Paradoxical Enhancement of Letter Recognition in Developmental Dyslexia

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In a number of studies, children diagnosed with developmental dyslexia reached normal scores in standard visual processing tasks, and some researchers concluded that visual processing deficits are not involved in the syndrome. The tasks used, however, may be insensitive to anomalous visual information processing strategies used to compensate for an underlying deficit. To determine whether children with dyslexia use anomalous visual processing strategies, a same–different task was applied, in which 2 items identical under rotation and reflection were judged as same. Pairs of letters or dot patterns were used, which were either symmetric or asymmetric in shape. Children with dyslexia performed faster than normal-reading children—in particular, remarkably, with letters. Symmetry of dot patterns facilitated performance in both children with dyslexia and normal-reading children; symmetry of letters facilitated performance in children with dyslexia but not in normal-reading children. Children with dyslexia, therefore, fail to adequately differentiate visual processing of linguistic and nonlinguistic materials; they process symmetry in letters similarly to that in shapes, which leads in this particular task to the paradoxical observation of children with dyslexia outperforming normal readers with letters.

More than 100 years of scientific research have failed to provide a consistent account of developmental dyslexia (Miles & Miles, 1999). Controversies are still ongoing...
over fundamental issues, such as whether the deficit mainly resides in visual processing (Hulme, 1988; Lovegrove, Bowling, Badcock & Blackwood, 1980; Skottun, 2001; Slaghuis & Ryan, 1999; Stanley & Hall, 2005; Stein, 2001; Willows, 1998) or is phonological in nature (Rack & Olson, 1993; Siegel, 1993; Snowling, 2001; Vellutino, 1987; Vellutino, Steger, Moyer, Harding, & Niles, 1977).

To solve this puzzle, we need sharper diagnostic tests than those typically used to localize the deficit in a single subcomponent of the cognitive process. In particular, it has been observed that children with dyslexia perform similar to unimpaired readers in many visual tasks (see Willows, 1998, for a review). Some researchers, therefore, concluded that visual processing deficits are not involved in the syndrome (Vellutino, 1987; Vellutino, et al., 1977). However, we believe that this conclusion is premature. Children with dyslexia may be quite flexible in their ability to compensate for a deficit. They may be doing this so well that they reach normal scores in standard visual processing tasks. But these scores are reached using anomalous processing strategies. To detect these strategies, we need to consider what is specific about reading.

A deficit that fails to reveal itself in standard tasks may, nevertheless, play an important role in complex tasks such as reading. The ability to read poses specific functional coordination demands on the cognitive subcomponents of the task. In fact, any of these subcomponents may function normally in standard tasks, but it is only in reading that their functional coordination breaks down. The specific functional coordination demands of normal reading (and writing) are the result of the dual graphemic and phonological encodings that linguistic materials normally receive, and their interactions (Everatt et al., 1999; Perfetti & Sandak, 2000; Talcott & Witton, 2002). Reading and writing require a dynamic mapping between these two encodings (Breznitz & Meyler, 2003; Lachmann, 2002). A deficit in coordination of the cognitive component functions involved in reading may therefore be the common denominator in developmental dyslexia.

Although the label of functional coordination deficit (Lachmann, 2002) has not previously been used to address dyslexia, this notion has a long ancestry. Consider Orton (1925). Orton’s original explanation of dyslexia is mono-causal, and the neurological assumptions on which it is based are no longer of fashion these days. Nevertheless, his early theorizing contains certain elements of the notion of a functional coordination deficit. Since Orton’s seminal work in the 1920s, classical reversal errors have dominated early dyslexia research and practice. Typical reversal errors are, for instance, the confusions between letters such as “d” and “b.” These static reversals are observed in the reading and writing performance of children with dyslexia. In the last three decades, the relevance of these errors was questioned by those who believed them merely to be yet another illustration of phonological deficits (Bigsby, 1981; Liberman, Shankweiler, Orlando, Harris, & Bell Berti, 1971). Although people with dyslexia in general may have no problems in distinguishing nonletter objects, it was believed that the confusion of reversed letters was based on their
phonological similarity ("bee", "dee"). In other words, it was argued that children with dyslexia can “see” (Vellutino, 1987) the distinction between “d” and “b” very well. In fact, Orton never said they could not. He believed that the problem resides at a level of abstract labeling of the visual representation by a phonological code (Corballis & Beale, 1993; Lachmann & Geyer, 2003).

