Different letter-processing strategies in diagnostic subgroups of developmental dyslexia

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Normally reading adults (\(N = 15\)) and primary school children (\(N = 24\)) and two diagnostic subgroups of children with developmental dyslexia (\(N = 21\))—all native German speakers—performed a successive *same–different* task with pairs of letters and nonletters (pseudoletters or geometrical shapes). The first item of a pair was always presented on its own, and the second either on its own or surrounded by a congruent or incongruent nontarget shape. Adults showed congruence effects with nonletters but not with letters, and children with both types of stimuli. Frequent-word reading-impaired dyslexics (\(N = 11\)) in addition showed dramatically slower overall reaction times. Nonword reading-impaired dyslexics (\(N = 10\)) showed congruence effects with nonletters but negative congruence effects with letters. The results support the notion that normal readers have established a special visual processing strategy for letters. Processing speed rather than reading expertise seems crucial for this strategy to emerge. The contrasting effects between subgroups of dyslexics reveal specific underlying deficits.

**Keywords**: Developmental dyslexia; Specific learning disability; Letter recognition; Subgroups of dyslexia; Dysphonetics; Dyseidetics; Congruence effects; Grapheme-to-phoneme conversion.

Reading expertise manifests itself in the availability of specialized visual processing strategies for lexical items (Burgund, Schlaggar, & Petersen, 2006). Whereas normally in perception, early visual feature binding leads to the perception of integral object structure, in Rumelhart and McClelland’s (1982) parallel activation model for letter recognition, for instance, visual feature binding between adjacent letters is disabled. Instead, isolated letter detection supports word-level recognition processes that, through interactive activation, are responsible for, among other things, the well-known word superiority effect (Cattell, 1886).

A reliable indicator for the occurrence of visual feature binding is the *congruence effect* (Bavelier, Deroelle, & Proksch, 2000; Lockhead &
Pomerantz, 1994; Pomerantz & Pristach, 1989; van Leeuwen & Bakker, 1995). Suppose that early visual processes combine features of an object with those of its surroundings. Then, when the object is selectively attended to, selection will automatically extend to surrounding features. Reporting on the target object will therefore be easier and faster when a surrounding feature calls for the same response then when it calls for a different one.

We studied the discrepancy in early visual processing between letters and nonletter shapes using the congruence effect, most recently in Lachmann and van Leeuwen (2008). Pairs of letters, pseudo-letters, or basic geometrical shapes were presented in a sequential same–different task. The first item was always presented on its own, the second one either on its own or surrounded by an irrelevant geometrical shape that could be congruent or incongruent to the target (see Figure 1). In nonletter shapes such as in the bottom row of Figure 1, congruence effects were found to be robust, which indicates holistic processing of these items. In corresponding letters, such as in the top row of Figure 1, congruence effects failed to occur if the interval (interstimulus interval, ISI) between the first and second items was short (320 ms), indicating analytic processing. As analytic processing of letters is highly automatized, it is effective for stimuli appearing at a relatively fast rate.

In the present study, we adopted this paradigm in order to compare congruence effects in letters and nonletter shapes across four subgroups: normally reading adults and children, and two subgroups of children diagnosed with developmental dyslexia. Our first question is whether dissociation—that is, the contrasting effects between letters and nonletters—can be reproduced in less experienced readers. Burgund et al. (2006) found that letter-specific processing strategies emerge in children and adults between 6 and 19 years as a consequence of reading experience. Third and fourth graders, who are already accomplished readers, nevertheless may not have reached a sufficient level of experience to manifest the dissociation to the same extent as adults.

Our second question is what happens to the special letter-processing strategy if reading experience is marred by developmental dyslexia. In principle, we may expect that dyslexic children are either anomalously slow on the task or show a letter specialization pattern that differs from that of their normally reading comppeers.

**Diagnostic subtypes of developmental dyslexia**

While its aetiology is still unknown, developmental dyslexia is generally diagnosed, according to international classification systems (e.g., *Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition, DSM-IV*; American Psychiatric Association, 1994), as failing in a reading test while performing like normal readers matched in age, background, intelligence, and history of instruction, in tests measuring nonverbal general intelligence, in the absence of sensory defects in vision or hearing (for a discussion of this definition, see, e.g., Stanovich, 1991). This descriptive definition fails to consider that there may be important subtypes with distinct cognitive impairments (see, e.g., Heim et al., 2008). Diagnostic tests reveal subgroups with characteristic reading and writing failures (Au & Lovegrove, 2007; Baylis & Livesey, 1985; Boder, 1970, 1973; Facoetti et al., 2006; Flynn & Deering, 1989; McPherson & Ackerman, 1999; Milne, Nicholson,
In general accordance with these studies, our diagnostic tests distinguish two subgroups of dyslexic children. One is impaired in reading high-frequency words but not in nonword reading (frequent-word reading impaired, FWRI); the other is impaired in nonword reading or in both nonword and frequent-word reading (nonword reading impaired, NWRI).

