The phonological representations hypothesis of dyslexia: consequences for the formation of associations
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Citation for published version (APA):
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.

Chapter 3

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.
Paired associate learning in Dutch dyslexic children

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 subtest 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>
<thead>
<tr>
<th>Variable</th>
<th>DYS</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (in months)</td>
<td>120.52</td>
<td>94.19</td>
<td>120.29</td>
</tr>
<tr>
<td></td>
<td>SD 7.05</td>
<td>SD 6.15</td>
<td>SD 5.33</td>
</tr>
<tr>
<td>Word decoding</td>
<td>29.24</td>
<td>29.05</td>
<td>68.71</td>
</tr>
<tr>
<td></td>
<td>SD 7.44</td>
<td>SD 7.32</td>
<td>SD 8.30</td>
</tr>
<tr>
<td>Reading Grade</td>
<td>2.4</td>
<td>2.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Vocabulary&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.52</td>
<td>16.05</td>
<td>13.57</td>
</tr>
<tr>
<td></td>
<td>SD 2.84</td>
<td>SD 3.34</td>
<td>SD 3.09</td>
</tr>
<tr>
<td>Non-verbal intelligence&lt;sup&gt;b&lt;/sup&gt;</td>
<td>57.38</td>
<td>45.24</td>
<td>55.71</td>
</tr>
<tr>
<td></td>
<td>SD 25.38</td>
<td>SD 13.65</td>
<td>SD 24.76</td>
</tr>
</tbody>
</table>

<sup>a</sup> Standardized vocabulary score.

<sup>b</sup> 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 VLEIGTUIG ('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, Sciliar-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*

<table>
<thead>
<tr>
<th>Task</th>
<th>DYS</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Phoneme Deletion (max. 24)</td>
<td>17.67</td>
<td>4.81</td>
<td>18.00</td>
</tr>
<tr>
<td>Word Completion (max. 29)</td>
<td>20.48</td>
<td>3.59</td>
<td>20.29</td>
</tr>
<tr>
<td>Nonword Repetition (max. 48)</td>
<td>32.57</td>
<td>7.49</td>
<td>33.71</td>
</tr>
</tbody>
</table>

40
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

<table>
<thead>
<tr>
<th>Task</th>
<th>DYS</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Nonwords</td>
<td>8.29</td>
<td>4.62</td>
<td>7.29</td>
</tr>
<tr>
<td>Words</td>
<td>18.81</td>
<td>3.60</td>
<td>16.86</td>
</tr>
<tr>
<td>Symbols</td>
<td>19.57</td>
<td>3.03</td>
<td>15.86</td>
</tr>
</tbody>
</table>

*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*

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

*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>
<thead>
<tr>
<th>Type of error</th>
<th>DYS</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoneme level</td>
<td>36.76</td>
<td>30.42</td>
<td>31.23</td>
</tr>
<tr>
<td>Syllable level</td>
<td>30.43</td>
<td>27.39</td>
<td>24.59</td>
</tr>
<tr>
<td>Word level</td>
<td>32.81</td>
<td>42.20</td>
<td>44.18</td>
</tr>
</tbody>
</table>

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

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

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.