In modern terms, the specific mechanism involved in reversal errors in reading could be understood as follows: Mirror images of nonletter objects are likely to belong to the same object or category. Because of this, it is of advantage to represent mirror images of nonlinguistic objects by similar visual codes (“symmetry generalization,” Lachmann, 2002); object constancy is one important result of this. In contrast, for linguistic objects, such a representation would be a hindrance, because it would interfere with the mapping between phonemes and graphemes. It is, therefore, important to treat graphemes as symbols distinct from other objects. This is exactly what we believe normal readers do. They will develop a special strategy for processing letters and words, involving the active suppression of mirror images in mapping a phoneme to a grapheme. The strategy of suppressing symmetry for letters might become automatized with practice, but at present, we want to leave this issue open when we use the term “strategy,” as this is beyond the scope of our article (for a discussion on different aspects of an automatization deficit in dyslexia, see, e.g., Moores, Nicolson & Fawcett, 2003; Savage, 2004; Wimmer, Mayringer & Raberger, 1999). It is enough that this strategy becomes habitual. The strategy will be learned during the first phase (e.g., pre-alphabetic phase; Ehri, 1995) of learning to read. Learning initially is far from perfect; early readers and writers make reversal errors just like children with dyslexia do. On the other hand, children with dyslexia, presumably, fail to develop the symmetry-suppressing strategy altogether. The reason for this could be found in functional coordination problems. Because the phoneme-grapheme mapping cannot efficiently be made, the symmetry-suppressing strategy offers them no advantage.

There is evidence that letters and nonletter objects are perceived with different strategies in normal-reading adults (Burgund, Schlaggar, & Petersen, 2006; Lachmann & van Leeuwen, 2004; van Leeuwen & Lachmann, 2004). For instance, in the latter two studies, when a nonletter object was surrounded by a congruent shape, this led to facilitation of object recognition. When, however, a letter was surrounded by a congruent shape, this resulted in impaired recognition. Congruent surrounding emphasizes the symmetry of a configuration. This facilitates processing for shapes but makes it harder for letters, as symmetry generalization is performed in object encoding and symmetry suppression in letters.

Dyslexia, rather than being caused by a general visual impairment, may thus engender a specific processing strategy. Because children with dyslexia fail to suppress symmetry in letters, they will apply the same perceptual strategies as for nonletter objects (Lachmann, 2002). This explains why they perform equal to normal readers in many nonlinguistic visual processing tasks (Vellutino, et al., 1977;
Willows, 1998). The way visual processing differs between children with dyslexia and normal readers will bring no disadvantage in visual tasks other than reading.

A strong test is possible for the hypothesis that children with dyslexia use an anomalous strategy for visual processing of linguistic materials. In some tasks, this strategy may be of advantage, in particular, when the task involves the detection of symmetry. In such tasks, children with dyslexia are predicted to perform superior to normal-reading children, in particular, when linguistic materials are used. This is a strong test because it is highly paradoxical and counterintuitive that children with dyslexia could perform any task involving linguistic materials better than normal readers.

We test this prediction using a version of the *same–different* task. Two items are shown in succession, and the participant must decide whether they are the *same* or *different* (Nickerson, 1969). Importantly, a *same* response must be given to objects that are identical under rotation or reflection. We used both nonlinguistic and linguistic items in this task. As nonlinguistic objects, we used Garner and Clement’s (1963) classical dot patterns; five-dot patterns that can be constructed on an imaginary $3 \times 3$ grid, leaving neither row nor column empty. Some of these patterns have a single axis of symmetry; others have no symmetry axis at all. In our experiment, we included these as symmetric versus asymmetric patterns, respectively (there are also ones with several axes of symmetry, such as the “cross” or the “five of dice,” which, however, were not used in our experiment). Reaction times (RT) in this task were shown previously to depend strongly on the symmetry in the patterns (Lachmann & Geissler, 2002; Lachmann & van Leeuwen, 2005b, 2005c). We may expect that for this nonlinguistic material, advantages of symmetry will occur both in normal readers and children with dyslexia.