Which effects could we predict in our present task with FWRI dyslexics? Frequent-word reading is normally done by a rapid conversion of the visual word form to a lexical representation (Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993). FWRI children are traditionally termed as “dyseidetics” (Boder, 1970; Lorusso, Facoetti, & Pesenti, 2004; Milne et al., 2003). It was assumed that they have a deficit in visual word Gestalt recognition (Boder, 1970) or some other visual deficit (Farmer & Klein, 1995).

However, it appears that FWRI dyslexics do not suffer from a specifically visual deficit. In this sense, the label “dyseidetics” frequently attached to this group may in fact be misleading. Besides visual, also lexical and phonological deficits have been established for this group. Milne et al. (2003) found that these children have deficits in lexical access and fail in phonological decoding tasks. As an electrophysiological study has shown, this group also scored abnormally on measures of unattended phonological discrimination (Lachmann, Berti, Kujala, & Schröger, 2005). These authors argued that FWRI children have a generic, material-unspecified deficit in processing speed, leading to delays in visual as well as in phonological activation. The processing speed hypothesis was supported by a number of experiments (Fuchs & Lachmann, 2003; Lachmann, 2007), in which FWRI children showed the same overall pattern of effects as controls for linguistic as well as nonlinguistic materials, but with dramatically slower processing rates.

When speed is a generic constraint to this group, their near-normal ability to read nonwords in reading tests could easily be understood. As normal readers also do this slowly, by one-to-one conversion of graphemes to phonemes, this task will not present a special difficulty to FWRI dyslexics. For our current task, we expect this subgroup to process single letters in a normal way, except that a general delay will be visible. The same general delay will also occur in processing of nonletter items. Therefore we expect this group to differ from normally reading children only by an additive component to their response times. We also expect them to be slower on this task than the other subgroup, that of NWRI dyslexics, to which we turn now.

What kind of effects are to be expected from NWRI dyslexics? Failure in nonword reading has been recognized as a major symptom of dyslexia in both children and adults (Svensson & Jacobson, 2006). Nonword reading consists to a large extent of piecemeal grapheme-to-phoneme conversion. NWRI dyslexics are likely to have specific problems with these conversions.

These problems have been explained in terms of auditory and/or phonological processing deficits (Badian, 2005; Benasich, 2002; Bishop, 2007; Bradley & Bryant, 1978; Kujala, 2007; Siegel, 1998; Snowling, 2001; Stanovich, Siegel, & Gottardo, 1997; Steinbrink & Klatte, in press; Tallal & Benasich, 2002; Vellutino, 1987), visual processing deficits (Galaburda, 2002; Hulme, 1988; Lovegrove, Bowling, & Badcock, 1980; Skottun, 2001; Slaghuis & Ryan, 1999, 2006; Stein, Talcott, & Walsh, 2000; Willows, Kruk, & Corcos, 1993), or, as we believe, as a deficit in the coordination of these two processes (e.g., Lachmann, 2002; Lachmann & Geyer, 2003; Lachmann & van Leeuwen, 2007; Rusiak, Lachmann, Jaskovski, & van Leeuwen, 2007). The latter hypothesis was supported by a number of studies, showing that whereas NWRI children perform equally to normals in auditory discrimination of tones and phonemes (Lachmann et al., 2005), they struggle when phonological information is presented visually (Fuchs & Lachmann, 2003; Lachmann, 2007, Exp. 12). The origin of this problem is not necessarily a phonological deficit. This interpretation automatically implies that the traditional label of this group, dysphonetics, is as misleading at that of the other group.

Deficits in grapheme–phoneme conversion will lead to nonword reading failure, but how can it explain that many of these children, (the so-called
dysphoniedetics), also fail on frequent word reading? This can be understood as a secondary symptom. These children are hampered in reaching a stage of reading expertise, in which they easily recognize integral word images. From this, a conclusion follows that, at first sight, seems rather paradoxical: Those who fail on the frequent-word reading test only have a generic deficit, while those who fail on both tests have a specific deficit. But this is paradoxical only if we reason from test scores rather than from the sources of the deficit.

