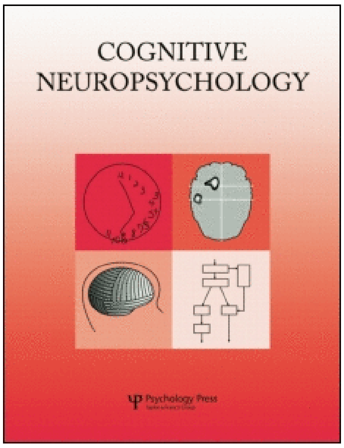

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A dual-route perspective on poor reading in a regular orthography: Evidence from phonological and orthographic lexical decisions

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A dual-route perspective on poor reading in a regular orthography: Evidence from phonological and orthographic lexical decisions

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Impairments of the lexical and the nonlexical reading route were examined for German-speaking dyslexic readers by measuring accuracy and speed of phonological and orthographic lexical decisions. Different from English-based findings, we found little difficulty with the phonological distinction between pseudohomophones and nonwords, but a major difficulty with the orthographic distinction between words and pseudohomophones. Subtyping identified pure surface dyslexia cases but no case of pure phonological dyslexia. Dyslexic speed impairments were traced to three loci in the dual-route model: an impoverished orthographic lexicon, and slow access from orthographic to phonological lexicon entries (lexical route) and from graphemes to phonemes (nonlexical route). A review of distal cognitive deficits suggested that the orthographic lexicon is affected by phonological deficits and that the slow functioning of the lexical and the nonlexical route reflects a general visual-verbal speed impairment and not a purely visual-attentional deficit.

Keywords: Dyslexia; Phonological lexical decision; Orthographic lexical decision; Reading speed impairment; Dual-route model.

A number of studies over the last 15 years documented that dyslexic children in orthographies more regular than English suffer from a pervasive and persistent reading speed deficit but much less from the reading accuracy problem characteristic for "English" dyslexic children (e.g., Dutch: Van den Bos, 1998; Yap & Van der Leij, 1993; German: Wimmer, 1993; Italian: Zoccolotti et al., 1999; Spanish: González & Valle, 2000; Norwegian: Lundberg & Hoien, 1990; Greek: Porpodas, 1999). The reading accuracy advantage of dyslexic children in regular orthographies was

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substantiated in English and German comparisons that used similar words in the two languages/orthographies (Landerl, Wimmer, & Frith, 1997; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). To illustrate, the English dyslexic children (11-year-olds) of Landerl et al. had a problem with the word *character*. Some refused to read it and others produced misreadings ranging from *chancelor* and *calendar* to nonwords such as *tschraekter*. Their German peers, for *Charakter*, produced few misreadings (all nonwords close to the target), but their reading time was between 2 and 3 times higher than normal. Closer focus on the reading speed deficit of children in regular orthographies revealed an abnormal word length effect. Ziegler et al. (2003) found reading latencies of dyslexic German readers (11-year-olds) to increase by about 300 ms for each additional letter in monosyllabic items, and this effect was similar for words and nonwords. An abnormal word length effect was also impressively documented for Italian dyslexic children who, similar to German dyslexic children, exhibit rather accurate reading (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Di Filippo, De Luca, Judica, Spinelli, & Zoccolotti, 2006; Spinelli et al., 2005; Zoccolotti et al., 2005). An abnormal word length effect was also shown in a recent study with Dutch dyslexic children (Martens & De Jong, 2006).

Two different interpretations of the reading speed problem of dyslexic readers in regular orthographies were advanced, and both were framed with reference to the dual-route model of competent visual word processing (for a recent version see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Wimmer (1993) coined the term "phonological speed dyslexia" and proposed that, due to the regularity of German, both normally advancing and dyslexic children rely predominantly on the nonlexical (grapheme–phoneme based) route from print to sound and that dyslexic children are impaired in progressing from laborious serial grapheme–phoneme coding to efficient parallel coding. Zoccolotti et al. (1999) interpreted the similar reading difficulties of their Italian dyslexic children as due to "surface dyslexia"—that is, a specific impairment in establishing an orthographic word lexicon and using it for efficient visual word recognition. The surface dyslexia interpretation for German dyslexic readers is supported by findings showing that the reading speed deficit is frequently accompanied by a spelling deficit (Wimmer & Mayringer, 2002). Spelling problems arise from the asymmetric regularity of German, which is high in the reading but not in the writing direction (see Discussion).

