight words, the view of the written word form immediately activates its pronunciation and meaning in memory, because detailed connections between the spoken and the written form of the word have been developed (Ehri, 1998). The ease with which printed words are recognized and pronounced is dependent on the quality and number of connections between the spelling and the pronunciation (Booth, Perfetti & MacWhinney, 1999; Ehri, 1992). Accordingly, the question becomes whether impoverished phonological representations might affect the formation and storage of connections between spoken and written forms of words, that is, the acquisition of orthographic knowledge.

There are many studies including normal or dyslexic readers that support, directly or indirectly, the hypothesis that impoverished phonological representations affect performance when words are phonologically or orthographically similar. For example, studies examining spoken word recognition in normal reading children and adults have consistently shown that it is more difficult to recognize words from dense neighborhoods (i.e., words that share all letters but one in the same position as the target word) than words from sparse neighborhoods (Garlock, Walley, & Metsala, 2001; Ziegler, Muneaux, & Grainger, 2003). The tasks required lexical decision (is the auditorily presented word a real word or not), the recognition of a word presented in noise, or the recognition of a word in a gating task (e.g., when increasingly longer speech segments from word onset were presented). Thus, in general, when words sound alike more information is needed to correctly identify the words.

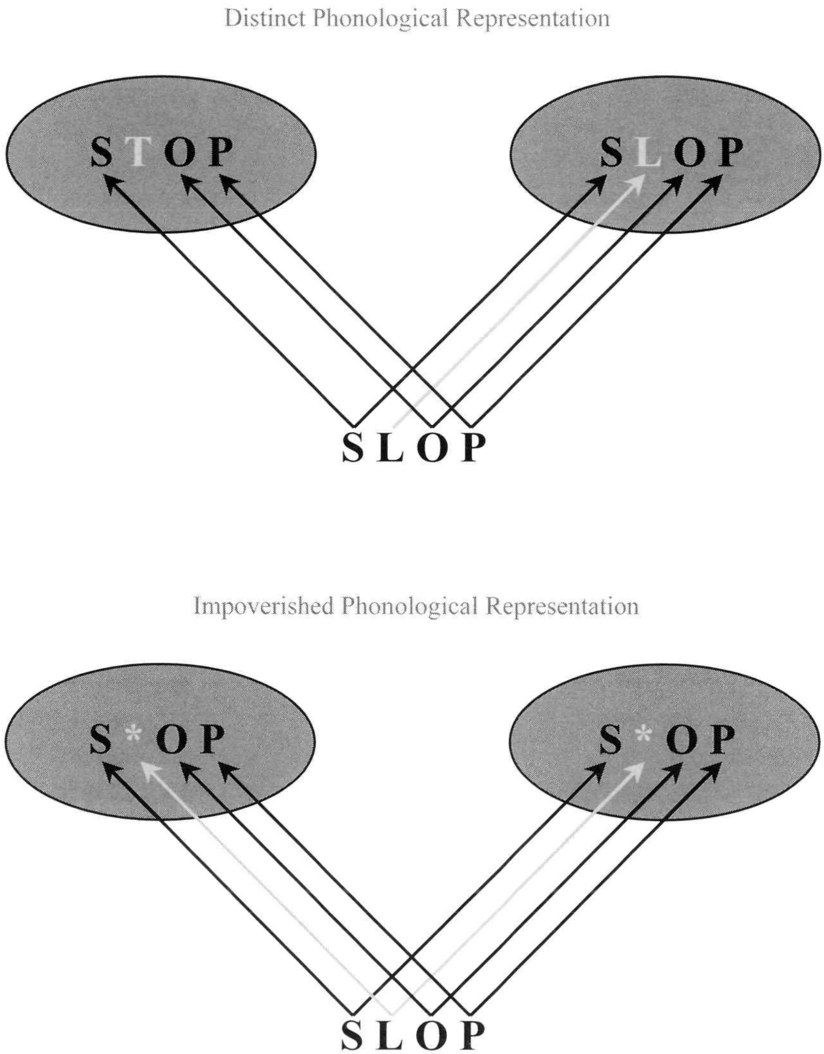
To our knowledge, only a study by Metsala (1997) compared spoken word recognition in reading disabled and normal readers. From the assumption that phonological representations are less segmentalized in dyslexic readers, Metsala hypothesized that it would be more difficult for dyslexic children to identify words in a gating task than for normal reading peers. Indeed, the results showed that poor readers needed more speech information to correctly identify words, but only for words from sparse neighborhoods. For words from dense neighborhoods, however, no differences were found between the reader groups. Both poor and normal readers needed a similar amount of information to correctly identify the words. Metsala argued that the results supported the lexical restructuring hypothesis, that is, children's initial holistic phonological representations become increasingly more segmentalized in the early school years under the driving force of vocabulary growth. Accordingly, the need for segmentalized representations is less acute for sparse neighborhoods than for words in dense neighborhoods.

In a recent study examining the consequences of underspecified phonological representations, however, Messbauer and de Jong (submitted) assumed that for dyslexic readers, having less distinct phonological representations, neighbors from both sparse and dense neighborhoods are relatively more similar than for normal readers. Performance differences between dyslexic and age-matched normal readers were studied in a visual-verbal paired associate learning task in which a set of phonologically similar words and a set of phonologically dissimilar words had to be associated with pictures. It was hypothesized that dyslexic children would be more strongly affected by the phonological distinctness of the words than normal reading peers. The results did not support this hypothesis. Dyslexic and normal reading children were similarly affected by the phonological similarity of the set of words.

As none of the above mentioned studies involved the actual reading process (i.e., studied the formation of connections between spoken and written forms of words), it can only be speculated how underspecified phonological representations affect reading acquisition. Although the paired-associate learning study by Messbauer and de Jong (submitted) approached the basic process of reading acquisition, an important difference between the connections that have to be formed in reading and the connections made in the visual-verbal paired associate learning task was the absence of a relation between the words and the associated visual stimuli. For reading, phonological information embedded in the written forms of words is used to retrieve the correct pronunciation from memory. It was suggested that this absence of connections between the two items in the paired associate learning tasks might have caused the comparable performance of dyslexic and normal readers. Possibly, differential effects of underspecified phonological representations only become apparent in tasks requiring the parallel processing of phonological and orthographic information, that is, reading acquisition (see also Metsala & Walley, 1998).

The current study addressed the possibility that the availability of detailed phonological representations becomes critical when connections have to be formed in a context of learning to read similar words. Words can be either orthographically or phonologically similar. However, in transparent orthographies, orthographically similar words have quite similar pronunciations and vice versa.

Figure 1
Phonological representations and the formation of connections



For dyslexic children, having underspecified phonological representations, the representations of phonologically similar words are assumed to overlap with each other to a greater extent than in normal reading children. The effects of the two extremes, good and poor phonological representations, on the formation of connections are illustrated in Figure 1. If each phoneme in the phonological representations of /STOP/ and /SLOP/ is specified correctly then accurate connections between the written form SLOP and the spoken form /SLOP/ can be formed, even in the context of STOP. However, if the critical phonemes /T/ and /L/ in the phonological representations of /STOP/ and /SLOP/ are poorly specified, it becomes more difficult to form connections between the written form SLOP and the spoken form /SLOP/ in the context of the written form STOP. Consequently, the chance of incorrect mappings of phonology to orthography increases. Accordingly, we assumed that it is more difficult for dyslexic readers to learn to read a set of phonologically indistinct words than a set of phonologically distinct words.

To test this hypothesis, in the current study dyslexic and normal readers learned to read nonwords in either an *indistinct* (*kwog* with *kwos, knos,* and *knog*), or a *distinct* context (*kwog* with *kwes, snar,* and *skal*). The lower quality phonological representations in dyslexic children were expected to overlap with one another to a great extent, especially in an indistinct condition. Therefore, we hypothesized that for dyslexic children the acquisition of orthographic knowledge is more difficult in an indistinct than in a distinct orthographic context. Consequently, dyslexic children are expected to need more time to retrieve the correct pronunciation of a written word from memory when this word has been learned to read in an indistinct context. This will be observed as a decrease in reading accuracy and in reading speed. For normal readers, however, orthographic context was not expected to have an effect on learning to read nonwords. This hypothesis is denoted as the *Similarity Hypothesis*.

However, there is also an alternative hypothesis. The lower quality of phonological representations in dyslexic children has been assumed to result in more holistic representations of words. In several simulation studies based on connectionist models, Harm and Seidenberg (1999) degraded the ability to form highly structured phonological representations. As a consequence, holistic and item-specific representations of written words were formed that shared *fewer* structures with other, similar words. Thus, in impaired models (modeling dyslexic readers) the phonological representations are much more diverse within neighborhoods than in the normal model. For the construction of mappings between the spoken and written forms of words this implicated that connections were acquired more slowly. Additionally, impaired models treated orthographically similar words differently and could not take advantage of the similarity between them. Consequently, the mapping of orthography onto phonology became dependent on the word-specific aspects of the orthography when the capacity to represent phonological structure was limited (Harm & Seidenberg, 1999).

To overcome these problems, McCandliss, Beck, Sandak, and Perfetti (2003) hypothesized that changing successive words just one letter at a time would force the formation of more componential orthography to phonology mappings (i.e., ones that are more sensitive to the internal parts or components of words). An intervention program that taught dyslexic readers to form a chain of words that differed by a single letter transformation, progressive minimal pairing, was found to lead to improvements of decoding abilities (see also van den Broeck, 1997). Harm, McCandliss, and Seidenberg (2003) additionally tested this remediation technique in a computational model and found that a strong emphasis on systematic letter-sound relationships for each position within a word increased the sensitivity of the model for subword components making word reading easier. Additionally, improvements in reading new or nonwords were found. Therefore, our alternative hypothesis, the *Minimal Difference Hypothesis*, was that for dyslexic children the acquisition of orthographic knowledge is less difficult in an indistinct than in a distinct orthographic context, whereas for normal readers orthographic context does not have an effect. In an indistinct orthographic context, the minimal differences among the words encourage a focus on each individual letter in a word. Such a focus enhances the acquisition of fully specified representations of printed words, thus orthographic knowledge. As a result of this increase in orthographic knowledge reading accuracy and reading speed will increase.

In addition to the examination of the two previously mentioned hypotheses, we also considered the generalization of learning to read words in a distinct and indistinct context on reading transfer nonwords. In other words, we examined the transfer of the acquired orthographic knowledge. Previous studies on reading remediation consistently showed that training, enhancing attention to the internal structure of words, also improved reading of new words or nonwords (Hatcher, Hulme, & Ellis, 1994; McCandliss et al., 2003; Torgesen, Wagner, Rashotte, Alexander, & Conway, 1997; Wise, Ring, & Olson, 2000). The capacity to generalize and to pronounce unfamiliar letter strings is essential in becoming a skilled reader. Simulations by Harm and Seidenberg (1999) support the assumption that the quality of phonological representations fundamentally affects the ability to generalize. Their computational models showed that for impaired models the mapping of orthography onto phonology became dependent on the word-specific aspects during training. As a result, impaired models treated new, orthographically similar words differently and could not take advantage of the similarity between them. Accordingly, they argued that mappings from orthography to phonology must be more precise or training generalizes poorly.

To study transfer effects, we created transfer nonwords that differed on only one grapheme from previously trained nonwords read in a distinct or in an indistinct context. From the *Similarity Hypothesis* it was expected that for dyslexic children reading transfer nonwords would discord with the acquired orthographic knowledge during training. It was hypothesized that this dissonance would result in lower reading accuracy and reading speed for all transfer nonwords. For younger and age-matched normal readers reading speed and accuracy differences between previously trained and transfer nonwords were also predicted, but the magnitude of this interference was expected to be considerably smaller than for the dyslexic children. Furthermore, the difference between trained and transfer nonwords was expected to be larger in the indistinct context then in the distinct context for dyslexic children. For the age-matched and younger normal readers, however, no effect of orthographic context was expected.

According to the *Minimal Difference Hypothesis*, however, it was hypothesized that dyslexic children would benefit from the acquired orthographic knowledge during training when reading transfer nonwords. Nonetheless, their reading speed and accuracy of the transfer nonwords were expected to be lower than of the previously trained nonwords. The decrease in reading speed and accuracy, however, was expected to be of a similar magnitude as for the age-matched and younger normal readers. For the distinct context, a larger difference between the trained and transfer nonwords was expected for the dyslexic children, but not for the normal reading children.

In summary, the present study examined the effects of dyslexic children's presumed low quality phonological representations on learning to read new words. To this end, dyslexic children and groups of reading and age-matched normal readers repeatedly read lists of nonwords presented in a distinct or an indistinct context. One day after the training the first posttest was administered; the second posttest was given one week later. Finally, a phoneme recognition task was administered to assess phonological processing problems.