Given that NWRI dyslexics find single-letter processing difficult, they will have to rely on active inhibition of the surrounding visual features. Previous studies with normally reading adults provide at least three cases in which the task required such active suppression. This led invariably to negative congruence effects: better performance with incongruent than with congruent stimuli. This effect occurred, first, with nonletter stimuli that have many, confusing, nontarget features (Bavelier et al., 2000; van Leeuwen & Bakker, 1995), which require their active inhibition for target detection. The nontargets are harder to inhibit when they are similar in shape and thus call for integration, yielding the negative congruence effects. Second, van Leeuwen and Lachmann (2004) obtained negative congruence effects for letters, using stimuli such as those in Figure 1 in a choice response task, where items similar in shape belonged to different response categories. Congruent surroundings emphasized the similarity in shape, hence the need to actively suppress them. Third, the same stimuli were used in a version of the present same–different task (Lachmann & van Leeuwen, 2004) with mixed pairs. For letters as well as nonletters, participants found it difficult to respond different to letters and nonletter objects that were similar in shape. Congruent surroundings emphasized the similarity in shape and thus were effortfully suppressed. Again, more effort was needed in congruent than in incongruent conditions.

NWRI children will need effort to suppress surrounding information in letter processing even in the relatively relaxed conditions of the present experiment, because processing of single-letter items is intrinsically difficult for them. They are therefore expected to produce negative congruence effects for letters. Table 1 presents a summary of the predictions.

### EXPERIMENT

The present study used a version of the same–different task of Lachmann and van Leeuwen (2008). We compared the performance of normally reading adults, normally reading children, and FWRI and NWRI dyslexics on this task.

#### Method

**Participants**

All participants were native German speakers and had normal hearing and normal or corrected-to-normal vision. Normally reading adults were 15

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<th>Congruence effect</th>
<th>Shapes</th>
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<td>Normal adults</td>
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<td>Normal children</td>
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<td>FWRI</td>
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student volunteers (11 female) from the University of Leipzig (a major city in central Germany), between 18 and 31 years old. They either were paid or received course credit for their participation. None of them reported having a history of any kind of reading or spelling problems.

A total of 24 normally reading and 21 dyslexic children participated in the experiment. They, their parents and their teachers, and the Federal Office of Education gave their agreement to this study. All children were recruited from the same primary school in Leipzig, Germany, which has a special 2-year programme for children diagnosed as dyslexic. Children in the normally reading group were age matched to the dyslexics and were recruited from nonprogramme Grades 3 and 4. The dyslexic participants were recruited from the programme, either 3 or 15 months after their diagnosis, depending on whether they were in their first or second year of the programme. The experiment was part of a larger series that was run in the school over a period of 12 months. A total of 12 of the normally reading participants and 16 of the dyslexics in the present study also took part in the study of Lachmann et al. (2005).

All participating children had normal hearing and normal or corrected-to-normal vision, and all children were right-handed as measured with a handedness test, except two dyslexic children who were ambidextrous and one dyslexic child who was left-handed. There were no significant differences between the groups in age, grade, and nonverbal intelligence as determined with Raven’s Standard Progressive Matrices test (Heller, Kratzmeier, & Lengfelder, 1998); see Table 2. The children received toys and candies in reward for their participation.

### Diagnosis

In accordance with state law (Saxony), every school child is given a screening test for developmental dyslexia in Grade 2 (at an average age of 7.5 years). Children who score positive on the screening undergo a week of intensive testing by a team consisting of one educational psychologist, two specialist teachers for dyslexic children, and one specialist for language disorders. This examination uses a test battery (Weigt, 1980), which includes reading and spelling tests for both contextualized and isolated letters and words, phoneme segmentation, visual recognition, and phonological and visual differentiation (Breuer & Weuffen, 1995), as well as a number of test lessons. Furthermore, physical development and sensory functioning are tested by an ophthalmologist and an otolaryngologist.

Children diagnosed as dyslexic are brought together from different schools within a district, to join a special 2-year training programme, such as that offered by the current school. During this period, children in this programme follow the normal Grade 3 curriculum, which is spread over a period of 2 years in order for specialized teachers to provide training in basic reading and writing skills. After completion of the training programme, the children return to their original school to join Grade 4.

All participating children had thus previously been screened for dyslexia; dyslexic participants from the special training programme had in addition gone through the extensive diagnosis procedure. We tested all children again, 5 to 10 days before the experiment. This was done, not only in order to validate the previously given

| Table 2. Test scores, ages, and gender for normally reading children and developmental dyslexics |
|----------------------------------|------------------|------------------|
| Normally reading | FWRI | NWRI |
| N | 24 | 10 | 11 |
| Age | 9.3 | 9.3 | 9.4 |
| Female | 11 | 6 | 4 |
| IQ | 109 | 100 | 93 |
| FWR time | 21 | 85 | 66 |
| NWR time | 49 | 56 | 144 |

**Note:** FWRI = frequent-word reading impaired. NWRI = nonword reading impaired. N = number of participants. Age = average age in years (decimal). Female = number of female participants. IQ = average of individual intelligence quotients according to Raven’s Standard Progressive Matrices norms. FWR time = reading time (s) for the frequent-word reading test of the Salzburger Lese- und Rechtschreibtest (SLRT; Landerl et al., 1997). NWR time = reading time (s) for the nonword reading test of the SLRT (Landerl et al., 1997).
diagnosis, but also in order to classify those with reading deficits as FWRI or NWRI. To this purpose we administered three pretests: Raven’s Standard Progressive Matrices test (Heller et al., 1998) and two subtests of the Salzburger Lese-und Rechtschreibtest (SLRT; Landerl, Wimmer, & Moser, 1997), one of these for testing the ability to read frequently used words (FWR) and the other for testing nonword reading (NWR), both by means of reading times. In transparent languages like German, reading times discriminate better between groups than do error rates (cf. Landerl & Wimmer, 2000; Landerl et al., 1997). Accordingly, reading times were taken as measures of reading expertise in children.