A methodological problem to distinguish between these interpretations in regular orthographies is the absence or small number of exception words. In English and French dyslexia studies an impairment of the lexical route (i.e., surface dyslexia) is diagnosed by preponderance of reading errors for exception words as *yacht* and *choir* and an impairment of the nonlexical route (i.e., phonological dyslexia) by a preponderance of reading errors for nonwords such as *yeft* and *blirt* (English: e.g., Castles & Coltheart, 1993; French: e.g., Sprenger-Charolles, Cole, Lacert, & Serniclaes, 2000). In the English-based studies, depending on criteria, substantial proportions of dyslexic readers showed the phonological dyslexia profile or the surface dyslexia profile. For example, Castles and Coltheart (1993) identified 15% of their dyslexic sample with phonological dyslexia and 20% with surface dyslexia. However, when the dyslexic performance was assessed relative to younger reading-level-matched controls, the proportion of surface dyslexia cases dropped substantially, whereas a substantial proportion of phonological dyslexia remained (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Stanovich, Siegel, & Gottardo, 1997). This led to the interpretation that phonological dyslexia is a profound deviance from normal reading acquisition due to a problem with spoken language, whereas surface dyslexia reflects only developmental delay due to reduced print exposure.

The present study attempted to distinguish between surface and phonological dyslexia among German dyslexic adolescents and young adults by contrasting performance on a phonological lexical decision task with performance on an orthographic lexical decision task. The phonological task (i.e., "Does xxx sound like an existing word?") presented words, pseudohomophones, and nonwords (e.g., *Taxi*, *Taksi*, and *Tazi*), and the orthographic task (i.e., Is xxx correctly written?) presented words and pseudohomophones (e.g., *Taxi* and *Taksi*). Constructing pseudohomophones is not a problem in German, because quite often there is more than one grapheme that regularly relates to the same phoneme. For an accuracy impairment of the nonlexical route, the phonological lexical decision on pseudohomophones and nonwords are relevant as these letter strings find no match in the orthographic word lexicon, and access to the phonological word lexicon has to be mediated by the nonlexical (grapheme–phoneme based) route. For an accuracy impairment of the lexical route, the orthographic lexical decisions on words and pseudohomophones are relevant, as here decisions must depend on whether a letter string does or does not match an entry in the orthographic word lexicon. From the finding that German dyslexic readers (diagnosed by slow reading speed) tend to exhibit high reading accuracy, but poor spelling performance, we expected a low error rate on the phonological lexical decision task and a substantial error rate on the orthographic lexical decision task. This is the opposite of what was found for English dyslexic readers by Olson, Kliegl, Davidson, and Foltz (1985) who contrasted performance on a phonological lexical choice task with performance on an orthographic lexical choice task (see Discussion).

However, of main interest for understanding the reading speed deficit of German dyslexic readers within the dual-route model were the latencies in the phonological lexical decision task. This task presented not only pseudohomophones and nonwords—relevant for assessment of nonlexical route accuracy—but also existing words. This allowed comparison of latencies of the YES response to words (e.g., *Taxi*) with latencies of YES to pseudohomophones (e.g., *Taksi*). Obviously, both a word and its corresponding pseudohomophone access the same phonological word entry and result in the same response. With respect to speed of access to the phonological word lexicon, latencies of phonological lexical decisions may correspond to latencies of reading aloud responses. If German readers, due to the regularity of the orthography in the reading direction, independent from reading level (nonimpaired or dyslexic) rely predominantly on the nonlexical route, then both groups should exhibit little difference between words and pseudohomophones. Furthermore, dyslexic readers—due to an inefficient nonlexical route (i.e., phonological speed dyslexia)—should exhibit a marked latency deficit compared to nonimpaired readers for both words and pseudohomophones. However, the assumption that nonimpaired readers may rely on the nonlexical route even for processing existing words is contradicted by the finding from a recent study from our lab, which found shorter phonological decision latencies for words than for pseudohomophones (Kronbichler et al., 2007). This finding is consistent with the dual-route model of Coltheart et al. (2001), which assumes lexical access to phonology for words and nonlexical access for pseudohomophones. The faster lexical access for words is specifically expected from processing characteristics of the lexical route—that is, all letters of the visual input are processed in parallel, and all entries of the orthographic lexicon in parallel receive excitation or inhibition from the letters. The nonlexical route shares with the lexical one the initial parallel processing of the letter string, but then applies grapheme–phoneme rules to the letter string in a serial mode from left to right. These processing differences imply that, on average, letter strings with a match in the orthographic lexicon have faster access to entries in the phonological lexicon than do letter strings without a match and, therefore, require serial grapheme–phoneme translation. This implication of the dual-route model is supported by English-based findings that showed shorter reading latencies for words than for pseudohomophones (Borowsky, Owen, & Masson, 2002; Grainger, Spinelli, & Ferrand, 2000; Marmurek & Kwantes, 1996).