The patterns were complemented by a set of linguistic stimuli consisting of letters. These, in analogy to the patterns, differed in symmetry. For instance, the letter “A” has a central symmetry which is lacking in the letter “R.” Here, in contrast with the patterns, we expected no advantage of symmetry in normal readers, based on the understanding that they have learned to automatically suppress symmetry generalization for linguistic material. Children with dyslexia, however, who are supposed to have failed to acquire the ability to suppress symmetry in grapheme representation, were expected to still show an advantage for symmetry also for the linguistic material.

**EXPERIMENT**

**Methods**

*Participants.* Thirty-three children with dyslexia and 24 normal-reading children from a single primary school in Leipzig, Germany, participated in the experiment. The children, their parents and teachers, and the Federal Office of Education gave their agreement to this study. Children with dyslexia had been
diagnosed according to the discrepancy definition (cf. American Psychiatric Association, 1994); that is, these children were found to fail in a reading test while performing like normal-reading children in tests measuring nonverbal general intelligence. For a discussion of the discrepancy definition see Stanovich (1991).

Developmental dyslexia had been diagnosed using the test battery by Weigt (1980) in Grade 2 of primary school (at an average age of 7.5 years), either 6 or 18 months before the experiment, by a team consisting of one educational psychologist, two specialist teachers for children with dyslexia, and one specialist for language disorders. This examination included reading and spelling for both contextualized and isolated letters and words, phoneme segmentation, visual recognition, phonological and visual differentiation, as well as a number of test lessons. Furthermore, physical development and sensory functioning were tested by an ophthalmologist and an otolaryngologist. Children diagnosed with dyslexia were enrolled in a special 2-year training program which extends the normal Grade 3 curriculum over a period of 2 years to provide extra time for training of reading and writing skills by specialized teachers. The experiment was conducted while these pupils were in the first or second year of this program. After performing this program, the children were to be re-enrolled in Grade 4 of their original primary school. Participants of the control group were recruited from Grades 3 and 4 of the same primary school in Leipzig. The school was a regular primary state school. In order to validate this previously given diagnosis and the distinction between children with dyslexia and normal-reading children, we tested all children (children with dyslexia and normal-reading controls) again and individually some month before the experiment. For this purpose, the Raven Progressive Matrices test (Heller, Kratzmeier, & Lengfelder, 1998; we used the complete set of items of the German standard version) and two subtests of the Salzburger Lese-Rechtschreibtest (SLRT; Landerl, Wimmer, & Moser, 1997) were used, one testing the ability of reading frequently used words and the other testing nonword reading, both by means of reading time (cf. Landerl, 2003).

One child previously diagnosed with dyslexia had IQ < 70 and therefore was excluded from further examination. All other children had at least normal intelligence and thus meet this criterion of the discrepancy definition (e.g., American Psychiatric Association, 1994).

The performance of each child in both reading tests was compared to that of the corresponding reference population of the SLR test. As criterion of discrepancy a reading time higher than 2 SD of that of the reference population in at least one of the two subtests was used. There were four children previously diagnosed with dyslexia who were excluded from further analyses because they showed normal performance in both tasks. To serve as a control participant, a child had to perform within the norms of the reference population in both tasks (within 1 SD); four controls of the original set failed this criterion for the nonword reading test and were, therefore, excluded from further analyses (as a
consequence, none of the participants performed the reading tasks in a time between 1 and 2 SD over the reference population). The remaining 33 children with dyslexia and 24 controls are those described in this section.

Thirteen of the 33 children with dyslexia were girls. On average these children were 9.9 years old (SD = .4, minimum = 9.4, maximum = 10.7) with an average IQ of 95.6 (SD = 10, minimum = 81, maximum = 110) as measured by the Raven Progressive Matrices test.

Eleven of the 24 normal-reading children were girls. On average the normal-reading children were 9.6 years old (SD = .6, minimum = 8.7, maximum = 10.9) with an average IQ of 102 (SD = 11.64, minimum = 81, maximum = 130).