According to the *Similarity Hypothesis* the dyslexic children were expected to read the target nonwords slower in the indistinct context than in the distinct context as compared to the chronological-age and reading-age matched normal readers. However, following the *Minimal Difference Hypothesis* we expected that the dyslexic children would read the target nonwords faster in the indistinct context than in the distinct context as compared to both the groups of normal readers. With respect to transfer, the Similarity Hypothesis predicts considerable lower reading speed and accuracy of transfer nonwords for dyslexic children, whereas the Minimal Difference Hypothesis anticipates a slightly lower reading speed and accuracy of transfer nonwords as compared to previously trained ones. Normal reading children were expected to read transfer words at hardly altered speed and accuracy as the previously trained words.

Method

Participants

The study involved 21 dyslexic readers, 21 reading-age controls, and 21 chronological-age controls. Each group consisted of 14 boys and 7 girls. The dyslexic children were individually matched with the reading-age controls on reading ability and with the chronological-age controls on vocabulary, non-verbal intelligence and age.

Reading ability was assessed with the *Een-Minuut-Test* (EMT) *[One Minute Test]* (Brus & Voeten, 1979), a Dutch standardized test of single word reading. The test is commonly used to determine the reading level of children in primary schools. The test consists of a list of 116 words of increasing difficulty. The participants are required to read the words aloud as quickly as possible, without making errors. The raw score is the number of words read correctly within one minute. Standardized scores range from 1 to 19, with a mean of 10 and a standard deviation of 3 (van den Bos, Lutje Spelberg, Scheepstra, & de Vries, 1994). Children with a standardized reading score within one standard deviation of the mean were considered as normal readers. A reading lag of at least two years compared to their chronological-age, as indicated by a standardized reading score of 2 or less, was used as an indication of dyslexia.

Receptive vocabulary was measured with the Passive Vocabulary Test, a standardized subtest of the RAKIT (*Revisie Amsterdamse Kinder Intelligentie Test*) *[Revised Amsterdam Child Intelligence Test]* (Bleichrodt, Drenth, Zaal, & Resing, 1987), a Dutch intelligence test battery. The participants have to choose the picture from a selection of four that matches a given word. The test consists of 60 items. The raw vocabulary score is the number of correctly chosen pictures. Subsequently, this score was transformed into a standardized vocabulary score between 0 and 30, with a mean of 15 and a standard deviation of 5. Children with a standardized vocabulary score of one or more standard deviations below their age-norm were not included in the study.

Finally, as a measure of non-verbal intelligence, we administered the *RAVEN Standard Progressive Matrices* (Raven, Court, & Raven, 1986). The dyslexic children and their normal reading peers completed all of the 60 items. The younger normal readers completed only the first 36 items because only these items covered the range of intellectual development of these younger children. The raw score is based on the number of correct answers. Percentile points for 6-month age-ranges between 6.03 and 16.08 years of age were obtained. Children with a test score beneath the 40^{th} percentile according to their age-norm were not included in the study.

All normal reading children and eight dyslexic children attended regular primary schools. The other 13 dyslexic children came from special schools for children with learning disabilities. For the selection of the dyslexic children from the special schools, information from the school records was used to exclude children with an IQ of 85 or below (based upon the *Wechsler Intelligence Scale for Children - Revised: Dutch Edition* (1986) full scale IQ, which is generally administered at school entry). For the children who attended regular schools it was assumed that their IQ was above 85. Also, children with hearing or articulatory problems, neurological deficits, or who had been diagnosed as ADHD, as well as children for whom Dutch was not their native language were omitted from the study. The characteristics of the groups are presented in Table 1.

Training

The training involved the repeated reading of a list of 18 nonwords. Each nonword was read 12 times. Four different nonword lists were used to control for item specific effects. Participants were randomly assigned to one of the four nonword lists (for complete lists see Appendix B).

Nonwords. The nonwords were one-syllable CCVC nonwords. Within each list of 18 nonwords two target nonwords were presented in an orthographically indistinct context, two in a distinct context, and two in a unique context. For example, in the *indistinct context* the target nonwords SJAR and GRUIF were accompanied by the nonwords SJAL, SNAR, SNAL, SKAR, SKAL, and GRUIP, GLUIF, GLUIP respectively. The nonwords in this context differed on the second or final consonant from the root word in the set. In the orthographically *distinct context*, the target nonwords KWOG and PLIEK were read in the context of the nonwords KWES and PLOOM. These nonwords have similar onsets but different rimes. Finally, in the *unique context* the nonwords BLIP and TSAUN were read in the context of the nonwords DWUT and VREUS. The nonwords in this context had no letter clusters in common with one another and were clearly distinguishable from the nonwords read in the distinct and indistinct context.

Four different nonword lists were constructed. The target nonwords read in the indistinct context in nonword list I were read in the distinct context in nonword list II and vice versa. In nonword lists III and IV the target nonwords were exchanged.

Learning procedure. The training was evenly spread over two consecutive days. In each training session, a word list of 18 nonwords was presented 6 times. Within each of these 6 reading trials, the nonwords were randomly presented.

Table 1

Characteristics of the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group

	DYS		RA		CA	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age (in months)	129.90	10.33	96.05	4.24	129.67	9.76
Word decoding	36.43	7.97	36.81	7.62	76.67	10.90
Nonword reading	26.00	8.89	30.10	9.24	75.38	14.55
Vocabulary [a]	12.52	2.77	14.38	4.34	12.86	3.31
Raven (raw score)	37.76	6.39	26.05	5.32	40.10	6.89

[a] Based on the national norms the scores were transposed to standardized scores with a mean of 15 and a standard deviation of 5

The nonwords were presented visually in the center of a computer monitor. After a beep, to focus the attention of the child, a nonword appeared on the screen. The child was asked to name each nonword as quickly as possible, without making errors. A voice-key registered the time between the presentation of a nonword and the onset of the response of the child. In case the child needed to sound out the nonword, it was asked to do this subvocally in order to prevent the activation of the voice-key before the complete nonword was identified.

After the response of the child, the experimenter scored whether the nonword was read correctly, incorrectly, or invalid. This last category was used for responses that were too fast (i.e., RTs smaller than 200 ms) or too slow (i.e., RTs larger than 10.000 ms), or for cases in which the voice-key reacted on a sound other than the response of the child.

Each training session was preceded by five nonwords for practice to let the child become accustomed to the task, and to properly adjust the voice-key.

Measures

Phoneme recognition. This test consisted of 12 one-syllable and 12 two-syllable nonwords. The nonwords were presented one by one by the experimenter. The child was asked to repeat each nonword to make sure the child had heard it correctly and could pronounce the nonword accurately. Then, the experimenter gave a phoneme and the child had to decide whether or not it was present in the nonword. The child had to answer with yes or no. Six examples preceded the test items. The maximum score was 24.

Nonword reading (Posttests). The posttests consisted of 25 nonwords (for complete lists see Appendix C). These nonwords consisted of trained and transfer ones. The *trained nonwords* were the six target nonwords read in the indistinct, distinct, and unique context during training. The *transfer nonwords* were 12 transfer nonwords and seven filler items. The *transfer nonwords* differed in only one grapheme from a previously trained nonword. For each trained nonword (either distinct, indistinct, or unique), two types of transfer nonwords were constructed. In one nonword the second letter of the initial letter cluster of the trained nonword was substituted for a different letter (first letter transfer nonwords), and in one nonword the last letter of the trained nonword was substituted (last letter transfer nonword).

The 25 nonwords were randomly presented. The test was preceded by five nonwords for practice to let the child become accustomed to the task, and to properly adjust the voice-key.

General procedure

The RAVEN and receptive vocabulary test were administered group-wise during a one-day screening. Afterwards, the children were administered the single word reading test (EMT) individually in a quiet room.

Three weeks after the screening, the selected participants were tested individually in four sessions. The two training sessions took place on two consecutive days. One day after the last training session, the first posttest was done. One week later the posttest was administered again. The phoneme recognition task was assessed before the second training session.

Results

The results are presented in two sections. First, the results of the phoneme recognition task are shown. Second, the results of the nonword reading task (both the training and the posttests) are presented.

Phonological information processing

The mean scores and standard deviations of the groups on the phoneme recognition task are presented in Table 2. Because of ceiling effects, the data were subjected to two separate nonparametric Mann-Whitney tests (one comparing the dyslexics and the chronological-age controls, and one comparing the dyslexics and the reading-age controls) instead of a multivariate analysis of variance (MANOVA) for repeated measures.

The dyslexics were found to perform lower on phoneme recognition of both one and two-syllable nonwords compared to the age-matched normal readers ($U = 153.00$, $p < .05$ for one-syllable nonwords, $U = 128.50$, $p < .01$ for two-syllable nonwords).

The mean score difference between the dyslexics and the reading-age controls was only significant for the one-syllable nonwords ($U = 130.50$, $p < .01$). No performance differences were found for the two-syllable nonwords ($U = 171.00$, $p > .10$).

Table 2

Mean Scores (M) and Standard Deviations (SD) for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on Phoneme Recognition

	DYS		RA		CA	
	M	*SD*	*M*	*SD*	*M*	*SD*
One syllable	11.00	.77	11.57	.51	11.43	.75
Two syllables	10.48	1.03	10.81	1.17	11.24	.89

Note. Maximum score on each component of the phoneme recognition task is 12

Figure 2

Mean percentage correctly read nonwords for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the training trials

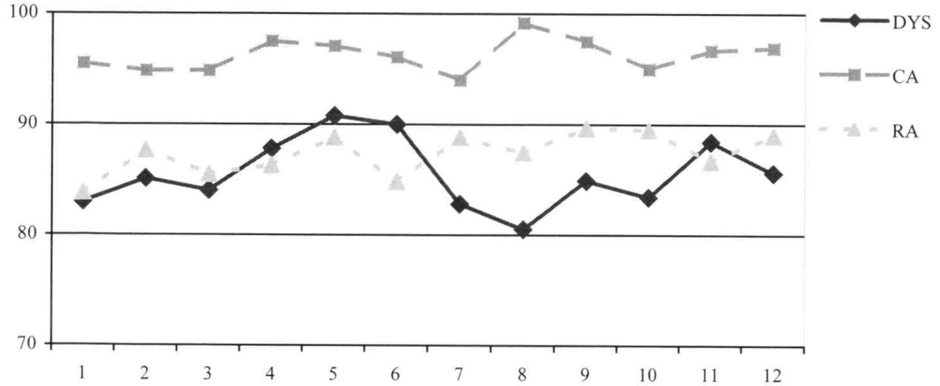
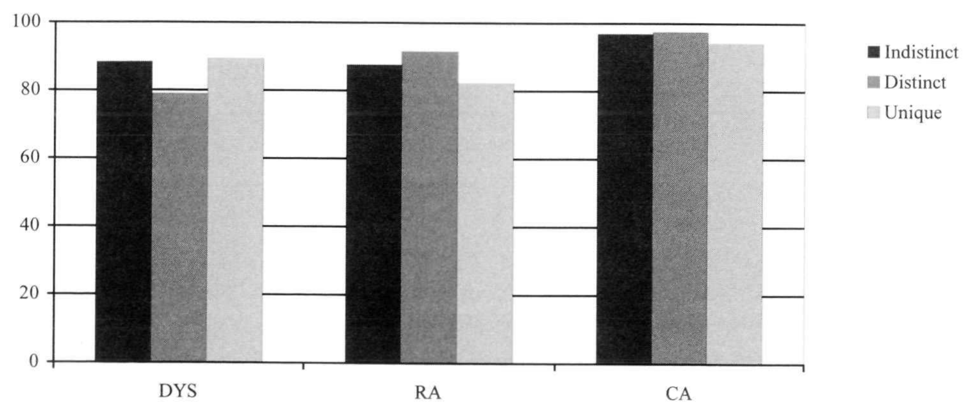


Figure 3

Mean percentage correctly read nonwords in each orthographic context for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group during training



Reading performance

One reading-age control missed the first training session, one chronological-age control and one dyslexic child were absent during the first posttest, and, finally, one dyslexic child missed the second posttest. These children were all excluded from the following analyses. Therefore, the results are based on 19 dyslexic readers, 20 age-matched normal reading peers, and 20 reading-age controls. Omission of these children did not alter group characteristics.

Reading during training

Reading accuracy. In Figure 2 the distribution of the accuracy percentages for the three reading groups on the 12 reading trails are shown. As the chronological-age controls were highly accurate on nonword reading (i.e., causing ceiling effects), they were not taken into account in the analysis. Of the valid responses the percentages of correctly pronounced nonwords were also determined for each orthographic context (indistinct, distinct, and unique).