We assume that the present nonimpaired German readers, similar to the nonimpaired

German readers of Kronbichler et al. (2007), will exhibit faster phonological lexical decisions for words than for pseudohomophones. Of main interest is the performance of the dyslexic readers. We expect that our dyslexic readers will exhibit a marked speed impairment compared to nonimpaired readers on pseudohomophones that require nonlexical route processing. This is suggested by findings showing a marked dyslexic speed deficit for reading aloud nonwords (e.g., Wimmer, 1996). If they rely on the nonlexical route for phonological lexical decision on words, then little latency difference between words and pseudohomophones is expected. This would be a surprising finding. A more plausible result would be that dyslexic readers will exhibit a latency advantage for words over pseudohomophones, but the size of this advantage may be smaller than that for controls. This would be expected from an impoverished orthographic lexicon—that is, when dyslexic readers possess orthographic lexicon entries only for a reduced number of the word items of the present study. Of specific interest will be the performance of our dyslexic readers for words for which the presence of fully specified entries in the orthographic lexicon can be assumed—that is, for orthographically known words that in the orthographic task were correctly distinguished from their corresponding pseudohomophones (e.g., YES to *Taxi* and NO to *Taksi*). If dyslexic readers suffer only from an efficiency impairment of the nonlexical route, then no latency deficit of phonological lexical decisions should be observed for orthographically known words that can be processed by the lexical route.

Method

Participants and general procedure

A total of 20 dyslexic readers (4 female) and 20 age-matched controls (6 female) in the age range from 15–18 years of age (dyslexics: $M = 16$; 11, $SD = 1$; 2; controls: $M = 16$; 3, $SD = 1$; 2) were recruited from two large German-speaking Austrian samples on reading development. The reading instruction received by these samples (synthetic phonics based) and their reading in elementary school have been described in previous papers (Landerl & Wimmer, 2008; Wimmer & Mayringer, 2002; Wimmer, Mayringer, & Landerl, 2000). Participants of these longitudinal studies were asked for participation based on previous reading and IQ scores. They were included in the dyslexic sample when their present reading score corresponded to a percentile below 15 and when they scored within the normal range (i.e., a standard score higher than 7) on two nonverbal subtests (Block Design and Object Assembly) of the German version of the Wechsler Adult Intelligence Scale (WAIS). The present reading assessment relied on a speeded sentence reading test for which currently norm data are collected. This paper and pencil test presents a list of sentences with the instruction to read the sentences quickly and to mark each sentence as meaningful or not. The sentences are of simple content so that erroneous markings are infrequent, and the number of sentences marked within 3 minutes largely reflects reading speed. The norms for the test scores of the participants (i.e., number of correctly marked sentences within 3 minutes) are based on 84 subjects in the age range from 14 to 15 years. Table 1 shows that the mean number of correctly marked sentences of the dyslexic readers was less than half the mean of the controls. The very low mean score of the sample corresponds to a percentile of 5 in relation to the norm sample. This percentile indicates that a majority of the dyslexic sample (despite the inclusion criterion of percentile below 15) suffered from severely impaired reading speed. This reading speed impairment is also evident from the performance on an additional test that required reading aloud a list of words. From the mean word per minute score in Table 1 it is evident that the average reading speed of the dyslexic group was only about 60% of the speed of the nonimpaired readers. The mean error percentage of the dyslexic readers on the word list test was only 2.7%.