There was no significant difference in age (t = –.79, p = .38) nor nonverbal intelligence (t = 1.4, p = .17) between the groups (see Table 1). Neither did the proportion between girls and boys differ between the groups (χ² = .23, p > .5). The reading times for frequent word reading and for nonword reading are displayed in Table 1; both times differed significantly between the groups, t(43) = –3.1 to –3.9, p < .01. All children had normal or corrected-to-normal vision and normal hearing.

Participants were right-handed as measured with a handedness test, except for two children with dyslexia who were ambidextrous.

**Material and design.** The materials consisted of linguistic and nonlinguistic items. As nonlinguistic items, we used three symmetric and three asymmetric five-dot patterns from the pattern set introduced by Garner and Clement (1963). See Figure 1. None of the patterns has an obvious similarity to letters.

Each item could occur in four different orientations as well as their mirror images. Note that this yields four different versions of each symmetric pattern and eight different versions of each asymmetric pattern. The issue that arises, therefore, is how to present these patterns in a balanced design. This problem has a theoretical counterpart in Garner’s notion of equivalence set size (ESS; Garner &

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Test Scores and Ages for Normal Reading Children and Developmental Dyslexics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Normal Reading Children</td>
</tr>
<tr>
<td>n</td>
<td>24</td>
</tr>
<tr>
<td>Age</td>
<td>9.9</td>
</tr>
<tr>
<td>IQ</td>
<td>96</td>
</tr>
<tr>
<td>FWR time</td>
<td>24.4</td>
</tr>
<tr>
<td>NWR time</td>
<td>48.9</td>
</tr>
</tbody>
</table>

*Note.* Age = average age in years; IQ = average of individual intelligence quotients according to German norms of the Standard Progressive Matrices Test; FWR time = reading time (in seconds) for the frequent word reading test of the Salzburger Lese-Rechtschreibtest (SLRT; Landerl, Wimmer, & Moser, 1997); NWR time = reading time (in seconds) for the nonword reading test of the SLRT (Landerl et al., 1997).
Clement, 1963). Each of the five-dot patterns belongs to an equivalence set (ES). An ES is a category of items related by a group action. For Garner and Clement’s patterns, this is the union of two transformation operations: rotation in steps of 90° and reflection over a vertical, horizontal, or one of two oblique axes, yielding eight different patterns (ESS = 8) for patterns without a symmetry axis. Patterns with a symmetry axis have an ES consisting of four rotated items, (ESS = 4). Therefore, ESS is a direct expression of pattern symmetry. In a previous work (Lachmann & van Leeuwen, 2005b), we have shown that in order to balance the stimuli in a design, it is necessary to consider the ES as well as the individual item presentation frequency. For this reason, the same procedure was followed here. Of the symmetrical patterns, each of the four versions from their respective ESs was included into the experiment. From the asymmetrical patterns, four out of the eight versions were chosen randomly from their respective ESs. For each of these patterns, reflected versions occurred with equal frequency as merely rotated ones.

To complement the dot patterns, six capital letters were chosen. Three were symmetrical, corresponding to (ESS) = 4 patterns, and three were asymmetrical, corresponding to ESS = 8 patterns. In the same way as for the dot patterns, the symmetrical letters occurred in four possible orientations. As with the asymmetrical patterns, for each asymmetrical letter four versions were chosen randomly in such a way that unreflected and reflected versions of each letter occurred with equal frequency.

For patterns as well as for letters there were 2 (symmetrical vs. asymmetrical) × 3 (items) × 4 (versions) = 24 unique stimuli. The stimuli were combined to pairs. We may distinguish these pairs according to their type of matching: identity matching (IM), that is, matching in shape and orientation, categorical matching (CM), that is, matching in shape but not in orientation, and nonmatching (NM). There were 24 IM, 72 CM, and 480 NM pairs possible. Both IM and CM pairs have to be responded as to same, NM pairs require a different response.

To balance the conditions, each IM pair was presented twice (see Table 2), yielding a total of 48 IM pairs for each material set. These were matched with 48
CM pairs chosen from the 72 possible ones with a probability of 2/3 by means of a Latin square. This resulted in 96 same pairs. These were matched by an equal number of different pairs, selected from among the NM combinations in a manner to assure that, across participants, each pattern appeared first and second with equal frequency. In addition, the chosen NM pairs were determined to be equally frequent to two symmetrical ones, two asymmetrical ones, a symmetrical followed by an asymmetrical one, or an asymmetrical followed by a symmetrical one. This led to a total of 192 pairs for each material class.