In Table 3 the distribution of the accuracy scores across these contexts are presented. The accuracy scores were subjected to a multivariate analysis of variance (MANOVA) for repeated measures with reading group (dyslexics and reading-age controls) as a between-subjects factor, and training trial (1 to 12) and orthographic context (distinct, indistinct, and unique) as within-subjects factors.

To test the hypothesis that dyslexic children read nonwords in an indistinct context less accurate than younger normal readers compared to reading accuracy of distinct and unique nonwords, two contrasts were specified on the within-subjects factor orthographic context. In the first contrast, we compared the indistinct versus distinct and unique nonwords. In the second contrast, the differences between the distinct and unique nonwords were compared. A main effect of reading group indicated that one of the groups performed less accurate on reading nonwords despite the context in which the words were read (indistinct, distinct or unique). An interaction effect of reading group by orthographic context indicated that the difference between the groups was dependent on the context in which the nonwords were read (indistinct versus distinct and unique or distinct versus unique).

Table 3

Mean percentage correctly read indistinct, distinct, and unique nonwords for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group during training

	DYS		RA		CA	
	M	*SD*	*M*	*SD*	*M*	*SD*
Indistinct	88.34	14.32	87.56	18.27	96.94	9.79
Distinct	78.91	21.41	91.60	11.84	97.47	6.30
Unique	89.33	14.23	82.27	19.81	94.18	12.40

Table 4

Mean naming latencies (in ms) for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group and for the orthographic contexts on the training trials

	DYS		RA		CA		Indistinct		Distinct		Unique	
Trial	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	1864.96	712.77	1869.05	1005.05	715.65	154.36	1376.26	916.63	1572.72	973.88	1484.27	992.33
2	1450.18	482.15	1408.96	492.95	656.20	137.80	1055.07	489.21	1191.61	592.52	1254.52	736.05
3	1319.92	393.58	1261.00	621.90	633.58	109.37	1058.58	775.16	1024.82	409.37	1118.48	668.89
4	1206.35	434.68	1253.08	500.43	640.16	161.60	981.60	485.37	1046.33	526.25	1062.86	546.06
5	1292.71	560.58	1200.20	434.53	606.57	112.68	1054.60	664.19	1038.21	518.86	1027.36	569.51
6	1181.14	300.68	1082.59	360.74	628.43	106.31	940.30	410.48	960.86	400.59	979.95	422.10
7	1323.79	655.02	1276.53	622.50	701.82	246.06	1128.11	821.03	1062.92	677.49	1099.77	681.58
8	1189.91	535.30	1103.62	381.95	640.64	125.24	1023.86	575.48	931.27	443.65	968.27	506.18
9	1101.30	647.44	1093.18	335.81	646.22	110.37	1008.03	682.52	897.84	389.58	926.97	447.75
10	1213.99	759.72	1017.51	240.07	674.59	166.48	952.64	518.93	975.73	537.62	965.25	556.34
11	1263.74	978.50	1061.42	314.30	636.21	101.39	1033.74	799.34	920.59	650.34	993.31	598.03
12	1088.44	573.83	991.47	246.34	638.86	109.38	973.76	526.82	888.60	519.05	847.14	301.82

The analysis revealed that the accuracy scores of the dyslexic and younger normal readers were similar ($F < 1$). However, one contrast on orthographic context approached significance ($F\,(1, 31) = 3.81, p = .06$). Dyslexic children tended to read distinct nonwords less accurate than unique ones as compared to the younger normal readers (see Figure 3). No other significant effects were found.

Reading speed. Voice-key errors such as anticipations or mouth clicks (1.42%), naming latencies (i.e., reaction times, RTs) smaller than 200 ms (0.31%) and larger than 10.000 ms (0.07%), and RTs that were three standard deviations above or below an individuals grand mean (2.60%) were excluded from the analyses. The percentages of incorrectly read nonwords across the 12 trials were 4.53% for the dyslexic readers, 5.00% for the reading-age controls, and 3.68% for the chronological-age controls for the selected nonwords[1].

For each orthographic context (indistinct, distinct, and unique), a mean reading speed was calculated, with the requirement that each child had read at least one of the two nonwords in a context correctly. If a child had read both nonwords incorrectly, a missing value was attributed to that specific variable. To prevent that the analysis would have to be conducted with considerably less subjects in one or more reading groups, missing scores were replaced. The percentage replaced scores in the training was 3.80% for the dyslexic children, 2.78% for the younger normal readers, and 0.69% for the age-matched normal readers. For one dyslexic reader 11 of the 36 scores in total had to be replaced, whereas for the remaining children less than eight scores had to be replaced. Estimation of the missing scores was conducted by the EM algorithm (Little & Rubin, 1987). The mean naming latencies for each reader group and orthographic context are presented in Table 4.

Although the standard deviations of the naming latencies between the reader groups differed considerably from one another, analysis of the data after a 1/RT transformation yielded virtually identical results.

The naming latencies were subjected to a MANOVA for repeated measures with reading group (dyslexics, reading-age controls, and chronological-age controls) as a between-subjects factor, and training trial (1 to 12) and orthographic context (distinct, indistinct, and unique) as within-subjects factors. To test the hypothesis that dyslexic children read nonwords in an indistinct context slower than normal reading peers and younger normal readers as compared to the reading speed of distinct and unique nonwords, two contrasts were specified on the within-subjects factor orthographic context and two contrasts were specified on the between-subjects factor reading group (dyslexic children versus age-matched normal readers, and dyslexics versus reading-age matched controls). In the first contrast on orthographic context, we compared the indistinct versus distinct and unique nonwords.

[1] This distribution does not differ much for the dyslexics (10.83%) and the reading-age controls (10.42%) when all 18 nonwords read were taken into account. The chronological-age controls, however, were more accurate when all nonwords were considered (1.20%).

Figure 4a

Mean naming latencies (in ms) of the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the training trials presented per 2 successive trials

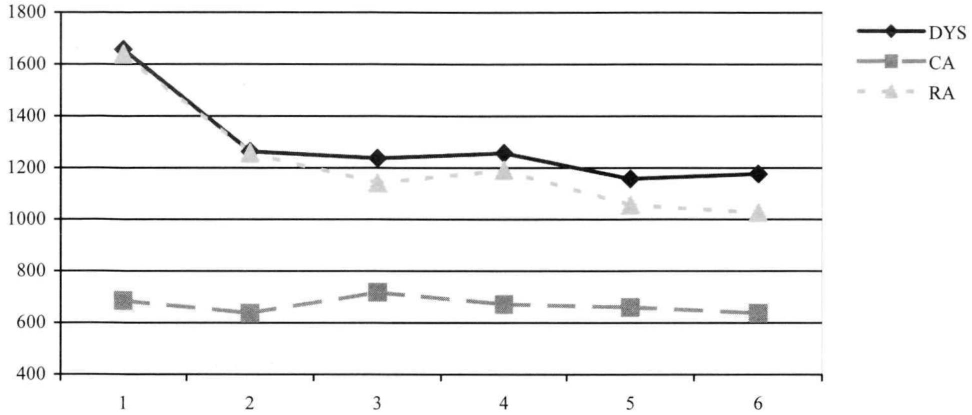
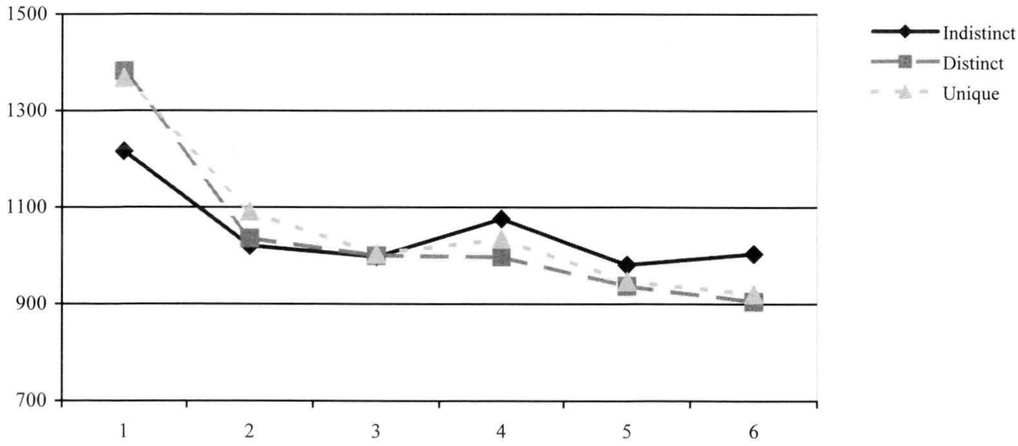


Figure 4b

Mean naming latencies (in ms) for the indistinct, distinct, and unique nonwords on the training trials presented per 2 successive trials



In the second contrast, the differences between the distinct and unique nonwords were compared. For each between-subjects contrast, a main effect of reading group indicated that one of the groups read the nonwords slower regardless of the context in which the words were read (indistinct, distinct or unique). An interaction effect of reading group by orthographic context indicated that the difference between the contrasted groups was dependent on the context in which the nonwords were read (indistinct versus distinct and unique or distinct versus unique).

The analysis revealed significant main effects of trial (F (11, 616) = 15.55, $p < .001$), and reading group (F (2, 56) = 18.22, $p < .001$). In addition, an interaction effect of trial and reading group (F (22, 616) = 3.31, $p < .001$) was found. Examination of the contrasts on the reading groups factor revealed that the dyslexic children read the nonwords at a similar speed as the younger normal readers ($F < 1$), but slower than the age-matched normal readers (F (1, 56) = 30.00, $p < .001$). However, the reading speed of both dyslexics and younger normal readers increased more during training than the reading speed of the age-matched normal readers (see Figure 4a).

Furthermore, a trial by orthographic context interaction was found (F (22, 1232) = 1.90, $p < .01$). As can be seen in Figure 4b, the reader groups read the distinct nonwords faster than the indistinct ones at the last training trials as opposed to the earlier trials[2]. No interaction of orthographic context by reading group was found ($F < 1$).

In sum, dyslexics were found to read nonwords less accurate and slower (though reading speed improved significantly) than age-matched normal readers during a two-day training. Additionally, dyslexics read at similar accuracy and reading speed as younger normal readers. As training progressed, the distinct nonwords were read faster than the indistinct ones by all participants. However, the absence of a reader group by orthographic context interaction indicated that all reader groups were affected similarly by orthographic similarity.

Reading at posttest

The first posttest (Posttest 1) was administered one day after the training; the second posttest (Posttest 2) was given one week later. On both tests accuracy and latencies were recorded. Independent analysis of the posttests yielded quite similar results. Hence, to maximize the power of the analysis, we have analyzed the data of both posttests simultaneously.

For the analysis of the data the nonwords were divided into trained and transfer nonwords. The *trained nonwords* (a total of 6) consisted of two indistinct, two distinct, and two unique nonwords, which were all previously trained. Furthermore, 12 *transfer nonwords* were read, that is, new nonwords that differed on one grapheme from a previously trained nonword.

[2] The analysis including all 18 nonwords read in the training revealed identical results.

Table 5

Percentage correctly read nonwords for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the Posttests

	DYS		RA		CA	
	M	*SD*	*M*	*SD*	*M*	*SD*
Posttest 1						
Trained nonwords						
Indistinct	94.74	15.77	92.50	18.32	97.50	11.18
Distinct	89.47	26.77	97.50	11.18	100	0
Unique	89.47	20.94	87.50	22.21	100	0
Last letter transfer nonwords						
Indistinct	86.84	28.10	95.00	15.39	95.00	15.39
Distinct	76.32	25.65	85.00	28.56	100	0
Unique	68.42	34.20	80.00	29.91	97.50	11.18
First letter transfer nonwords						
Indistinct	97.37	11.47	75.00	38.04	92.50	18.32
Distinct	78.95	30.35	80.00	29.91	100	0
Unique	78.95	34.62	80.00	29.91	100	0
Posttest 2						
Trained nonwords						
Indistinct	94.74	15.77	92.50	18.32	100	0
Distinct	84.21	23.88	100	0	100	0
Unique	78.95	30.35	90.00	20.52	97.50	11.18
Last letter transfer nonwords						
Indistinct	86.84	22.62	82.50	33.54	100	0
Distinct	78.95	25.36	90.00	20.52	100	0
Unique	78.95	25.36	90.00	26.16	97.50	11.18
First letter transfer nonwords						
Indistinct	84.21	33.55	92.50	18.32	95.00	15.39
Distinct	76.32	25.65	92.50	18.32	97.50	11.18
Unique	81.58	34.20	92.50	18.32	97.50	11.18

Within the transfer nonwords a subdivision was made in first and last letter transfer nonwords. Either the second letter of the first letter cluster of the nonword or the last letter was substituted by a different grapheme. This resulted in six categories (transfer by context) of 2 nonwords each.