For further information on the reading and spelling profile of the dyslexic sample, Table 1 includes data from a previous assessment, which provided accuracy data for reading aloud a short text passage (150 words) under speed instruction

Table 1. *Reading and WAIS standard scores*

Measure		Controls ($N = 20$) *M*	Controls ($N = 20$) *SD*	Dyslexic readers ($N = 20$) *M*	Dyslexic readers ($N = 20$) *SD*	*t*
Reading rate	Silent reading (sentences in 3 min)	55.8	7.0	26.6	4.5	15.6**
	Reading aloud (words in 1 min)	122.2	6.1	72.6	17.5	11.9**
Reading and spelling accuracy	Text reading (% error)[a]	1.0	0.8	5.3	3.5	
	Spelling (% error)[a]	24.7	15.3	71.2	14.7	9.3**
WAIS–Verbal	Digit Span	10.6	1.8	9.2	1.9	2.4*
	Vocabulary	13.5	1.9	11.3	1.7	3.9**
	Similarities	13.3	1.8	12.1	1.8	2.1*
WAIS–Performance	Block Design	12.0	1.6	11.9	1.5	0.2
	Object Assembly	11.6	2.4	12.3	2.6	−0.9
	Digit Symbol	11.6	2.0	9.4	2.4	3.1*

Note: WAIS = Wechsler Adult Intelligence Scale. [a]In each group data of 2 participants missing.
*$p < .05$. ** $p < .01$.

and which also presented a spelling test. As evident from Table 1, the dyslexic participants exhibited few misreadings (only about 5%) but many misspellings. This pattern corresponds to the asymmetric regularity of German orthography, which, like many other orthographies, is more regular in the reading than in the writing direction. For the reading errors no *t* test comparison was done because nearly all controls and the majority of dyslexic participants made no errors.

Table 1 also shows the central tendency measures of the two groups on several subtests of the WAIS. From the means of the standard scores it is evident that the dyslexic participants were above average not only on Block Design and Object Assembly used for selection, but also on Vocabulary and Similarities. However, as shown from the *t* test results, dyslexic readers scored lower than controls on the verbal subtests and also on Digit Span and on the speeded Digit Symbol subtest. All testing was done in our lab and lasted about 2 hours for each participant.

Tasks and materials

Phonological lexical decision task. The instruction for this task was “Does xxx sound like an existing word?”, and participants had to respond quickly with YES when a letter string was pronounced like some real word and with NO otherwise. Each participant saw 336 letter strings with half of the strings (84 words and 84 pseudohomophones) receiving a YES response and half (168 nonwords) receiving a NO response. The pseudohomophones were derived from the words by exchanging one or two letters (e.g., *Taxi* changed to *Taksi*), and the same manipulation was done for 84 of the 168 nonwords (e.g., *Taxi* changed to *Tazi*). The 84 additional nonwords with little similarity to the word items were added to keep the number of YES and NO responses the same. To allow examination of the generality of results, two different item sets (Set A and Set B) were used, and each set was presented to half of the participants in each group. All items are shown in the Appendix.

Orthographic lexical decision task. The purpose of this task was to gain information on orthographic knowledge of those words that were presented in the phonological lexical decision task. Therefore, for each word and for each corresponding pseudohomophone of the phonological lexical decision task, an orthographic judgement was obtained. The instruction was “Is xxx a correctly spelled word?”, and participants had to quickly respond with YES or NO. The nonwords of the phonological lexical decision task were not presented, because we felt that the instruction "Is xxx a correctly spelled word?" only makes sense when the word intended by letter string can be identified. Therefore, the orthographic lexical decision task mimics the usual spelling check routine when for a given phonological word a letter string is produced and is then checked for orthographic correctness. Similar to the phonological lexical decision task, each participant was presented 336 items. Half of the items (i.e., 84 words and 84 corresponding pseudohomophones) were common with the phonological lexical decision task and came either from Item Set A or from Item Set B. Further 168 items (84 words and 84 corresponding pseudohomophones) were added to keep the number of items the same in the phonological and the orthographic lexical decision tasks. These additional items are shown in the Appendix.

Main characteristics of the three item types are shown in Table 2 with the data combined for the two items sets. All words were one- or two-syllable nouns with a length of 3 to 6 characters, and all items started with a consonant letter, which was capitalized in accordance with German spelling convention. Table 2 shows that all three item types were of identical mean length. Pseudohomophones exhibited a slightly lower bigram frequency than words and nonwords, but the differences were not reliable, $Fs(2, 753) < 0.10$; $p > .90$. From the mean and the standard deviation of word frequency in Table 2 it is obvious that there were substantial differences among the word items with respect to frequency. Word and bigram frequencies are based on CELEX data (Baayen, Piepenbrock, & van Rijn, 1993).