**Apparatus and procedure.** An instruction was presented using a sheet of paper with pattern and letter combinations printed as samples. The patterns on the sheet showed IM, CM, and NM pairs from the experiment, labeled with the correct responses. Further instruction was given verbally to the children. They were advised that items had to be judged for sameness independently of their orientation or reflection. The children reported that this task would be no problem to them. Instructions gave equal emphasis to speed and accuracy. During the experiment, participants were seated approximately 70 cm from a 15’ CRT computer monitor screen. Stimuli were presented in black against a gray background with a visual angle of about 3.5°. The first stimulus appeared on the left for 250 msec. After an inter-stimulus interval of 500 msec, the second appeared on the right, remaining on until the response was given. Participants had to press one of two response keys

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**TABLE 2**

Pattern Combinations Included in Experiment 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>ESS</th>
<th>Number of Sets</th>
<th>Total Number of Pairs</th>
<th>Frequency of Pair Inclusion</th>
<th>Number of Pairs Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IM</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
<td>12</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>CM</td>
<td>4</td>
<td>3</td>
<td>36</td>
<td>2/3</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
<td>36</td>
<td>2/3</td>
<td>24</td>
</tr>
<tr>
<td>Different</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>4</td>
<td>3 × 3</td>
<td>96</td>
<td>1/4</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3 × 3</td>
<td>96</td>
<td>1/4</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>4 and 8</td>
<td>3 × 3</td>
<td>144</td>
<td>1/6</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>8 and 4</td>
<td>3 × 3</td>
<td>144</td>
<td>1/6</td>
<td>24</td>
</tr>
</tbody>
</table>

*Note.* Same combinations consist of patterns from one set, identity matching (IM) are pairs of identical patterns, categorical matching (CM) are the remaining combinations. Different pairs consist of patterns from two sets of either the same or different equivalence set size (ESS). The total number of pairs (i.e., the total number of combinations in a given condition) is the product of ESS and the number of sets. The number of pairs included is the product of the total number of pairs and the frequency of pair inclusion (i.e., the multiplication factor that was applied to adjust the pair frequency in accordance with the particular balancing strategy). NM = nonmatching.
which, counterbalanced between participants, represented *same* or *different*, respectively. The next trial started automatically 2500 msec after the response.

The experiment consisted of one patterns block and one letters block. Each consisted of 192 trials in which the selected stimulus pairs (see Table 2) were presented in random order. Before each block, participants performed 30 random trials with accuracy feedback. Both blocks were performed on 1 day, their order counterbalanced between participants. Thus, a total of 384 responses were collected from each child. The whole experiment took about 40 minutes plus the time needed for instruction and a short break between the blocks.

**Results**

RT and errors of the total of 21,888 responses were collected. For RT analyses, only correct responses were used. Only responses given in a time window between 145 msec and an individual- and material-specific 5 SD outlier criterion entered into the analysis. Analyses were run on *same* responses. Mean RT was 883 msec ($SD = 408$) and error rate was 6.4%. Individual RT means and error rates were not correlated.

Analyses of variance (ANOVAs) were performed on response speed (1/RT) and error rates (%). Both were 4 factor (2×2×2×2) ANOVAs using the within-subject factors Material (letters vs. patterns), Type of Matching (IM vs. CM), Symmetry (symmetric vs. asymmetric), and the between-subject factor Group (children with dyslexia vs. normal readers). Generally for the present study, the Greenhouse-Geisser correction was used to calculate levels of significance, while $F$ values are reported with the uncorrected degrees of freedom. Means reported are arithmetic means of RT and error rates, respectively.

**Reaction times.** The effects for Material, $F(1, 55) = 61.7, p < .01$; for Type of Matching, $F(1, 55) = 66.2, p < .01$; for Symmetry, $F(1, 55) = 57.1, p < .01$, and for Group, $F(1, 55) = 4.24, p < .05$ were statistically significant (see Table 3). This indicates that letters (775 msec) were compared faster than patterns (924 msec); IM (806 msec) was faster than CM (891 msec); symmetric was faster (815 msec) than asymmetric (880 msec); and children with dyslexia (843 msec) responded faster than normal readers (938 msec).