Reading accuracy. In Table 5 the percentage correctly read nonwords of the reading groups on both posttests are presented. Although in general relatively few trained and transfer nonwords were read incorrectly in the posttests, accuracy differences between the reading groups were observed. On Posttest 1, both dyslexics and reading-age controls read trained nonwords more accurately than transfer nonwords (both first and last letter transfer ones), whereas chronological-age controls read all nonwords highly accurate. For dyslexics, reading accuracy of trained nonwords decreased slightly on Posttest 2 compared to both control groups. Finally, dyslexics read indistinct trained and transfer nonwords more accurate than distinct and unique ones on both posttests.

As the chronological-age controls were highly accurate on nonword reading (i.e., causing ceiling effects), they were not taken into account in the analysis.

The accuracy data were subjected to a MANOVA for repeated measures analysis with reading group (dyslexics and reading-age controls) as a between-subjects factor, and posttest (first or second), transfer (trained nonwords, first letter transfer nonwords, and last letter transfer nonwords), and orthographic context (distinct, indistinct, and unique) as within-subjects factors.

To test hypotheses on the differential effects of orthographic context and transfer on reading accuracy of dyslexic children and younger normal readers, two contrasts were specified on the within-subjects factor orthographic context (indistinct versus distinct and unique nonwords, and distinct versus unique), and two subsequent contrasts were specified on the factor transfer (trained versus transfer nonwords, and first letter transfer versus last letter transfer nonwords). A main effect of reading group indicated that one of the groups performed less accurate on reading nonwords despite context (indistinct, distinct or unique) or transfer type (trained, first letter transfer or last letter transfer). An interaction effect of reading group by orthographic context indicated that the difference between the groups was dependent on the context in which the nonwords were read (indistinct versus distinct and unique, or distinct versus unique). Similarly, an interaction of reading group by transfer indicated that the difference between the groups was dependent on the type of transfer (trained versus transfer nonwords, and first letter transfer versus last letter transfer nonwords).

The analysis revealed a significant main effect of transfer (F (2, 74) = 5.72, $p < .01$), and a significant interaction effect of posttest by reading group (F (1, 37) = 4.21, $p = .05$). Both effects were qualified by the second order interaction of posttest, transfer and reading group (F (2, 74) = 4.21, $p < .05$). The results in Table 5 show that the younger normal readers read the first letter transfer nonwords on the second posttest more accurate than on the first one, whereas the trained and last letter transfer nonwords were read at similar accuracy levels in both posttests.

Dyslexic children, however, had most difficulty reading last letter transfer nonwords accurately in the first posttest while the other nonwords were all read at virtually similar accuracy levels in both posttests.

In addition, orthographic context (F (2, 74) = 2.58, p = .08), and the interaction between orthographic context and reading group (F (2, 74) = 2.61, p = .08) both approached significance. However, examination of the contrasts revealed a significant group by context interaction (F (1, 37) = 7.47, p = .01). Reading accuracy of dyslexic children for indistinct nonwords (trained and transfer) was higher than for distinct and unique nonwords, whereas younger normal readers were not affected by orthographic context (see Figure 5).

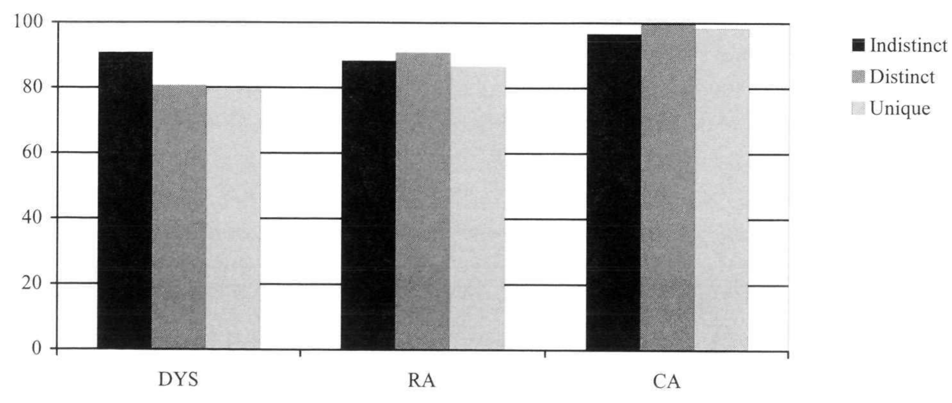
Reading speed. Voice-key errors (e.g., anticipations, mouth clicks) were excluded from the analyses (1.70% in the first posttest, and 1.18% in the second posttest). In addition, RTs that were smaller than 200 ms (0.26% respectively 0%), and larger than 10.000 ms (0.07% respectively 0.13%) were excluded. Finally, RTs that were three standard deviations above or below the child's grand mean were excluded (3.34% respectively 2.49%).

For each orthographic context, a mean reading speed was calculated, with the requirement that each child had read at least one of the two nonwords in a context correctly. If a child had read both nonwords incorrectly, a missing score was attributed to that specific variable. All age-matched normal readers read at least one of the words in each context correctly resulting in no missing values. The percentages of missing values for the dyslexics were 12.28% in the first posttest and 8.77% in the second posttest, and 10% and 5% respectively for the younger normal readers.

To prevent that the analysis would have to be conducted with considerably less subjects in the dyslexic or the reading-age control group, missing scores were replaced. The percentage replaced scores for the dyslexic children was 4.09% in posttest one, and 2.92% in posttest 2.

Figure 5

Percentage correctly read nonwords for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group for the orthographic contexts on the Posttests



For the younger normal readers 3.89% of the scores was replaced in posttest one, and 0.56% in posttest two. For none of the children more then two missing scores on a total of nine had to be replaced. Estimation of the missing scores was conducted by the EM algorithm (Little & Rubin, 1987). The mean naming latencies for each reader group and orthographic context are presented in Table 6.

For both posttests the standard deviations of the naming latencies differed considerably between reader groups on many occasions. Analysis of the data after a 1/RT transformation yielded virtually identical results.

The naming latencies were subjected to a MANOVA for repeated measures analysis with reading group (dyslexics, reading-age controls, and chronological-age controls) as a between-subjects factor, and posttest (first or second), transfer (trained nonwords, first letter transfer nonword, and last letter transfer nonword), and orthographic context (distinct, indistinct, and unique) as within-subjects factors.

To test hypotheses on the differential effects of orthographic context and transfer on reading speed of dyslexic children and younger normal readers, two contrasts were specified on the within-subjects factor orthographic context (indistinct versus distinct and unique nonwords, and distinct versus unique), and two additional contrasts were specified on the factor transfer (trained versus transfer nonwords, and first letter transfer versus last letter transfer nonwords). A main effect of reading group indicated that one of the groups read the nonwords slower despite context (indistinct, distinct or unique) or transfer type (trained, first letter transfer or last letter transfer). An interaction effect of reading group by orthographic context indicated that the difference between the groups was dependent on the context in which the nonwords were read (indistinct versus distinct and unique, or distinct versus unique). Similarly, an interaction of reading group by transfer indicated that the difference between the groups was dependent on the type of transfer (trained versus transfer nonwords, and first letter transfer versus last letter transfer nonwords).

Significant main effects of transfer (F (2, 112) = 38.18, $p < .001$) and reading group (F (2, 56) = 19.40, $p < .001$) were found. Both effects were qualified by a significant interaction effect of transfer and reading group (F (4, 112) = 10.59, $p < .001$). The difference between trained and transfer nonwords was larger in the dyslexic and younger normal reader groups than in the age-matched normal reader group (see Figure 6a).

Contrasts revealed that dyslexic children read the previously trained nonwords faster than the transfer nonwords as compared to the age-matched normal readers, who read both words at similar speed (F (1, 56) = 10.80, $p < .01$). As compared to the younger normal readers, however, dyslexic children read the previously trained nonwords slower but the transfer nonwords at similar speed (F (1, 56) = 7.22, $p < .01$). Thus, in general, transfer affected reading speed of the younger normal readers more than of the dyslexics.

However, dyslexic readers appeared to read last letter transfer nonwords faster than first letter transfer nonwords as compared to the younger normal readers (F (1, 56) = 3.77, $p = .06$), which possibly implies a more subtle effect of transfer on reading speed. Transfer did not affect age-matched normal readers; they read both the trained and the two types of transfer nonwords at

Table 6

Mean naming latencies (in ms) for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group on the Posttests

	DYS		RA		CA	
	M	*SD*	*M*	*SD*	*M*	*SD*
Posttest 1						
Trained nonwords						
Indistinct	1333.71	613.75	1094.13	338.51	656.30	129.13
Distinct	1173.26	490.27	1111.28	465.43	657.10	203.25
Unique	1185.95	528.78	1180.40	497.89	665.43	131.38
Last letter transfer nonwords						
Indistinct	1463.16	703.44	1467.90	579.92	660.43	152.27
Distinct	1374.61	582.73	1531.28	624.80	722.10	348.12
Unique	1517.53	850.30	1571.63	780.47	696.23	233.62
First letter transfer nonwords						
Indistinct	1677.18	933.92	1412.48	696.80	678.30	153.39
Distinct	1475.00	935.37	1338.35	522.17	721.60	203.16
Unique	1424.53	618.71	1502.13	815.58	694.58	181.12
Posttest 2						
Trained nonwords						
Indistinct	1325.92	516.40	1205.83	351.56	703.75	134.89
Distinct	1112.26	450.91	1040.78	257.80	664.15	111.54
Unique	1253.00	628.52	1110.90	347.14	740.05	145.24
Last letter transfer nonwords						
Indistinct	1371.05	522.33	1448.30	520.39	721.23	170.53
Distinct	1242.89	386.20	1309.90	377.76	697.95	152.09
Unique	1345.66	521.74	1515.45	610.92	706.68	143.95
First letter transfer nonwords						
Indistinct	1512.26	473.24	1399.53	500.00	668.30	123.41
Distinct	1367.97	574.20	1424.58	555.55	740.03	209.86
Unique	1279.37	623.51	1525.83	709.71	697.08	193.74

similar reading speed. The contrast for the dyslexic children and their age-matched controls revealed no interaction (F (1, 56) = 1.56, $p > .20$). Thus, the reading speed differences across the two reader groups were not dependent on the type of transfer.

Additionally, an orthographic context by reading group interaction was found (F (4, 112) = 2.49, $p < .05$). Examination of the contrasts revealed that reading speed of the dyslexic children for indistinct (trained and transfer) nonwords was lower than for distinct nonwords, whereas the younger and age-matched normal readers were not affected by orthographic context (F (1, 56) = 6.22, $p < .05$, F (1, 56) = 7.11, $p = .01$ respectively)(see Figure 6b).

Figure 6a

Mean naming latencies (in ms) of the trained and transfer nonwords read in the Posttests for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group

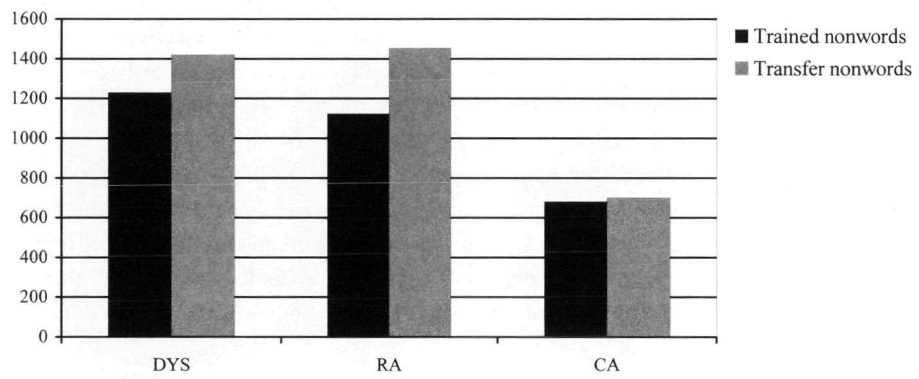
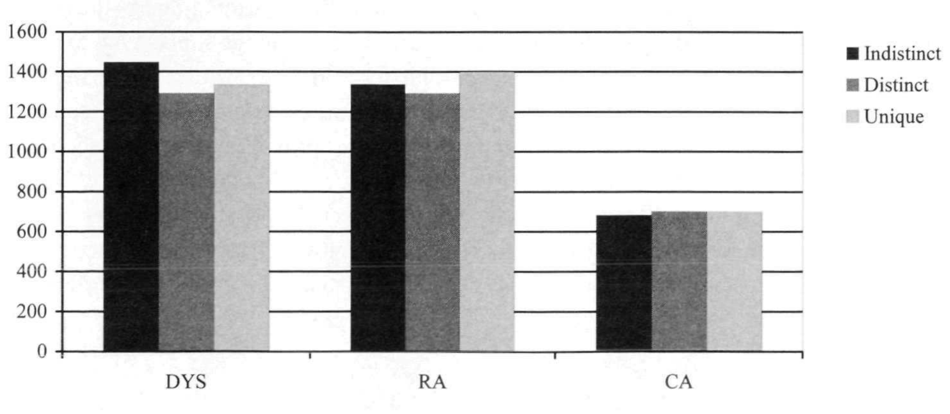


Figure 6b

Mean naming latencies (in ms) of the indistinct, distinct and unique nonwords read in the Posttests for the Dyslexic (DYS), the Reading-Age control (RA), and the Chronological-Age control (CA) group



In sum, orthographic context affected accuracy and reading speed of dyslexic and younger normal readers at posttest. Dyslexic children read indistinct nonwords slower, but more accurate than distinct and unique ones. Unique nonwords, however, were read slower than the indistinct and distinct ones. In addition, transfer also affected reading performance. The younger normal readers were found to read the previously trained nonwords faster than the transfer nonwords. Finally, age-matched normal readers were not affected by transfer, orthographic context or posttest; they read all nonwords at a similar reading speed and highly accurate.

