The phonological representations hypothesis of dyslexia: consequences for the formation of associations
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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.
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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study</th>
<th>Dyslexic</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Age (in months)</td>
<td>1</td>
<td>132.75</td>
<td>7.45</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>126.35</td>
<td>9.36</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>141.88</td>
<td>6.97</td>
</tr>
<tr>
<td>Word decoding</td>
<td>1</td>
<td>33.57</td>
<td>11.22</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>29.27</td>
<td>8.58</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>38.61</td>
<td>11.98</td>
</tr>
<tr>
<td>Reading Grade</td>
<td>1</td>
<td>2.5</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.4</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.9</td>
<td>a</td>
</tr>
<tr>
<td>Calculation Speed</td>
<td>1</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>52.43</td>
<td>14.48</td>
</tr>
<tr>
<td>Arithmetic Grade</td>
<td>1</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Vocabulary$^b$</td>
<td>1</td>
<td>12.93</td>
<td>3.58</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>14.15</td>
<td>3.06</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>12.72</td>
<td>3.60</td>
</tr>
<tr>
<td>Raven (raw score)</td>
<td>1</td>
<td>34.09</td>
<td>6.90</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>38.19</td>
<td>7.65</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>34.24</td>
<td>7.06</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th></th>
<th>Concrete pictures</th>
<th>Abstract pictures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distinct</td>
<td>Indistinct</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyslexic</td>
<td>17.56</td>
<td>10.70</td>
</tr>
<tr>
<td>Normal</td>
<td>21.70</td>
<td>14.17</td>
</tr>
</tbody>
</table>

**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 I**
The effect of semantic content was not significant \((F (1, 85) = 2.47, \text{ns}, \eta^2 = .03)\). 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 in 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 $\eta^2$-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 ($F(1, 76) = 3.61, p = .056$).

**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 first 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 ($F (1, 48) = 13.23, p = .001, \eta^2 = .21$). 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>
<thead>
<tr>
<th>Group</th>
<th>Distinct words</th>
<th>Indistinct words</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Dyslexic</td>
<td>18.88</td>
<td>4.48</td>
</tr>
<tr>
<td>Normal</td>
<td>18.92</td>
<td>3.60</td>
</tr>
</tbody>
</table>
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 ($F(1, 80) = 7.75, p < .01, \eta^2 = .09$) and reader group ($F(1, 80) = 11.87, p < .01, \eta^2 = .13$). 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 ($F(1, 80) = 4.70, p < .05, \eta^2 = .06$). In addition, the interaction of distinctness and group ($F(1, 80) = 3.70, p = .06, \eta^2 = .04$) and the second order interaction of distinctness, group and order of presentation approached significance ($F(1, 80) = 3.35, p = .07, \eta^2 = .04$). 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 ($F(1, 82) = 14.18, p < .01, \eta^2 = .15$). 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 ($F(1, 80) = 8.31, p < .01, \eta^2 = .09$).

### 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

<table>
<thead>
<tr>
<th>Group</th>
<th>Order 1</th>
<th></th>
<th></th>
<th></th>
<th>Order 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distinct</td>
<td>Indistinct</td>
<td></td>
<td>Distinct</td>
<td>Indistinct</td>
<td></td>
<td>Distinct</td>
<td>Indistinct</td>
</tr>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Dyslexic</td>
<td>11.89</td>
<td>5.09</td>
<td>11.58</td>
<td>4.90</td>
<td>12.27</td>
<td>4.36</td>
<td>11.55</td>
<td>4.00</td>
</tr>
<tr>
<td>Normal</td>
<td>15.33</td>
<td>4.81</td>
<td>14.91</td>
<td>5.76</td>
<td>17.00</td>
<td>4.46</td>
<td>11.72</td>
<td>4.65</td>
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<tr>
<td>Total Score (max. 24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score Last Trial (max. 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Dyslexic</td>
<td>2.63</td>
<td>1.01</td>
<td>2.16</td>
<td>1.39</td>
<td>2.55</td>
<td>1.41</td>
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<td>Normal</td>
<td>3.19</td>
<td>1.21</td>
<td>2.71</td>
<td>1.27</td>
<td>3.41</td>
<td>0.85</td>
<td>2.36</td>
<td>1.09</td>
</tr>
</tbody>
</table>

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 than 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>
<thead>
<tr>
<th>Table 5</th>
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<tbody>
<tr>
<td>Summary of the manipulations examined in the Studies 1 to 3</td>
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</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Learning task</th>
<th>Main effects</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Visual (VD/VI)</td>
<td>Verbal (PD/PI)</td>
</tr>
<tr>
<td>1</td>
<td>Concrete VD</td>
<td>Name PD</td>
</tr>
<tr>
<td></td>
<td>Concrete VI</td>
<td>Name PD</td>
</tr>
<tr>
<td></td>
<td>Abstract VD</td>
<td>Name PD</td>
</tr>
<tr>
<td></td>
<td>Abstract VI</td>
<td>Name PD</td>
</tr>
<tr>
<td>2</td>
<td>Abstract VD</td>
<td>Word PD</td>
</tr>
<tr>
<td></td>
<td>Abstract VI</td>
<td>Word PI</td>
</tr>
<tr>
<td>3</td>
<td>Concrete VI</td>
<td>Word PD</td>
</tr>
<tr>
<td></td>
<td>Concrete VI</td>
<td>Word PI</td>
</tr>
<tr>
<td></td>
<td>Abstract VI</td>
<td>Word PD</td>
</tr>
<tr>
<td></td>
<td>Abstract VI</td>
<td>Word PI</td>
</tr>
</tbody>
</table>

*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.