A triple interaction was found between Material, Symmetry, and Group, $F(1, 55) = 18.6, p < .01$. Post hoc pair-wise comparisons showed that in children with dyslexia there was a Symmetry effect for patterns $F(1, 32) = 25.8, p < .01$ and letters $F(1, 32) = 46.6, p < .01$), whereas in normal readers there was a Symmetry effect for patterns $F(1, 23) = 18.2, p < .01$ but not for letters. The effects are visualized in Figure 2.

Two further triple interactions reached significance at the .05 level. The first one is between Type of Matching, Material, and Group, $F(1, 55) = 6.13, p < .05$. Post hoc ANOVAs revealed that in children with dyslexia the effects of Type of
Matching, $F(1, 32) = 45.7, p < .01$, and Material, $F(1, 32) = 33.1, p < .01$, are additive ($F < 1$), whereas for normal readers, the effects of Type of Matching, $F(1, 23) = 24.7, p < .01$, and Material, $F(1, 23) = 36.4, p < .01$ interact, $F(1, 23) = 9.12, p < .01$. Post hoc pair-wise comparisons showed that this interaction is the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal Readers</th>
<th>Developmental Dyslexics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Letters</td>
<td>Patterns</td>
</tr>
<tr>
<td>IM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetric</td>
<td>800</td>
<td>325</td>
</tr>
<tr>
<td>Asymmetric</td>
<td>804</td>
<td>347</td>
</tr>
<tr>
<td>CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetric</td>
<td>852</td>
<td>398</td>
</tr>
<tr>
<td>Asymmetric</td>
<td>841</td>
<td>324</td>
</tr>
</tbody>
</table>

Note. RT = reaction time; ER = error rate; IM = identity matching; CM = categorical matching.

**Figure 2** Error rates, reaction times (RTs) and standard deviations for symmetric and asymmetric letters and patterns for normal readers ($n = 24$) and children with dyslexia ($n = 33$). Note. Notice the absence of the Symmetry effect for letters that is found for patterns in normal readers and for both patterns and letters in children with dyslexia, indicating that letters and patterns are not differentiated in children with dyslexia. Notice also that in the present task, where mirror imaged items are responded to as *same*, this is actually an advantage, and so linguistic materials receive shorter RTs in children with dyslexia than in normal readers.
consequence of a stronger Type of Matching effect for patterns, $F(1, 23) = 27.9, p < .01$, than for letters, $F(1, 23) = 5.77, p < .05$ in normal readers. In other words, in normal-reading children, the Type of Matching effect is larger for patterns than for letters, whereas in children with dyslexia it is the same for both material types.

The second significant interaction was obtained between Type of Matching, Symmetry, and Group, $F(1, 55) = 6.43, p < .05$. Post hoc analyses showed that the effects of Type of Matching, $F(1, 23) = 23.2, p < .01$, and Symmetry $F(1, 23) = 9.1, p < .01$, are additive, $F(1, 23) = 1.37, p > .05$, for normal readers, whereas the effects of Type of Matching, $F(1, 32) = 41.4, p < .01$, and Symmetry, $F(1, 32) = 62.5, p < .01$ interact, $F(1, 32) = 5.78, p < .05$, for children with dyslexia. For normal readers, the effect of type of matching is equal in size for symmetrical and asymmetrical patterns, whereas for children with dyslexia, it was larger for symmetric than for asymmetric patterns (see Table 3).