Discussion

The main aim of this study was to examine the effects of orthographic context on learning to read new words in dyslexic and normal reading children. During training we found that the increase of reading speed for distinct nonwords was stronger than for indistinct nonwords. This is in accordance with our assumption that the formation of connections between the spoken and written forms of words is easier for words that are orthographically distinct, than for words that are orthographically similar. We also found overall differences among the groups in reading speed and accuracy during the training. Age-matched normal readers were more accurate and read with greater speed than the dyslexic and the younger normal readers. Dyslexic children were found to perform at similar accuracy and speed levels as the younger-normal readers. However, we did not find that dyslexic children read the target nonwords slower and less accurate in an indistinct context than in a distinct context. Orthographic context affected dyslexic children and age-matched and younger normal readers during training equally.

The central hypothesis of the current study was that the availability of detailed phonological representations becomes critical when connections have to be formed in a context of reading similar words. The results at posttests are most relevant here. Orthographic context was found to affect *reading speed* of the dyslexic children. Their reading speed of indistinct (trained and transfer) nonwords was *lower* than their speed of reading of distinct nonwords. Age-matched normal readers, however, were not affected by orthographic context. More importantly, the reading speed of the children with the same reading-age as the dyslexic children was also not affected by orthographic context. These findings support the *Similarity Hypothesis*. That is, for dyslexic children learning to read new words, the mapping of phonology to orthography is more difficult in a context of similar words than in a context of orthographically dissimilar words, whereas normal readers are not affected by orthographic context.

However, for *reading accuracy* the results were different. For dyslexic children, reading accuracy was higher for indistinct (trained and transfer) nonwords than for distinct ones. In contrast, age-matched and, more importantly, younger normal readers were not affected by orthographic context. The dyslexic children's increase in reading accuracy in the indistinct context supports the *Minimal Difference Hypothesis*. This hypothesis states that the minimal differences among the words read in an indistinct context encourage a focus on each individual letter in a word. Such a focus would enhance the acquisition of fully specified representations of printed words.

Although at posttest, transfer nonwords (i.e., new, orthographically similar nonwords) were read more slowly than previously trained nonwords, the orthographic context effect was similar for trained and transfer nonwords. Therefore, the main result of our study was that for dyslexic children reading speed was lower and reading accuracy was higher for all nonwords read in a context of orthographically similar words as compared to the nonwords read in a distinct context.

A comparable trade-off between reading accuracy and reading speed was found in a study by Wise et al. (2000). They examined the effects of two computer assisted remedial reading programs on reading accuracy and reading speed in poor and good readers. One remedial reading program trained accurate reading by instruction in comprehension strategies and reading stories. The other program trained accurate reading by instruction in phonological strategies, practicing phonological exercises and story reading. Wise et al. found that phonologically trained children gained more in phonological skills and untimed word reading, whereas children trained in contextual reading gained more in time-limited word reading. Thus, both remedial reading programs improved reading skills, but explicit instruction that focused on the constituent letters of words (i.e., the phonological training) increased accurate word reading at the expense of a decrease in reading speed.

Training to read (non-) words is assumed to enhance the acquisition of orthographic knowledge for beginning and poor readers. For the current study, the Minimal Difference Hypothesis stated that learning to read nonwords in an indistinct context increased orthographic knowledge as a result of a better or more accurate mapping between the written and spoken forms of words. In turn, these accurate mappings were assumed to increase reading speed up to the level of sight word reading. Accordingly, for dyslexic children higher reading accuracy and reading speed of the nonwords read in a context of orthographically similar nonwords were believed to support this hypothesis. However, the results of our study were only partly in accordance with the Minimal Difference Hypothesis. How can we explain these paradoxical results? It seems as if the training has taught the dyslexic children to look at the nonwords read in an indistinct context in a specific manner. Possibly, they classified nonwords read in this indistinct context and new words that are orthographically similar, as a certain type of words that need more focus on the internal structure in order to read them correctly (see also McCandliss et al., 2003). Accordingly, this increased attention for nonwords read in an indistinct context results in higher accuracy at the expense of reading speed as this process costs more time.

Our study's major result was that dyslexic children were sensitive for the orthographic context in which the nonwords were read. The hypothesis concerning the effects of orthographic context on learning to read nonwords followed from the assumption of lower quality phonological representations in dyslexic children. These lower quality representations were expected to affect the mappings of orthography to phonology, especially for nonwords read in an indistinct context. The finding that the reading speed of indistinct nonwords was lower than the speed of reading of distinct nonwords for dyslexic children, whereas the reading speed of age-matched and younger normal readers was not affected by orthographic context, was taken as support for our assumption that phonological representations are qualitatively less well specified in dyslexic children. However, the finding of dyslexic children's high accuracy levels for the nonwords read in an indistinct context seems to be in conflict with the lower quality phonological representations hypothesis. Another incompatible finding is that orthographic context did not affect dyslexic children's reading accuracy and speed during training. We have no ready explanation for these contradicting findings. We do think, however, that overall the results suggest that dyslexic children are susceptible to the orthographic context in which the nonwords were read because of the lower quality of their phonological representations. In all probability, this forced the dyslexic readers to change their reading strategies during the repeated reading of these nonwords. In tasks where strategies are instantly required, such as in the posttests in the current study, orthographic similarity does affect their reading performance as they cannot rely on high quality phonological representations that accurately connect the written and spoken forms of similar words.

In the actual reading process, it could quite possibly also be the case that dyslexic readers are sensitive to the orthographic context in which words are read. In text words with few and with many neighbors are read. However, an important difference with the actual reading process is that our training involved the repeated reading of nonwords. Unlike with words, the new orthographic word forms could not be associated with verbally known words and their semantics. Learning to read these nonwords required the acquisition of the orthographic word forms as well as the correct pronunciations. Both representations had to be acquired simultaneously. Although our results were obtained in a design using specifically created sets of nonwords simulating dense neighborhoods, our results cannot be generalized to the actual reading process. For more valid conclusions about the effects of orthographic similarity on the acquisition of orthographic knowledge, our study has to be replicated using existing words from dense and sparse neighborhoods.

Another finding worth mentioning concerns transfer. As argued earlier, from the Minimal Difference Hypothesis it was presumed that learning to read nonwords in an indistinct context would increase the acquisition of fully specified representations and, as a consequence, would facilitate rapid and accurate discrimination between orthographically similar words. As a result, dyslexic children were hypothesized to benefit from this acquired orthographic knowledge even when new, orthographically similar words had to be read. The finding that, in general, the effect of transfer was similar for nonwords read in an indistinct and in a distinct context suggests that the amount of transfer was not dependent on the orthographic context in which words were learned to read.

However, it was found that dyslexic children and younger normal readers read transfer nonwords slower than trained nonwords as compared to age-matched normal readers. The difference in reading speed of trained and transfer nonwords, however, was larger for the younger normal readers than for the dyslexic children. The dyslexic children read the trained nonwords slower than the younger normal readers, whereas both reader groups read the transfer nonwords at similar speed. This suggests that the younger normal readers had relatively more difficulty reading the transfer nonwords than the dyslexic children.

Additionally, the type of transfer, that is, the position of the altered grapheme within a word was found to affect reading performance. Transfer nonwords differed from a trained nonword on a grapheme within the onset cluster of the nonword or on its last grapheme. For the dyslexic children, reading accuracy of the last letter transfer nonwords was lower than for the other nonwords (trained and first letter transfer nonwords), which were all read at virtually similar accuracy levels. Transfer also affected reading accuracy of the younger normal readers, however, quite different as compared to the dyslexic children. Younger normal readers read the transfer nonwords with different onset clusters less accurate, whereas the trained and last letter transfer nonwords were read at similar accuracy levels. Dyslexic children's lower reading accuracy for last letter transfer nonwords could be seen as a typical example of inaccurate mapping or relying on partial information. Transfer nonwords (e.g., SJAT) with similar onset clusters as previously trained nonwords (e.g., SJAR and SJAL) contain a lot of overlapping information. Perhaps reading these transfer nonwords with similar onsets as trained ones induces guessing (e.g., van der Schoot, Licht, Horsley, & Sergeant, 2002). Our finding that dyslexic children read transfer nonwords with a different last grapheme faster then transfer nonwords with a different onset (i.e., a reversed trade-off effect of increased reading speed at the expense of accuracy), whereas the younger normal readers read the first letter transfer nonwords more accurate but slower, is compatible with the idea that dyslexic children use guessing as a reading strategy when words differ on only the last grapheme. An explanation for the lower reading accuracy for first letter transfer nonwords in younger normal readers might be sought in the instruction at school.
In the Dutch educational system, children in grade 3 have only just begun reading onset clusters. Accordingly, reading onset clusters might have been especially difficult for these younger readers.

To conclude, the dyslexic children's increase in accuracy at posttest in the indistinct context tends to support the *Minimal Difference Hypothesis*. However, their decrease in reading speed tends to support the *Similarity Hypothesis*. One way or another, orthographic context seems to affect reading acquisition in dyslexic readers and this sensitivity for orthographic context can be viewed as a *direct* consequence of underspecified phonological representations that is not mediated by phonological awareness.

CHAPTER 6
Epilogue

6. Epilogue

Review of the experimental studies

In the study described in *Chapter 2* it was examined whether dyslexic children had problems with the formation of associations between words and pictures and between nonwords and pictures as compared to age-matched and younger normal readers. Dyslexic children were found to have more difficulty with the learning of phonologically unfamiliar words than the age-matched normal readers. In addition, dyslexic children were found to have more difficulty with the learning of familiar words. On both verbal learning tasks dyslexic children performed similar to younger normal readers.

The lower performance of the dyslexic children on the nonword learning task could be explained by their general problems with the processing of novel phonological material. The analysis of the errors made in the responses of the children during the acquisition of new phonological representations revealed that these representations were less well specified. Dyslexic children were found to make a similar amount of errors at the global word level as age-matched and younger normal readers, but they made more single phoneme errors than their normal reading peers. The distribution of error types in nonword learning of the dyslexic children did not differ from younger normal readers, which indicates that the specification of dyslexic children's phonological representations is related to their reading level.

More speculatively, underspecified phonological representations might also underlie dyslexic children's observed learning problems for known words. The finding that dyslexic children made somewhat more phonological errors than the normal readers tends to support this hypothesis.

In *Chapter 3*, we aimed to replicate the findings on word and nonword learning reported in Chapter 2. As an extension, it was investigated whether dyslexic children's paired associate learning problems were confined to verbal learning or also included nonverbal learning. The paired associate learning performance of dyslexic children was compared to the performance of age-matched and younger normal readers. The findings of both word and nonword learning problems in dyslexic children were replicated. Dyslexic children performed worse as compared to age-matched normal readers, but similar to younger-normal readers on both learning tasks. Nonverbal learning, however, was not impaired in dyslexic children. They performed similar to their normal reading peers, and outperformed the younger normal readers on this learning task.

The existence of this exclusive verbal learning problem in dyslexic children could indicate that their problems arise from an underlying phonological deficit. The disappearance of the performance difference between dyslexics and age-matched normal readers on both word and nonword learning when phonological awareness was taken into account supported this view. Though the dyslexic children made more errors than their normal reading peers in the verbal learning task, the percentage of phonological errors made was similar to that made by the normal readers. In contrast to the previous study, these findings support the idea that dyslexic children have more difficulty with the acquisition of phonological representations of new words, but that this process is not qualitatively different from normal readers.