Based on the Raven test, two children previously diagnosed as dyslexic scored an IQ < 70 and were therefore excluded from participation. All other children had at least normal intelligence.

FWR and NWR scores of each child were compared to the reference population in relation to grade level. To enter the normally reading group, a child had to perform within the norms of its reference population in both tasks (percentage rank > 16; within 1 SD of the population average). A total of 4 normally reading child entrants failed this criterion for the nonword reading test and were, therefore, excluded from participation. To qualify as dyslexic, performance had to be below 2 SDs (percentage rank < 3) of the population average in at least one of these tests. A total of 3 children previously diagnosed as dyslexics were excluded from participation because they showed normal performance in both tasks (within 1 SD from the reference population mean).

**Diagnostic subgroups of dyslexics**

A total of 11 children (4 females, mean age = 9.4 years, SD = 0.6; IQ = 93) performed similarly to the reference population in the NWR test (percentage rank > 17; < 1 SD) but scored reading times more than 2 SDs over the reference population average (percentage rank < 3) on the FWR test. These children were identified as FWRI dyslexics. A total of 10 children (6 female, mean age = 9.3 years, SD = 0.7; IQ = 100) were classified as NWRI dyslexics based on reading times 2 SDs (percentage rank < 3) above the reference population average in the NWR test. No significant difference in general intelligence, age, or grade was found between these two dyslexic subgroups.

Figure 2 provides a scatterplot of the reading times on the FWR and NWR tests for all child participants. Note the lack of overlap between the groups as well as the relative homogeneity of the normally reading group, both resulting from the selection criteria. Overall, reading times and reading errors correlated positively, both for FWR ($r_s = .706, p < .01$) and NWR ($r_s = .675, p < .01$). Within the normally reading children, these correlations were positive for NWR ($r_s = .407, p < .01$) but absent for FWR ($r_s = .111, ns$). The same was the case for NWRI dyslexics (resp. $r_s = .665, p < .01$, and $r_s = .426, ns$) but for FWRI dyslexics, the opposite pattern was obtained (respectively, $r_s = .001, ns$, and $r_s = .903, p < .01$). According to these correlations, none of the groups showed evidence of speed–accuracy trade-off in their reading behaviour. Reading times, moreover, were consistent with error patterns at least in

![Figure 2. Scatter plot of individual reading times (s) on frequent-word reading (FWR) and nonword reading (NWR) pretests for normally reading children and frequent-word reading impaired (FWRI) and nonword reading impaired (NWRI) dyslexics.](image-url)
those tests that mattered most in the selection (NWR for NWRI dyslexics and FWR for FWRI dyslexics).

**Materials: Stimuli and apparatus**
The same stimulus set as that in Lachmann and van Leeuwen (in press) was used: the three capital letters, A, L, and C; three corresponding pseudoletters, pseudo-A, pseudo-L, and pseudo-C; and three shapes that correspond to the outline envelopes of the letters: a triangle, a rectangle, and a circle, respectively. The targets are shown in Figure 3. A target was presented on its own or surrounded by one of three nontarget geometrical shapes. These were slightly enlarged versions of the triangle, rectangle, and circle targets (see Figure 3). Target and nontarget surrounding shapes could either be congruent or incongruent. In total, there were nine sets of stimuli: isolated letters, letters with congruent surrounding, letters with incongruent surrounding, isolated pseudoletters, pseudoletters with congruent surrounding, pseudoletters with incongruent surrounding, isolated shapes, shapes with congruent surrounding, and shapes with incongruent surrounding. Each set contained three stimuli, resulting in a total of 27 unique displays.

All stimuli were presented in white (28 cd/m²) on a CRT computer monitor screen set to black (0.46 cd/m²). Target stimuli were 30 mm, and surrounding shapes were 70 mm in height. They were presented at about 50-cm distance, resulting in a visual angle of about 3.5 degrees without and 8 degrees with surrounding. Participants were seated in a chair, without head fixation.