**Model fit.** To clarify the interactions, a model was applied to obtain a linear prediction of the RT data in Table 3. The model describes the representation and processing of objects with different levels of symmetry. It includes the variables MAT ($1 =$ letters, $2 =$ patterns), GRP ($1 =$ normal readers, $2 =$ children with dyslexia) and the theoretical prediction variable, PRE. This PRE describes the role of symmetry generalization in the *same–difference* task (Lachmann & Geissler, 2002; Lachmann & van Leeuwen, 2005a, 2005b, 2005c). The PRE calculates the expected processing complexity in IM and CM conditions as a function of pattern symmetry, theoretically specified by its ESS. According to the model, for IM, $\text{PRE} = (\text{ESS} + 1)/2 + 1$ and for CM, $\text{PRE} = (\text{ESS} + 1)/2$. As our studies describe in great detail, these formulas are derived from basic assumptions involving the idea that the task is performed by search of a working memory representation of the ES. The model was shown to result in excellent fits for normal-reading adults with dot patterns. In the present study it is applied for normal-reading children as well as children with dyslexia, for RT obtained with dot patterns as well as letters. To calculate PRE, the theoretical ESS values of the patterns, ESS $= 4$ of symmetric patterns and ESS $= 8$ of asymmetric patterns, respectively, were used. For letters, also the values ESS $= 4$ for symmetric and ESS $= 8$ for asymmetric ones were used. However, according to our assumptions, normal readers suppress the symmetry in letters. For this reason, the theoretical value for asymmetric items, ESS $= 8$, was entered into the calculation of PRE for symmetric patterns in normal readers.

As shown in Figure 3, an excellent fit was obtained with the following linear model: $\text{RT} = (171.8 \times \text{MAT}) + (26.36 \times \text{PRE}) – (75.3 \times \text{GRP}) + 550.95, R^2 = .9, p < .01$, all three variables contributed significantly at the 1% level to the fit. It is noteworthy that PRE contributes more to the prediction than GRP. The assumption that normal readers suppress symmetry generalization in letters whereas children with dyslexia do not is crucial for the goodness of fit of this model. If, instead, PRE is calculated without the assumption that normal readers suppress symmetry
generalization for letters, the result is a reduction of the fit and GRP becomes more important than PRE; this is so, even though the change affects only two values of PRE.

**Error rates.** The same $2 \times 2 \times 2 \times 2$ ANOVA design was run on error rates. The effect of Material, $F(1, 55) = 26.2, p < .01$, indicating that errors were twice as frequent for patterns (7.9%) than for letters (3.6%); and for Type of Matching, $F(1, 55) = 11.4, p < .01$, where IM (3.6%) received a lower error rate than CM (7.9%), were statistically significant. An interaction was found between Material and Type of Matching, $F(1, 55) = 5.7, p < .05$, which indicates that the Type of Matching effect is restricted to patterns (letters: IM = 3.2%, CM = 4%; patterns: IM = 5.9%, CM = 10%). An interaction was also found between Type of Matching and Symmetry, $F(1, 55) = 4.1, p < .05$. The Symmetry effect is obtained for IM (symmetric 3.6% vs. asymmetric 5.5%) but not for CM (symmetric 7.4% vs. asymmetric 6.6%). No group effects were found for error rates.

**Discussion**

Some studies have claimed that children with dyslexia are weaker than normal readers in visual processing of nonlinguistic items; others failed to find such
differences. For instance, it has been found that children with dyslexia are slower than normal readers in performing spatial transformation tasks (Rüsseler, Scholz, Jordan & Quaiser-Pohl, 2005), and in tasks that require visuoperceptual organization (Becker, Elliott & Lachmann, 2005). Others, however, failed to find increased RT in children with dyslexia performing visual tasks (Stanovich, 1985, Vellutino, 1987; see Willows, 1998 for a review). In the present study, children with dyslexia perform superior to normal-reading children. Moreover, they do so for both nonlinguistic and linguistic items. As shown in Figure 2, the difference was strongest for the linguistic material. These results are paradoxical but in accordance with the prediction, based on our hypothesis that children with dyslexia fail to repress symmetry generalization. Their somewhat better performance with non-linguistic material may result from practice. They used the same strategy for dot patterns and letters. Noteworthy in this respect, those children with dyslexia who started the experiment with a letters block have a practice advantage that normal readers do not have. In accordance with this explanation, we found that superior scores on patterns were obtained more often for those children with dyslexia who started with a letters block.