As another extension, compared to the study in Chapter 2, in this study the long-term retention of the learned associations was considered. For verbal learning (both words and nonwords), dyslexic children were found to have problems with the acquisition of the correct associations, but not with the long-term retention of the verbal labels as compared to age-matched and younger normal readers.

In *Chapter 4* three experiments were reported that aimed to test the phonological representations hypothesis in the context of visual-verbal learning. Phonological representations of words in the mental lexicon of dyslexic children are assumed to be either less distinct (e.g., Elbro, 1996) or to be less segmentalized (Fowler, 1991; Metsala & Walley, 1998). The implication of both hypotheses is that underspecified (i.e., less distinct or less segmentalized) phonological representations of words in the mental lexicon are more similar than fully specified phonological representations. Accordingly, it follows that for dyslexic children, having less segmentalized representations, words from the same neighborhood (i.e., words that differ on one phoneme) are relatively more similar than for normal readers. From this assumption, it was hypothesized that for dyslexic children the visual-verbal paired associate learning of a set of words with many neighbors would be more difficult than the learning of a set of words that are phonologically distinct. Normal readers, however, were expected to be less affected by the phonological distinctness of the set of words to be learned. As expected, indistinct word sets were more difficult to learn than distinct word sets. However, dyslexic children were not hampered more by the phonological similarity across a set of words than their normal reading peers.

In addition to the effect of phonological distinctness on visual-verbal paired associate learning, distinctness of the visual stimuli was also considered. As expected, normal and dyslexic readers were found to be equally affected by the visual distinctness of the pictures used. Both normal and dyslexic readers performed more poorly on the set of visual indistinct pictures than on the set of visual distinct pictures.

As in the studies reported in Chapters 2 and 3, dyslexic children performed worse than the age-matched normal readers on nearly all learning tasks. The differences in word learning between normal and dyslexic children could, to a large extent, be accounted for by their differences in phonological processing. This finding supports the hypothesis that dyslexic children's verbal learning problems are manifestations of a single underlying phonological deficit.

In *Chapter 5* a study was reported which aimed to investigate the consequences of impaired phonological representations for the acquisition of orthographic knowledge. From the assumption that dyslexic children have underspecified phonological representations, it was hypothesized that learning to read words in a context of orthographically and phonologically similar words would be more difficult than learning to read words in an orthographically and phonologically dissimilar context. This hypothesis is denoted as the *Similarity Hypothesis*, which states that for dyslexic children learning to read new words, the mapping of phonology to orthography is more difficult in a context of similar words than in a context of orthographically dissimilar words because the lower quality phonological representations of words overlap with one another to a great extent, especially in an indistinct condition. As a consequence, dyslexic children need more time to retrieve the correct pronunciation of the written word from memory.

The repeated reading of lists of nonwords in a distinct (*kwog* with *kwes, snar,* and *skal*) and in an indistinct context (*kwog* with *kwos, knos,* and *knog*) revealed that the dyslexic children were affected by the context in which the words were read. They read nonwords read in an indistinct context more slowly than nonwords read in a distinct context. Both age-matched and younger normal readers were not affected by orthographic context.

For reading accuracy, however, the results were different. Dyslexic children were found to read the nonwords read in a distinct context less accurate than the nonwords read in an indistinct context. Both normal reader groups, however, were not affected by orthographic context. The finding of the dyslexic children's higher accuracy rates for words read in an indistinct context is in disagreement with the Similarity Hypothesis. The accuracy findings can be explained by the *Minimal Difference Hypothesis*. This hypothesis states that the minimal differences among the words read in an indistinct context encourage a focus on each individual letter in a word. Accordingly, the acquisition of fully specified phonological representations is supported and this increase in orthographic knowledge will be observed in an increase in reading accuracy.

Reading new nonwords that were orthographically similar to the nonwords read in the training (i.e., transfer nonwords) was found to be more difficult for dyslexic and younger normal readers. Both reader groups read the transfer nonwords slower than the previously trained nonwords. Although reading-age controls were affected more by transfer than the dyslexic children, the younger normal readers had most difficulty reading the transfer nonwords that differed in the onset cluster of the word. This finding, combined with the finding that dyslexic children read the transfer nonwords that differed on the last grapheme less accurate but at similar speed as trained and first letter transfer nonwords, suggests that dyslexic readers are less receptive to the subtle differences between the nonwords than the younger normal readers.

In all, the results of this study suggest that the availability of detailed phonological representations becomes critical when connections have to be formed in a context of learning to read similar words.

Limitations of the studies

Some limitations of the studies reported in this thesis need to be addressed. These limitations mainly concern the materials and manipulations used in the various studies. For the studies reporting on the visual-verbal paired associate learning performance of dyslexic and normal readers abstract and concrete visual stimuli were used. The manipulations in these materials were based upon the manner in which neighboring words differ from one another. Due to the characteristics of the stimuli the manipulations were analogue but not equal. This might have affected the learning performance of the children differently. Though we did not report these findings, the results of Study 3 in Chapter 4 did indicate that the paired associate learning of words paired to abstract pictures was easier than the learning of words to concrete pictures. However, it needs to be pointed out that the stimuli in this study were indistinct, whereas the stimuli in the sets used in Study 1 of Chapter 4 were distinct. The finding in the latter study that words were more easily paired to concrete pictures then to abstract pictures can easily be explained by the namebility of the concrete pictures. However, in a learning task with sets of indistinct visual stimuli, the similarities and differences across the sets of abstract stimuli might have been more obvious then across the concrete stimuli enhancing the learning performance of the children.

With regard to the study reported in Chapter 5 investigating the consequences of underspecified phonological representations for the acquisition of orthographic knowledge, the following points need to be addressed. First, as the number of nonwords per orthographic context (indistinct, distinct, and unique) differed across the training and posttests, a selection of nonwords had to be made for the analyses. To ensure that the results would be unambiguous, the analyses only included nonwords that were read in both the posttests and the training. This selection of nonwords, however, implied that only two nonwords were available in each orthographic context, decreasing the power of the analyses.

Second, only the correctly read nonwords were included in the accuracy and reading speed analyses. For several analyses, the amount of incorrectly read nonwords decreased the participants in the reader groups to less than 16, endangering the solidity of the data. Replacement of the missing values with estimations ensured the validity of the analyses. A replication of the study would ensure a more reliable representation of the findings.

General discussion

The studies presented in this thesis aimed to explore the consequences of the assumed underspecified or lower quality phonological representations of words in the mental lexicons of dyslexic children. The question whether dyslexic children have problems with the formation of visual-verbal associations and whether these problems are manifestations of the phonological deficit characteristic for dyslexia was addressed.

Furthermore, conditions were investigated in which dyslexic children's problems with the formation of associations between the spoken and written forms of words (i.e., in reading acquisition) are aggravated.

In the sections below, several central themes and findings across the studies reported in this thesis are discussed.

Manifestations of a phonological deficit

The results of the various studies reported in this thesis suggest that manifestations of a phonological deficit mainly concern the verbal domain and not the non-verbal domain. Visual-visual paired associate learning was found to be unimpaired in dyslexic children (see also Liberman, Mann, Shankweiler, & Werfman, 1982; Nelson & Warrington, 1980; Rapala & Brady, 1990; Vellutino, Steger, & Pruzek, 1973). In addition, dyslexic children and normal reading peers were similarly affected by the visual distinctness of the stimuli in a visual-verbal paired associate learning task. This last finding is also in accordance with other studies on this matter (Mauer & Kamhi, 1996; Palmer, 2000).

However, within the verbal domain, manifestations of a phonological deficit were found. Each study reported in this thesis included the assessment of phonological processing skills. Dyslexic children were found to perform lower on all phonological processing tasks (phoneme deletion, rapid automatic naming, word completion, nonword repetition, spoonerisms, and phoneme recognition) as compared to age-matched normal readers. The only exception was a nonword span task, which did not differentiate between the dyslexic children and their normal reading peers.

In addition, the studies documented problems of dyslexic children in the acquisition of phonological representations of new words. Dyslexic children needed more time to learn the associations between the nonwords and pictures as compared to age-matched normal readers (also see Mayringer & Wimmer, 2000; Vellutino et al., 1975, 1995; Vellutino & Scanlon, 1989; Windfuhr & Snowling, 2000). Dyslexic children were also found to have problems with the paired associate learning of familiar words. Interestingly, when phonological awareness was taken into account, the differences between dyslexics and age-matched normal readers on both word and nonword learning disappeared. This result suggests that phonological awareness and visual-verbal learning largely reflect the same underlying ability.

The robust finding that dyslexic children have impairments on a wide range of phonological processing tasks is in accordance with the results of many previous studies (see for example Vellutino, et al., 2004). These impairments are generally believed to be the consequence of one, single underlying phonological deficit (Stanovich, 1986).

Implications of impaired phonological representations

Evidence that all phonological processing problems of dyslexic children might be attributed to a single underlying phonological deficit, does not clarify the particular nature of this deficit. According to the Phonological Representations Hypothesis, this phonological deficit can be characterized as a deficit in the quality of the phonological representations of words in the mental lexicons of dyslexic children (e.g., Snowling, 2000). In the studies presented in the Chapters 4 and 5 specific consequences of this interpretation of a phonological deficit were examined.

From the assumption that dyslexic children have impairments in the phonological representations of words, it was hypothesized that they would also have problems in the acquisition of novel representations. Indeed, nonword learning was found to be more difficult for dyslexic children than for their normal reading peers. However, the hypothesis that the acquired representations would be less segmentalized (Metsala & Walley, 1998), especially at the phoneme level, could not be supported. The errors made by dyslexic children in the pronunciation of the novel words to be learned, concerned errors at levels of the word, ranging form the complete word, to the syllable, to errors at the level of the phoneme. Furthermore, the distribution of errors over these levels was comparable to the distribution in normal readers. Although the errors of dyslexic children were not specifically tied to the phoneme level, their larger overall amount of errors suggests that the acquisition of novel representations was more difficult, and, that these representations were, at least during acquisition, less well specified than in normal reading children.

Problems in the acquisition of novel representations do not necessarily imply that existing representations are impaired. It remains possible that these representations are well specified, but that dyslexic children only needed more exposures. As said, the Phonological Representations Hypothesis states that representations of existing words are also impaired. Several researchers have shown that the performance of dyslexic children on phonological processing tasks is related to the quality of phonological representations of familiar words (Elbro, Borstrøm, & Petersen, 1998; Foy & Mann, 2001; Griffith & Snowling, 2002; Swan & Goswami, 1997a). However, the results of the current studies do not fully support impairments in the phonological representation of existing words. First, as in previous studies (Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983; compare Vellutino & Scanlon, 1989; Vellutino et al. 1995), differences between dyslexic and normal readers in visual-verbal paired associate learning with words were not consistently found. Dyslexic children performed worse than normal reading peers on the paired associate learning tasks using names as verbal stimuli (see studies in Chapters 2 and 3), whereas they performed similar to age-matched normal readers when high frequency words had to be associated with pictures (see Studies 2 and 3 in Chapter 4). Perhaps not all names were as familiar for the children as assumed and hence might have acted as nonwords. Secondly, the number of phonological errors of dyslexic children in word learning was negligible, suggesting that the representation of words with a relatively simple phonological form, is not impaired.

More importantly, a larger effect of the phonological distinctness of the sets of words on the learning performance of dyslexic children was not found. The paired associate learning performance of the dyslexic children and their normal reading peers was similarly affected by the phonological distinctness of the sets of words to be learned (see Studies 2 and 3 in Chapter 4). This finding is problematic for the idea that phonological representations are qualitatively less well specified in dyslexic children. Rather, it seems that the phonological representations of known words were of a quality that was sufficient to perform at a similar level as normal readers in this particular task.

However, some support for the Phonological Representations Hypothesis was found in the study reported in Chapter 5. That is, the results of this study suggest that the quality of the phonological representations of words might become critical in the specific context of reading. During reading acquisition associations have to be formed between phonological representations and written words. The specific context here is that, unlike the associations that had to be made in the other studies, the written and spoken forms of the words are systematically related. The written forms of words contain embedded phonological information, because the graphemes of written words are systematically connected to the sounds in spoken words. In the studies on visual-verbal paired associate learning, relationships between the visual and verbal stimuli did not exist. Perhaps of even greater importance might be the ability to make use if this enclosed phonological information in the written forms of words. As McNeil & Johnston (2004) reported, if processing of phonological information is obligatory, dyslexic children tend to perform worse than when they can rely on visual information alone.