**Procedure**
The experimenter gave instructions verbally. Participants were instructed to respond as quickly and as accurately as possible whether two successively presented items were either same or different and to ignore the surrounding shape, whenever one occurred, as irrelevant. They were not told explicitly that the first and second stimuli were always of the same category. The response was given by pressing one of two response keys on the computer keyboard. Response key allocation was counterbalanced across participants within groups (by approximation whenever the number of participants within a group is uneven). Prior to the experiment, participants completed a 30-trial practice session. Here and in the experiment, first, a 10 × 10-mm fixation cross occurred for 50 ms at the left half of the screen, at the position that marked where the target stimuli would follow (note that accuracy of presentation duration was limited by the screen refresh rate, which was 16.6 ms). After that the screen remained clear for 500 ms. Then the first target stimulus was presented for 800 ms, followed by an interval of 650 ms. This interval started with a mask, which was presented for the duration of the frame rate of the monitor (16.6 ms). The mask consisted of all stimuli superimposed on their original locations, combined with features of the stimuli distributed over random locations across the whole screen. The screen remained empty for the remainder of the interval. Subsequently, a second 10 × 10-mm fixation cross occurred for 50 ms in the right half of the screen, marking the place where 500 ms later the second stimulus was shown until the response of the participant. After the response, the mask appeared again for 16.6 ms, and subsequently the
screen remained empty. After 2,000 ms, the next trial started. Whereas both speed and accuracy feedback was given during the practice trials, no feedback was given during the experimental trials.

A pair of stimuli always consisted of two letters, of two pseudoletters, or of two shapes. Whereas the first stimulus was always isolated, the second stimulus could occur on its own, or within a congruent surrounding, or within an incongruent surrounding. Thus, the first stimulus—for example, the letter A—could be followed by three stimuli that required a same response: the same stimulus A without surrounding, A within a triangle, or A within a rectangle. The A could also be followed by stimuli that required a different response: C or L without a surrounding, C within a circle or L within a rectangle, or C within a rectangle or L within a triangle.

Given that there are three different material classes (letters, pseudoletters, shapes), in each of which six different pairs can be formed in each of which the second one could appear isolated, congruent or incongruent, there are $3 \times 6 \times 3 = 54$ unique different stimulus pairs. Likewise there are $3 \times 3 \times 3 = 27$ unique same pairs, which were repeated twice in order to balance same and different. This resulted in 108 trials per block. During the experiment the 108 pairs of stimuli were presented in fully random order. After the practice trials and a first block of 108 trials, participants had a short break before performing a second block, resulting in a total of 216 responses.

The experiment was performed in a dimly lit room without windows, in the laboratory for the adults and for the children in the basement of the school building during the regular lesson times; the children were taken off the class for one lesson. The whole experimental session lasted less than one lesson of 45 minutes.

Results and discussion

We report reaction times (RTs) for correct responses. There was no correlation between RTs and error rates. Hence there was no indication for speed–accuracy trade-off, and, therefore, error rate effects are reported only when they are inconsistent with RT results. As RT distributions tend to be skewed, parametric analyses were done for response speed (1/RT) without outlier rejection. However, all RT averages presented are arithmetic means, which were calculated, for the sake of consistency with our earlier publications, using standard outlier rejection criteria. We excluded individual trials of which the RTs exceed the individual mean $+3.5$ SDs, as well as individual trial RTs above 5,000 or below 145 ms. According to this criterion, 4.9% of trials were excluded, roughly equally distributed over all the experimental conditions.

Neither RTs nor error rates correlated with IQ in the pretest. We report correlations observed for the FWR and NWR pretests.

Overall statistics

Analyses of variance (ANOVAs) were conducted, followed by Bonferroni post hoc tests and controlled pairwise comparisons. A first ANOVA was conducted with the within-subject factors response type (same vs. different), material (letters, pseudoletters, shapes), and second target surrounding (isolated, congruent, incongruent), and the between-subject factor group (normal adult readers, normally reading children, FWRI dyslexics, and NWRI dyslexics). In these and subsequent ANOVAs, for F-values the Greenhouse–Geisser correction was used to determine significance level, whereas the degrees of freedom reported are the uncorrected ones. The ANOVA revealed main effects for all factors.

For response type, $F(1, 56) = 60.67$, $p < .01$, post hoc pairwise comparisons revealed that same responses ($M = 683$ ms, $SD = 387$ ms) were faster than different responses ($M = 758$ ms, $SD = 393$ ms). This reflects the well-known fast–same effect reported in the literature (Krueger, 1978; Lachmann & van Leeuwen, 2005; Proctor, 1981). The fast–same effect was qualified by an interaction of response type and group, $F(1, 56) = 3.17$, $p < .05$, response type and surrounding, $F(2, 112) = 2.71$, $p < .05$, and a triple interaction of response type, group, and surrounding, $F(6, 224) = 2.71$, $p < .05$, all of which appear to result from the exceptionally
large fast–same effect for NWRI dyslexics in the congruent conditions: 735 versus 878 ms. The fast–same effect is generally explained in terms of visual object recognition strategies. The size of the effect in the congruent condition in the NWRI group, therefore, suggests a strong reliance on visual processing.