Specific evidence that children with dyslexia fail to suppress symmetry generalization is the presence of a Symmetry effect for letters (see Figure 2). Whereas normal readers ignore the symmetry in linguistic material, children with dyslexia do not. As additional evidence, the model fit in Figure 3 could be considered. This fit is based upon a theoretical calculation of processing complexity in IM, CM, and NM stimuli as a function of symmetry (Lachmann & Geissler, 2002; Lachmann & van Leeuwen, 2005a, 2005b). The model fit could only be obtained if in normal readers the symmetry of letters was discarded. It could be argued that there was no baseline condition in the present study (the performance between the groups was not tested without the Symmetry variation). However, this does not weaken the results.

We observe that in both groups, identity matches were identified faster than categorical matches. This is what was called in the literature the fast–same effect (Nickerson, 1969; Proctor, 1988). It is interesting that the fast–same effect in normal readers is larger for patterns than for letters, whereas for children with dyslexia the effect is the same size for patterns and letters. This result supports the notion that children with dyslexia treat the two stimulus categories with the same strategy. At the same time, the fast–same effect in normal-reading children was equal for symmetric and asymmetric patterns, whereas for children with dyslexia, it was larger for symmetric than for asymmetric patterns. Both effects are accounted for by the model fit in Figure 3.

It is noteworthy that all of the effects on error rates were the same for both groups. This yields further support to the notion that the symmetry interferes with preferred strategy in normal readers. We may expect that extra time will be needed to resolve the interference, without necessarily leading to more errors.
We used a same–different task that was aimed specifically at testing differences in visual processing strategies between children with dyslexia and controls. Inspired by Posner and his colleague (Posner & Mitchell, 1967) the same–different task has been used repeatedly in attempts to dissociate visual or phonological deficits in children with dyslexia (Bigsby, 1981; Ellis, 1981) by using varying sameness criteria. Typically, in one case, a physical (A – A) and in another a phonological (A – a) sameness criterion was used. From the absence of a physical in combination with the presence of a phonological difference between normal-reading children and children with dyslexia, it was concluded that dyslexia is a (late) phonological and not a visual perception deficit (Bigsby, 1981). However, a mere dissociation in effect is not sufficient evidence to conclude dissociation in process (Van Orden, Pennington, & Stone, 2001). Neither is absence of difference evidence that both groups perform the task in the same way. One conclusion that can be drawn from our present study is that, at least for children with dyslexia, the simple formula: “observed visual object recognition deficit ↔ underlying visual processing deficit” is wrong. Our present results offer specific evidence for contrasting strategies used. Anomalous strategies used by children with dyslexia can lead to superior results in certain visual tasks, normal performance in others, and weak reading behavior. Differences in perceptual strategies should be taken into account when remedial teaching is offered to children with dyslexia.

Our explanation is based on the failure in readers with dyslexia to suppress symmetry in processing linguistic materials such as letters (Lachmann, 2002). Whereas normal readers have learned to suppress symmetry and other configurational properties in letter processing, in children with dyslexia, failure to suppress symmetry may lead to problems in reaching a mapping between grapheme and phoneme representations. In the context of the present same–different task, however, it leads to superior performance.

The question remains whether these results are representative for the difference between children with and without problems in learning to read. The conclusion that all children with dyslexia have the particular problem we identified here would be too strong, given that the participants were from matched school classes rather than randomly selected. As we argued in our introduction, several deficits could, in principle, be involved. It is very likely that there are different subgroups of children with dyslexia (e.g., Boder, 1973) with different reading patterns and different deficits underlying their problems (Becker, Elliott & Lachmann, 2005; Lachmann, Berti, Kujala & Schröger, 2005). Yet, reading requires functional coordination, and, hence, a deficit in functional coordination, whether as a result of subfunction failure or not, may be the common denominator in developmental dyslexia. It is recommended, therefore, that, even though phonological skills are undoubtedly very important, remedial teaching to children with dyslexia should always include basic skills of grapheme-to-phoneme conversion, so as to ease the coordination problems involved in reading.
In order to further investigate the nature of perceptual strategy variation in children with dyslexia, neurophysiological methods would be most promising (Goswami, 2004).

ACKNOWLEDGMENT

Many thanks are due to anonymous reviewers for their helpful comments on earlier drafts of this article. Thanks are also due to Katrin Berg (University of Leipzig) for technical support, and to the children, their teachers (3. Grundschule, Leipzig), and their parents for their cooperation.

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