Reading words that were orthographically and phonologically similar, that is, when the connections between the spoken and written words were most critical, appeared to be relatively problematic for dyslexic readers. Compared to normal readers, dyslexic children read the words in an indistinct context slower but more accurate than words read in a distinct context. Age-matched and younger normal readers were not affected by the orthographic context in which the words were read. However, it should be acknowledged that these findings were based on nonword reading. Learning to read nonwords not only required the formation of new phonological representations of these words, but simultaneously the formation of associations between the written and spoken forms of these words. In learning to read nonwords, the set up of the fine-grained correspondences between the graphemes in the written form of the word and the sounds in the spoken form of the word is critically dependent on the quality of the phonological representations of the new words (see also Ehri, 1998). It is possible that different results would be obtained if the children had to read known words in a context of orthographically similar or dissimilar words (i.e., words from dense and sparse neighborhoods).

Conclusion

The studies reported in this thesis considered the Phonological Representations Hypothesis of dyslexia and the consequences for the formation of associations. The Phonological Representations Hypothesis concerns the quality of representations of words in the mental lexicons of children. For dyslexic children, these representations are assumed to be poorly specified. The studies presented in the previous Chapters did not unequivocally support this hypothesis. The performance of the dyslexic children on the word learning tasks and their reaction to the phonological manipulations within the sets of words to be learned, supported the phonological deficit explanation of dyslexia, rather than the more specific hypothesis that dyslexic children's phonological representations of known words are underspecified. The hypothesis is not rejected though. Rather, the hypothesis should be reevaluated and adjusted. From the results obtained in the present studies, the visual-verbal paired associate learning difficulties of dyslexic children cannot be attributed to poorly specified phonological representations of the words. However, in a specific context, the context of learning to read new words, the quality of the phonological representations can explain the difficulties encountered in reading words in an indistinct context.

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APPENDICES

Appendices

Appendix A

Phonologically indistinct word sets (translation between brackets) used in Study 2 of Chapter 4

klop	*(knock)*	slaan	*(hit)*
klom	*(climb)*	slaaf	*(slave)*
krop	*(head of lettuce)*	staan	*(stand)*
krom	*(curved)*	staaf	*(bar)*
sloot	*(ditch)*	knip	*(snip)*
sloom	*(slow)*	knik	*(twist)*
stoot	*(punch)*	klip	*(cliff)*
stoom	*(steam)*	klik	*(click)*
brok	*(chunk)*	slik	*(swallow)*
brom	*(hum)*	slip	*(skid)*
blok	*(block)*	stik	*(choke)*
blom	*(flower)*	stip	*(dot)*

Appendix B

Four nonword lists used in the training reported in Chapter 5

Orthographic context	I	II	III	IV
Indistinct nonwords (set of 6)	**SJAR**	**KWOG**	**SJAR**	**KWOG**
	SJAL	KWOS	SJAL	KWOS
	SNAR	KNOG	SNAR	KNOG
	SNAL	KNOS	SNAL	KNOS
	SKAR	KROG	SKAR	KROG
	SKAL	KROS	SKAL	KROS
Indistinct nonwords (set of 4)	**GRUIF**	**PLIEK**	**PLIEK**	**GRUIF**
	GRUIP	PLIET	PLIET	GRUIP
	GLUIF	PSIEK	PSIEK	GLUIF
	GLUIP	PSIET	PSIET	GLUIP
Distinct nonwords (matched indistinct 6)	**KWOG**	**SJAR**	**KWOG**	**SJAR**
	KWES	SJUN	KWES	SJUN
Distinct nonwords (matched indistinct 4)	**PLIEK**	**GRUIF**	**GRUIF**	**PLIEK**
	PLOOM	GROEL	GROEL	PLOOM
Unique nonwords	**BLIP**	**DWIT**	**FLIG**	**BLAAP**
	TSAUN	**VLEUS**	**DWIJT**	**TSIN**
	DWUT	BREG	TSUN	FREG
	VREUS	TSAUP	BRAAP	DWIJS

Appendix C

Four nonword lists used in the Posttests reported in Chapter 5

Transfer context	I	II	III	IV
Trained nonwords				
Indistinct (set of 6)	**SJAR**	**KWOG**	**SJAR**	**KWOG**
Indistinct (set of 4)	**GRUIF**	**PLIEK**	**PLIEK**	**GRUIF**
Distinct (matched to indistinct 6)	**KWOG**	**SJAR**	**KWOG**	**SJAR**
Distinct (matched to indistinct 4)	**PLIEK**	**GRUIF**	**GRUIF**	**PLIEK**
Unique 1	**BLIP**	**DWIT**	**FLIG**	**BLAAP**
Unique 2	**TSAUN**	**VLEUS**	**DWIJT**	**TSIN**
Transfer nonwords				
Indistinct (set of 6)	SJAT SLAR	KWOP KLOG	SJAT SLAR	KWOP KLOG
Indistinct (set of 4)	GRUIK GNUIF	PLIEF PRIEK	PLIEF PRIEK	GRUIK GNUIF
Distinct (matched to indistinct 6)	KWOP KLOG	SJAT SLAR	KWOP KLOG	SJAT SLAR
Distinct (matched to indistinct 4)	PLIEF PRIEK	GRUIK GNUIF	GRUIK GNUIF	PLIEF PRIEK
Unique 1	BLIT BRIP	DWIN DRIT	FLIT FRIG	BRAAP BLAAF
Unique 2	TSAUL TRAUN	VLEUP VREUS	DRIJT DWIJS	TSIG TRIN
Unique nonwords	FREL DJOEG VLIM KNIJT TWEEL DRAAS SFEUR	TJUG BLOEP VRIM SNIJT TWEEL DRAAS SFEUR	BLEN TREUP VLAUM KNOOT TWEEL DJUS SFOER	DRUL FLEUS VLAUM SNUUT TWEEL DJUS PSOER

SAMENVATTING

Samenvatting (Summary in Dutch)

Een deel van de kinderen die leren lezen ondervindt hierin blijvende problemen. Zij verwerven onvoldoende kennis van de geschreven vorm van woorden (orthografische kennis) om woorden snel en accuraat te kunnen herkennen. Naast de leesproblemen hebben deze kinderen problemen met een breed scala aan fonologische verwerkingsvaardigheden waaronder een verminderd fonologisch bewustzijn, een gebrekkig functioneren van het verbaal korte termijngeheugen en problemen met het snel benoemen van bekende voorwerpen, kleuren, cijfers en letters.

Een fonologisch deficit wordt algemeen gezien als de centrale oorzaak van deze problemen met de verwerking van fonologisch materiaal. Dit fonologisch deficit wordt omschreven als een geringere kwaliteit van de fonologische representaties van woorden. Volgens de *Fonologische Representatie Hypothese* zijn de fonologische representaties van woorden bij dyslectische lezers minder gedetailleerd en minder goed gespecificeerd dan bij normale lezers. Ondergespecificeerde fonologische representaties zouden er de oorzaak van zijn dat fonologische vaardigheden zich minder snel en goed ontwikkelen met als gevolg dat het leren lezen gehinderd wordt.

Van de genoemde fonologische verwerkingsproblemen zijn de problemen in het fonologisch bewustzijn de meest prominente. Van deze problemen is bekend dat zij van grote invloed zijn op het leren lezen. Met name het bewustzijn dat de gesproken taal is opgebouwd uit fonemen (losse klanken) is een noodzakelijke voorwaarde voor het ontdekken van het alfabetisch principe en voor de vorming van nauwkeurige associaties tussen de grafemen in de geschreven vorm van woorden en de fonemen in de gesproken woordvormen.

Hoewel een beperking in het fonologisch bewustzijn de meest prominente voorspeller is van leesproblemen, lijken ook andere fonologische verwerkingsproblemen een rol te spelen bij leesproblemen. In een taal als het Nederland blijken fonologisch bewustzijnsproblemen minder uitgesproken te zijn dan in het Engels waarin de overeenkomsten tussen de spelling en de uitspraak van woorden minder consistent is. Zo kunnen Nederlandse dyslectische kinderen relatief nauwkeurig lezen terwijl hun leessnelheid in vergelijking met normale lezers laag blijft.

Leessnelheid is deels afhankelijk van het aantal woorden dat direct en vloeiend gelezen wordt. Het zien van woorden die vloeiend gelezen worden activeert onmiddellijk de uitspraak en de betekenis in het geheugen omdat gedetailleerde connecties tussen de gesproken en de geschreven vorm van deze woorden zijn opgebouwd. Het gemak waarmee geschreven woorden worden herkend en worden uitgesproken is afhankelijk van het aantal en de kwaliteit van deze connecties. Mogelijk beïnvloeden ondergespecificeerde fonologische representaties ook de vorming van connecties tussen de geschreven en gesproken vorm van woorden, ofwel de verwerving van orthografische kennis.

Het is bekend dat dyslectische kinderen problemen hebben met de vorming van associaties tussen visuele en verbale informatie. Vooral het associëren van nieuwe, fonologisch onbekende woorden met plaatjes is moeilijker voor dyslectische kinderen dan voor kinderen zonder leesproblemen. In sommige gevallen is gevonden dat ook het leren van woorden problemen geeft. De paarsgewijze leerproblemen van dyslectische kinderen lijken zich te beperken tot het verbale leren. Deze laatste bevinding zou erop kunnen wijzen dat zowel de problemen met paarsgewijs leren als de problemen met fonologisch bewustzijn gezien kunnen worden als manifestaties van een geringere kwaliteit van de fonologische representaties.

In dit proefschrift staan deze veronderstelde ondergespecificeerde fonologische representaties en de consequenties ervan voor de vorming van associaties tussen visuele en verbale informatie centraal. Allereerst is onderzocht of Nederlandse dyslectische kinderen problemen hebben met de vorming van associaties tussen visuele en verbale items en of deze problemen manifestaties zijn van het voor dyslexie karakteristieke fonologische deficit. Ten tweede is de vraag onderzocht of dyslectische kinderen problemen hebben met de verwerving van de specifieke associaties tussen de gesproken en geschreven vorm van woorden zoals bij lezen het geval is.

In *Hoofdstuk 2* wordt een studie beschreven waarin de paarsgewijze leerprestaties van dyslectische kinderen werden vergeleken met de prestaties van leeftijdsgenoten zonder leesproblemen en met die van jongere kinderen met hetzelfde leesniveau als de dyslectische kinderen. De kinderen leerden in dit onderzoek zowel woorden als onzinwoorden (non-woorden) met plaatjes te associëren. Dyslectische kinderen bleken in vergelijking met leeftijdsgenoten zonder leesproblemen meer moeite te hebben met het leren van de non-woorden bij plaatjes. Tevens bleken de dyslectische kinderen in vergelijking met leeftijdsgenoten meer moeite te hebben met het leren associëren van bekende woorden met plaatjes. De dyslectische kinderen bleken echter niet te verschillen van de jongere kinderen met hetzelfde leesniveau in het associëren van zowel woorden als non-woorden met plaatjes.

Verder werd onderzocht of de problemen van de dyslectische kinderen met de vorming van associaties gezien konden worden als een manifestatie van het voor dyslexie kenmerkende fonologische deficit. De lagere prestaties van de dyslectische kinderen op de leertaak met non-woorden bleken te kunnen worden verklaard door hun problemen met de verwerking van nieuw fonologisch materiaal. Uit de analyse van de gedurende de leertaak gegeven foute antwoorden bleek dat deze nieuw verworven fonologische representaties minder goed gespecificeerd waren. De dyslectische kinderen maakten meer fouten op foneemniveau (enkele letter niveau) dan hun leeftijdsgenoten zonder leesproblemen. Bij de dyslectische kinderen en de jongere normale lezers bleek de verdeling van de fouttypen in het leren van de non-woorden gelijk te zijn. Dit laatste resultaat impliceert dat de mate van specificatie van de fonologische representaties bij dyslectische kinderen gerelateerd is aan het leesniveau.

De bevinding dat dyslectische kinderen meer fonologische fouten maakten dan de gewone lezers in de leertaak met woorden zou kunnen betekenen dat hieraan eveneens onderspecificeerde fonologische representaties ten grondslag liggen.