For material, $F(2, 112) = 11.97, p < .01$, faster responses were given to letters ($M = 705$ ms, $SD = 390$ ms), than to pseudoletters, ($M = 732$ ms, $SD = 386$ ms) and to shapes ($M = 725$ ms, $SD = 398$ ms), whereas pseudoletters and shapes did not differ. Faster responses for letters are familiar from the literature (Ambler & Proctor, 1976; Burgund et al., 2006; van Leeuwen & Lachmann, 2004) and reflect the automatized character of letter processing in reading.

The factor surrounding, $F(2, 112) = 33.0, p < .01$, revealed that responses for isolated targets ($M = 699$ ms, $SD = 387$ ms) were faster ($p < .05$) than those for congruent targets ($M = 715$ ms, $SD = 379$ ms), which, in turn, were faster ($p < .01$) than those for incongruent targets ($M = 749$ ms, $SD = 408$ ms). Both congruent and incongruent surroundings reduce target detectability. Congruent surroundings do so to a lesser extent, however, than incongruent ones. The results, therefore, show a robust congruence effect overall. An interaction between material and surrounding, $F(4, 224) = 2.72, p < .01$, revealed higher congruence effects for the shape condition than for the other conditions. This result is consistent with the predicted dissociation between letters and nonletters.

The group main effect, $F(3, 56) = 15.68, p < .01$, was explored by a Bonferroni post hoc test. This test revealed that normally reading adults ($M = 490$ ms, $SD = 163$ ms, $p < .01$) were faster than all other groups. Normally reading children ($M = 717$ ms, $SD = 359$ ms) were faster than FWRI dyslexics ($M = 1,032$ ms, $SD = 498$ ms, $p < .01$), but not faster than NWRI dyslexics ($M = 781$ ms, $SD = 354$ ms, $p > .05$). There was a tendency for NWRI dyslexics to be faster than FWRI dyslexics. Using the least significant difference (LSD) post hoc test (which could be applied because of sphericity of the data), this tendency turned out to be significant at the 5% level. The slowness of FWRI dyslexics is in accordance with predictions for this group.

A surrounding and group interaction, $F(6, 112) = 2.2, p < .05$, showed a congruence effect in all groups except in the NWRI group. This is due to the presence of negative congruence effects for letters in this group, which cancels out the congruence effects for nonletters. This was revealed by the triple interaction of material, surrounding, and group, $F(12, 224) = 2.18, p < .05$, displayed in Table 3.

Do normally reading adults replicate previous results?

Table 3 reveals congruence effects for pseudoletters and shapes, but none for letters in normally reading adults. Post hoc analyses within this group revealed, besides a material main effect, $F(2, 28) = 11.51, p < .01$, and a surrounding main effect, $F(2, 28) = 12$, that pseudoletter conditions (504 ms, $SD = 166$) led to higher RTs than letter (481 ms, $SD = 159$; $p < .01$) and shapes (486 ms, $SD = 163$; $p < .01$), for which no difference could be found ($F < 1$). Incongruent conditions (505 ms, $SD = 162$) led to higher RTs than congruent (487 ms, $SD = 156$; $p < .05$) and isolated (479 ms, $SD = 169$; $p < .05$) targets, which did not differ. An interaction between material and surrounding was found, due to the absence of any congruence effect in letter conditions, $F(4, 56) = 5.11, p < .01$. This effect is depicted in Figure 4. This result duplicates for an ISI of 650 ms the one for the short ISI (320 ms) of Lachmann and van Leeuwen (in press), also shown in Figure 4. The result is in accordance with a letters and nonletter processing dissociation in normal adult readers (Ambler & Proctor, 1976).

Normally reading children

Table 3 and Figure 4 indicate that, in contrast with adults, normally reading children show congruence effects for all materials and letters as well as pseudoletters and shapes. Post hoc analysis within this group showed effects of material, $F(2, 46) = 7.16,$
Letters (695 ms, SD = 345) were responded to faster than pseudoletters (735 ms, SD = 373; p < .01) and shapes (721 ms, SD = 356; p < .05), whereas the last two did not differ. For surrounding, F(2, 46) = 15.12, p < .01, RTs were higher for incongruent (746 ms, SD = 371) than for congruent (711 ms, SD = 343; p < .01) and isolated (694 ms, SD = 361; p < .01) targets, which did not differ. No interaction between material and surrounding was found, and this group showed no dissociation between letter and nonletter stimuli.