De studie beschreven in *Hoofdstuk 3* was deels een replicatie van de voorgaande studie. Aanvullend werd onderzocht of de paarsgewijze leerproblemen van dyslectische kinderen zich beperken tot het verbale domein (woord en non-woord leren) of dat de leerproblemen zich uitstrekken tot in het non-verbale leren. Hiertoe werden wederom de paarsgewijze leerprestaties van dyslectische kinderen vergeleken met die van leeftijdsgenoten zonder leesproblemen en met de prestaties van jongere kinderen met hetzelfde leesniveau. Zowel de problemen met het associëren van non-woorden als van woorden met plaatjes werden gerepliceerd. Dyslectische kinderen bleken in beide taken meer fouten te maken dan leeftijdsgenoten zonder leesproblemen. De leerprestaties van de dyslectici waren opnieuw vergelijkbaar met die van jongere kinderen met hetzelfde leesniveau. Non-verbaal leren bleek niet afwijkend te zijn bij dyslectische kinderen. Zij presteerden even goed als hun leeftijdsgenoten zonder leesproblemen op deze taak en overtroffen zelfs de jongere kinderen.

Dit exclusieve verbale leerprobleem zou kunnen voortkomen uit het voor dyslexie kenmerkende fonologisch deficit. Deze hypothese werd ondersteund door het feit dat de verschillen in prestaties tussen de dyslectische kinderen en hun leeftijdsgenoten zonder leesproblemen op zowel de woord-leertaak als de leertaak met non-woorden wegvielen wanneer voor de prestaties op de fonologisch bewustzijnstaken werd gecontroleerd. De bevinding dat de dyslectische kinderen relatief gezien evenveel fonologische fouten maakten als hun leeftijdsgenoten zonder leesproblemen in het leren van non-woorden, is echter in tegenspraak met deze hypothese en met de bevindingen van het in Hoofdstuk 2 beschreven onderzoek. Deze laatste resultaten ondersteunen het idee dat dyslectische kinderen meer problemen hebben met de verwerving van fonologische representaties van nieuwe woorden, maar dat dit proces niet kwalitatief verschilt van dat bij normale lezers.

Een andere uitbreiding van dit onderzoek ten opzichte van het onderzoek beschreven in Hoofdstuk 2 betrof de lange termijn retentie van de geleerde associaties. Dyslectische kinderen bleken zowel bij het woordleren als bij het non-woord leren moeite te hebben met de vorming van correcte associaties, maar niet met de lange termijn retentie van de verworven associaties in vergelijking met beide groepen normale lezers.

In *Hoofdstuk 4* wordt een serie van 3 onderzoeken gepresenteerd waarin de *Fonologische Representatie Hypothese* getest werd in de context van visueel-verbaal leren. Deze hypothese veronderstelt dat fonologische representaties van woorden in het mentale lexicon van dyslectische kinderen minder goed gespecificeerd zijn (zie Elbro, 1996) of minder gesegmenteerd zijn (Fowler, 1991; Metsala & Walley, 1998). De implicatie van beide opvattingen over ondergespecificeerde fonologische representaties is dat deze representaties meer overlap met elkaar vertonen dan volledig gespecificeerde representaties. Door deze overlap zullen voor dyslectische kinderen buurwoorden (dat zijn woorden die van elkaar verschillen op één foneem) meer op elkaar lijken dan voor kinderen zonder leesproblemen. Deze redenering leidde tot de hypothese dat voor dyslectische kinderen het paarsgewijs leren van een set woorden met veel buren, dat wil zeggen fonologisch gelijkende woorden, moeilijker zou zijn dan het leren van een set woorden die fonologisch verschillend zijn. Van normale lezers werd verwacht dat ze minder beïnvloed zouden worden door de fonologische gelijkenis van de woorden die geleerd werden.

In de fonologisch gelijkende of verwarbare context leerden de kinderen de woorden *knip, knik, klip* en *klik* associëren met vier plaatjes. In de niet-verwarbare context werden de woorden *knip, staaf, brom* en *sloot* geassocieerd met plaatjes. Zoals verwacht waren de verwarbare woordensets moeilijker te leren dan de sets niet-verwarbare woorden. Dyslectische kinderen bleken echter niet extra gehinderd te worden door de sterkere fonologische gelijkenis van de woorden binnen een set dan leeftijdsgenoten zonder leesproblemen.

Naast de fonologische gelijkenis werd het effect van de visuele gelijkenis van de plaatjes op de paarsgewijze leerprestatie van dyslectische kinderen en kinderen zonder leesproblemen onderzocht. De belangrijkste reden hiervoor ligt in een eigenschap van een transparante orthografie. Daarin hebben woorden die fonologisch grote gelijkenis vertonen tegelijkertijd ook orthografisch gelijke woordbeelden. Hierdoor kunnen de effecten van fonologische en visuele gelijkenis op het leren moeilijk onafhankelijk onderzocht worden.

Aanloog aan de manipulatie van de verwarbare en niet-verwarbare woordensets werden sets eenvoudige verwarbare en niet-verwarbare zwart-wit afbeeldingen geconstrueerd. De *Fonologische Representatie Hypothese* voorspelt dat dyslectische kinderen en normale lezers in dezelfde mate beïnvloed worden door de visuele verwarbaarheid van de afbeeldingen in het paarsgewijs leren. Dit werd ook gevonden. Beide groepen presteerden overigens minder goed wanneer woorden geleerd moesten worden bij sets verwarbare plaatjes dan bij sets niet-verwarbare plaatjes.

Net zoals in de in Hoofdstuk 2 en 3 beschreven studies presteerden de dyslectische kinderen minder goed dan leeftijdsgenoten zonder leesproblemen op bijna alle paarsgewijze leertaken. Het verschil in woordleren tussen de twee groepen kon ook dit keer voor een groot deel verklaard worden door de verschillen in fonologisch bewustzijn. Deze bevinding ondersteunt de hypothese dat de paarsgewijze leerproblemen van dyslectische kinderen manifestaties zijn van één onderliggend fonologisch deficit.

In *Hoofdstuk 5* wordt een studie besproken waarin de effecten van fonologische en visuele gelijkenis op het lezen werden onderzocht. Het doel van dit onderzoek was de consequenties van ondergespecificeerde fonologische representaties te onderzoeken voor de verwerving van orthografische kennis. Uit de aanname dat de fonologische representaties van woorden bij dyslectische kinderen ondergespecificeerd zijn, volgde de hypothese dat voor dyslectische kinderen het leren lezen van woorden in een context van grote orthografische en fonologische gelijkenis specifieke problemen geeft ten opzichte van het leren lezen van woorden in een context van zowel fonologisch als orthografisch verschillende woorden. Volgens deze *Gelijkenis Hypothese* leidt de lagere kwaliteit van de fonologische representaties van de woorden tot een grotere overlap met andere woorden. Daardoor zullen dyslectische kinderen relatief meer moeite hebben met het verwerven van orthografische kennis in een context van gelijkende woorden dan leeftijdsgenoten zonder leesproblemen.

Om deze hypothese te kunnen onderzoeken lazen dyslectische kinderen, leeftijdsgenoten zonder leesproblemen en jongere kinderen met hetzelfde leesniveau herhaald lijsten non-woorden in een orthografisch en fonologisch gelijkende of verwarbare context (*kwog* met *kwos*, *knos* en *knog*) en in een niet-verwarbare context (*kwog* met *kwes*, *snar* en *skal*). Zowel leessnelheid als –nauwkeurigheid werden geregistreerd.

De dyslectische kinderen bleken te worden beïnvloed door de context waarin de woorden werden gelezen. Zij lazen non-woorden aangeboden in een verwarbare context *langzamer* dan non-woorden gelezen in een niet-verwarbare context. Leeftijdsgenoten zonder leesproblemen en jongere normale lezers werden echter niet beïnvloed door de orthografische context.

Voor *leesaccuratesse* lagen de resultaten anders. Dyslectische kinderen bleken de non-woorden gelezen in een verwarbare context *accurater* te lezen dan de woorden die aangeboden werden in een niet-verwarbare context. Ook qua accuratesse werden beide groepen normale lezers niet beïnvloed door de orthografische context. De bevinding dat dyslectische kinderen woorden in een verwarbare context nauwkeuriger lezen dan niet-verwarbare woorden staat haaks op de *Gelijkenis Hypothese*. Deze accuratesse bevindingen kunnen wel verklaard worden door de *Minimale Verschil Hypothese*. Volgens deze hypothese leiden de minimale verschillen tussen de woorden in een verwarbare context ertoe dat meer aandacht gegeven wordt aan iedere individuele letter binnen een woord. Als gevolg hiervan wordt de verwerving van volledig gespecificeerde orthografische representaties gestimuleerd. Deze toename in orthografische kennis manifesteert zich echter alleen in termen van een hogere leesaccuratesse.

Het gebruik van de tijdens de training verworven orthografische kennis bij het lezen van nieuwe non-woorden die grote fonologische en orthografische gelijkenis vertoonden (transfer non-woorden) bleek moeilijk te zijn voor zowel dyslectische als jongere normale lezers. Beide groepen lazen de transfer non-woorden langzamer dan de getrainde non-woorden. De jonge normale lezers bleken sterker te worden beïnvloed door de gelijkenis van de nieuwe non-woorden dan de dyslectische kinderen. Bovendien bleken de jongere lezers vooral moeite te hebben met het lezen van de nieuwe non-woorden die in het eerste lettercluster van het woord verschilden van eerder getrainde non-woorden. De dyslectische kinderen bleken juist meer moeite te hebben met het lezen van de nieuwe non-woorden met een andere eindletter dan de getrainde non-woorden. Deze nieuwe non-woorden werden door de dyslectische kinderen minder accuraat maar even snel gelezen als de getrainde non-woorden.

Samenvattend suggereren de resultaten van deze studie dat de beschikbaarheid van gedetailleerde fonologische representaties doorslaggevend wordt wanneer orthografische kennis van woorden verworven moet worden in een context van eveneens nieuwe, daarop lijkende woorden.

In de studies die gerapporteerd worden in dit proefschrift stond de *Fonologische Representatie Hypothese* van dyslexie centraal en in het bijzonder de consequenties van deze hypothese voor de vorming van associaties. De *Fonologische Representatie Hypothese* betreft de kwaliteit van de representaties van woorden in het mentale lexicon van kinderen. Bij dyslectische kinderen worden deze representaties verondersteld minder goed gespecificeerd te zijn. In de studies die werden uitgevoerd, werd geen eenduidige steun gevonden voor deze hypothese. De prestaties van de dyslectische kinderen op de woord-leertaken en hun reacties op de manipulaties binnen de sets van woorden die geleerd moesten worden, ondersteunden de algemene fonologisch deficit verklaring van dyslexie. In mindere mate, echter, werd de meer specifieke hypothese gesteund dat de fonologische representaties van bekende woorden bij dyslectische kinderen ondergespecificeerd zijn. Deze laatste hypothese wordt echter niet verworpen, maar zou opnieuw geëvalueerd en aangepast moeten worden. In het algemeen kunnen de visueel-verbaal paarsgewijze leerproblemen van dyslectische kinderen niet toegeschreven worden aan minder goed gespecificeerde fonologische representaties van woorden. Echter, in een specifieke context, te weten in de context van het leren lezen van nieuwe woorden, kan de kwaliteit van de fonologische representaties de moeilijkheden met het leren lezen van deze nieuwe woorden in een context van gelijkende woorden verklaren.

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Curriculum Vitae

Vera Messbauer is geboren op 25 augustus 1971 in Breda. In 1990 behaalde zij haar VWO-diploma aan het Contardo Ferrini College te Amsterdam. Daarna volgde ze de opleidingen Bewegingswetenschappen en Orthopedagogiek aan de Vrije Universiteit te Amsterdam. In augustus 1996 studeerde zij voor Bewegingswetenschappen cum laude af in de hoofdrichting Bewegingsagogiek en de nevenrichtingen Gezondheidkunde en Functionele Anatomie. Eveneens in augustus 1996 studeerde zij cum laude af in de richting Gezinnen in psycho-sociale moeilijkheden aan de faculteit Psychologie en Pedagogiek. Vanaf oktober 1996 was zij werkzaam als orthopedagoog bij de Kinder- en Jeugdpsychiatrische instelling Amstelland-Tulpenburg, later Triversum genaamd. Hier heeft zij de opleiding tot GezondheidsZorg-psycholoog voltooid. Naast deze werkzaamheden is zij in december 1997 als onderzoeker in opleiding in dienst getreden van de Vrije Universiteit bij de vakgroep Orthopedagogiek, later bij de afdeling Pedagogiek en Onderwijskunde aan de Universiteit van Amsterdam. Onder supervisie van prof. dr. A. van der Leij en dr. P. de Jong is in de periode tot juli 2005 dit proefschrift tot stand gekomen. Sinds november 2003 is zij werkzaam bij Meerkanten GGZ Flevo-Veluwe als GZ-psycholoog en als zodanig verbonden aan de polikliniek kinder- en jeugdpsychiatrie en de afdeling voor dagbehandeling de Asterisk* te Lelystad.