The result is consistent with the hypothesis that the emergence of a specific feature binding strategy for letters depends on reading expertise. However, this is not the only possible explanation. Many processes involved in reading differ between children and adults (e.g., Ceponiene et al., 2001; Courchesne, 1978; Ehri, 1995; Lachmann et al., 2005; Shafer, Schwartz, Morr, Kessler, & Kurtzberg, 2000). In particular, children are slower than adults overall on this task. This may be for a variety of reasons: maturation of the nervous system, the reading system, the verbal rehearsal system, or even the motor system. Regardless of the causes, the consequence is that they are dwelling longer on the stimuli. Lachmann and van Leeuwen (2008) showed that for normal reading adults, prolonged stimulus duration enhanced the congruence effect in letters. This is because, even if analytical processing of letters is automatized and therefore faster, participants prefer having one uniform strategy over having to switch perceptual integration strategies on a trial-by-trial basis. Longer exposure gave them enough time to adopt a holistic strategy uniformly for letters and shapes. So an alternative explanation may be that children process letters equally holistically as nonletters, because their lack of speed leaves enough time for the holistic image to emerge.

It is possible to test between these two hypotheses by correlating the size of the individual congruence effects for letters with indicators of reading expertise and response times (cf. Au & Lovegrove, 2007). According to the first hypothesis, congruence effect size should be correlated negatively with reading performance. However, effect size failed to correlate with reading tests, neither on the FWR (r_s = −.137, ns) nor on the NWR (r_s = −.225, ns) pretests (parametric correlations are even lower). According to the second hypothesis,

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Material</th>
<th>RT</th>
<th>SD</th>
<th>Error rate</th>
<th>RT</th>
<th>SD</th>
<th>Error rate</th>
<th>RT</th>
<th>SD</th>
<th>Error rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normally reading adults</td>
<td>15</td>
<td>Letters</td>
<td>478</td>
<td>164</td>
<td>5.9</td>
<td>483</td>
<td>161</td>
<td>5.9</td>
<td>483</td>
<td>152</td>
<td>4</td>
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<tr>
<td></td>
<td></td>
<td>Pseudoletters</td>
<td>501</td>
<td>185</td>
<td>9.5</td>
<td>498</td>
<td>150</td>
<td>7.6</td>
<td>515</td>
<td>160</td>
<td>5.4</td>
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<tr>
<td></td>
<td></td>
<td>Shapes</td>
<td>459</td>
<td>156</td>
<td>4</td>
<td>482</td>
<td>155</td>
<td>8.4</td>
<td>519</td>
<td>173</td>
<td>10.9</td>
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<tr>
<td>Normally reading children</td>
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<td>Letters</td>
<td>690</td>
<td>374</td>
<td>9.6</td>
<td>737</td>
<td>353</td>
<td>11</td>
<td>771</td>
<td>385</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pseudoletters</td>
<td>698</td>
<td>378</td>
<td>9.5</td>
<td>724</td>
<td>361</td>
<td>10.3</td>
<td>746</td>
<td>380</td>
<td>14.4</td>
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<tr>
<td></td>
<td></td>
<td>Shapes</td>
<td>694</td>
<td>327</td>
<td>9.7</td>
<td>724</td>
<td>361</td>
<td>10.3</td>
<td>746</td>
<td>380</td>
<td>14.4</td>
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<td>FWRI dyslexics</td>
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<td>Letters</td>
<td>1,006</td>
<td>522</td>
<td>8.5</td>
<td>965</td>
<td>492</td>
<td>11.4</td>
<td>1,059</td>
<td>536</td>
<td>11.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pseudoletters</td>
<td>990</td>
<td>460</td>
<td>8.5</td>
<td>1,015</td>
<td>414</td>
<td>12.1</td>
<td>1,085</td>
<td>500</td>
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<tr>
<td></td>
<td></td>
<td>Shapes</td>
<td>1,016</td>
<td>484</td>
<td>9.9</td>
<td>1,035</td>
<td>514</td>
<td>12.1</td>
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<td>533</td>
<td>11</td>
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<tr>
<td>NWRI dyslexics</td>
<td>11</td>
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<td>745</td>
<td>350</td>
<td>12.3</td>
<td>836</td>
<td>392</td>
<td>14</td>
<td>755</td>
<td>324</td>
<td>14.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pseudoletters</td>
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<td>355</td>
<td>16.2</td>
<td>797</td>
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<td></td>
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<td>361</td>
<td>10.8</td>
<td>842</td>
<td>367</td>
<td>19.3</td>
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</tbody>
</table>

Note: FWRI = frequent-word reading impaired. NWRI = nonword reading impaired. Means and standard deviations in ms; error rates in percentages.
letter congruence effect size should be correlated positively with RTs for the letters condition in our experiment. This effect was confirmed (r_s = .357, p < .05). For comparison, correlations between congruence effects and RTs were marginally significant for pseudoletters (r_s = .301, p < .1) and absent for shapes (r_s = .090, ns). We conclude that the difference between children and normal adults is more likely the result of their slowness on the task than of reading expertise. Hence, the present study fails to show evidence for the dependency of letter-specific visual strategies on reading expertise.

**FWRI children**

Compared to normal reading children, response times in FWRI dyslexics were particularly enhanced. This effect is rather large; an additional analysis revealed that failure to separate the two dyslexic subgroups would still result in a main group effect for the dyslexics as a whole. This might have led to the false impression that a uniform behavioural pattern characterizes the entire dyslexic population. This observation underlines the importance of distinguishing subgroups in experimental reading disability research (see also Becker, Elliott, & Lachmann, 2005).

FWRI dyslexics supposedly have a problem in functional activation, resulting in overall response time delays. The error rate in FWRI dyslexics was found to be similar to that of normal readers. Error rates are not affected by the generic temporal processing deficit in FWRI dyslexics. Unlike normally reading adults and children, this group is not faster with letters than with nonletters. This may be due to a lack in automatization of letter processing in this group.

Within the FWRI group, the factor surrounding, F(2, 20) = 6.75, p < .05, showed higher RTs
for incongruent (1,089 ms, SD = 524) than for congruent (1,004 ms, SD = 475; p < .01) and isolated (1,004 ms, SD = 490; p < .01) targets: congruence effects for both letter and nonletter items. Just like normally reading children, FWRI dyslexics failed to show a dissociation in feature binding effects between letters and nonletters. Size of the congruence effects did not correlate with reading times on the pretests, neither for FWR (r_s = .036, ns), nor for NWR (r_s = −.100, ns), but with RTs for letters (r_s = .800, p < .01). For comparison, these correlations failed to reach significance for pseudoletters (r_s = .182, ns) and geometrical shapes (r_s = .282, ns). With FWRI dyslexics, as with normal children, effects size of the congruence effect is related to their slow processing speed, rather than their lacking reading expertise.

**NWRI children**

NWRI dyslexics were similar to normal readers in their overall RT; there was no general slowing down. These children showed a main effect of surrounding, F(2, 18) = 9.68, p < .01. Isolated (750 ms, SD = 341) targets received faster responses than congruent (806 ms, SD = 369; p < .05) and incongruent (789 ms, SD = 348; p < .5) ones. There was no difference, overall, between congruent and incongruent surroundings (see Table 1). This was due to the interaction of surrounding with material, F(2, 36) = 2.6, p < .05. Surrounding effects were found for shapes (p < .05), which were faster when presented by themselves than when presented in congruent surroundings, and these in turn were faster than shapes in incongruent surroundings. For pseudoletters no surrounding effect was evident. For letters, congruent surroundings produced an increase in RT compared to isolated (p < .05) and incongruent conditions (p < .05), which did not differ (F < 1). Whereas in NWRI dyslexics, nonletters evoked a congruence effect, letters resulted in a negative congruence effect.

The negative congruence for letters is unique to this group (Figure 4). For normally reading adults, negative congruence effects have been found in nonletters (Bavelier et al., 2000; van Leeuwen & Bakker, 1995), as well as in letters (Lachmann & van Leeuwen, 2004; van Leeuwen & Lachmann, 2004). In all these cases, the negative congruence effect reflects the effort required to actively suppress nontarget context information. The effect in NWRI dyslexics, therefore, indicates that they need effort to exclude the surrounding context in single-letter processing.

Unlike both normally reading and FWRI children, the size of the (negative) congruence effect showed a relation to reading expertise, according to the FWR (r_s = −.770, p < .005) and NWR (r_s = −.530, p = .05), but not with RT (r_s = −.176, ns). The larger the reading times, the larger is the size of the negative congruence effect. In other words, the weaker the reading expertise in NWRI children, the more they have to rely on active suppression of the surrounding in order to perform the task.

**CONCLUSION**

We used congruence effects as a yardstick of perceptual feature binding and confirmed a dissociation earlier observed in normally reading adults between letters and nonletter shapes. The dissociation reflects a special visual feature binding strategy for letters in normally reading adults. Normally reading children show no evidence of this specific strategy. Rather than through lack of reading expertise as measured by reading tests, this is because children are slower on the task than adults. This allows time for holistic letter processing (cf. Lachmann & van Leeuwen, 2008).

The comparison of the diagnostic subgroups of FWRI and NWRI dyslexics shows that the former, whom we consider to have generic activation difficulties, show the same pattern as normally reading children, but are much slower overall. In particular, they show the same congruence effects in letters. As in normally reading children, failure of the letter-specific strategy does not depend on lacking reading expertise, but on slowness. NWRI dyslexics, who are thought to find single grapheme–phoneme conversion difficult, show indications of active suppression of surrounding...


REFERENCES


Au, A., & Lovegrove, B. (2007). The contribution of rapid visual and auditory processing to the reading