Apparatus and procedure

Stimulus presentation was identical for both the phonological and the orthographic lexical decision tasks: Items appeared singly in white on a black computer screen and were preceded by a fixation cross for 500 ms. Items remained visible until a response was provided. A Microsoft Game-Pad was used as response device, and participants used the index fingers of both hands to respond (left and right counterbalanced). For stimulus delivery, timing, and response registration Presentation 0.71 [computer software] was used (Neurobehavioral Systems Inc., Albany, CA, USA. Available from http://www.neurobs.com). The letter size of 10 mm (for upper-case letters) at a distance from the monitor of 70 cm corresponded to letter size in a natural reading situation and resulted in a vertical visual angle of 0.8°. The horizontal visual angle was between 1.5° and 3.7°.

In both tasks the 336 items were presented in two pseudorandomized lists. This allowed counterbalancing of the order with which the two items of a word–pseudohomophone pair were presented. In one list, the sequence was word before pseudohomophone for half of the pairs and the opposite for the other half. In the other list, the order for each pair was reversed. Half of the participants in each group were presented one of the lists. Furthermore, in constructing the lists, close proximity of a word and its pseudohomophone was avoided. Half of the participants in each group started with the phonological lexical decision task, and the other half began with the orthographic lexical decision task. Each task began with 30 practice trials. To reduce intralist priming, the two tasks were separated by a further experiment, which lasted about 20 minutes.

Table 2. *Item characteristics*

	Letters		*Bigram frequency*		*Word frequency*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Words	4.8	0.9	7,049	6,367	39	71
Pseudohomophones	4.8	0.9	6,799	6,398		—
Nonwords	4.8	0.8	6,968	6,367		—

Results

Preliminary analyses

To simplify presentation of main results, several preliminary analyses were done. First, the equivalence of the two item sets was examined by separate analyses of variance (ANOVAs) for each task. An ANOVA for accuracy with item type as within- and item set and group as between-subjects factors found no reliable main effect of item set and also no reliable interaction involving item set, all Fs < 1.32, $p > .273$. Analogous ANOVAs were done for latencies of correct decisions. For these and the following analyses, latencies lower than 300 ms and higher than three standard deviations above the individual mean for an item category were excluded (1.8% of the correct responses). Similar to accuracy, we found no reliable main effect of item set and no reliable interaction involving item set, Fs < 1.18, ps $>$ .285. The absence of reliable interactions involving item set suggests that the theoretically important effects, reported next, generalize over items. For the phonological lexical decision task, it was further shown that the two types of nonwords (similar vs. not similar to the word items) had no reliable effects on latency of correct responses and did not interact with group, all Fs < 1.84, $p > .18$. However, the similar nonwords led to more erroneous YES responses than did the nonsimilar nonwords, $F(1, 38) = 7.82$, $p < .01$ (dyslexics: 12.0% vs. 10.2%; controls: 7.5% vs. 5.5%). For the orthographic lexical decision task it was shown that the two types of word–pseudohomophone pairs (presented vs. not presented in the phonological decision task) did not reliably affect accuracy and latencies of correct responses and did not interact with group, all Fs < 2.31, $p > .14$.

Accuracy of orthographic versus phonological lexical decision

For accuracy of phonological lexical decisions, we counted as correct when on the phonological task both items of each of the 84 corresponding pseudohomophone–nonword pairs received correct judgements (e.g., *Taksi*–YES and *Tazi*–NO), and for accuracy of orthographic lexical decisions we counted as correct when on the orthographic task both items of each of the 168 word–pseudohomophone pairs received correct judgements (e.g., *Taxi*–YES and *Taksi*–NO). Figure 1 shows that the group difference in error rate was small (only 6.7%) for phonological lexical decisions and large (27.0%) for orthographic lexical decisions. The task by group interaction was highly reliable, $F(1, 38) = 30.26$, $p < .001$. Post hoc comparisons found both the markedly increased error rate of the dyslexic group from phonological to orthographic lexical decisions to be reliable (14.1%, $p < .001$), but also the decreased error rate of the nonimpaired readers was reliable (6.3%, $p = .021$). The main effect of group (nonimpaired: 16.4%, dyslexic: 33.2% errors) was also reliable, $F(1, 38) = 32.46$, $p < .001$. The small group difference on the phonological lexical decision task was reliable ($p = .05$). The specifically high error rate of dyslexic readers on the orthographic lexical decision task did not result from specifically fast responding. Actually, dyslexic readers tended to exhibit a

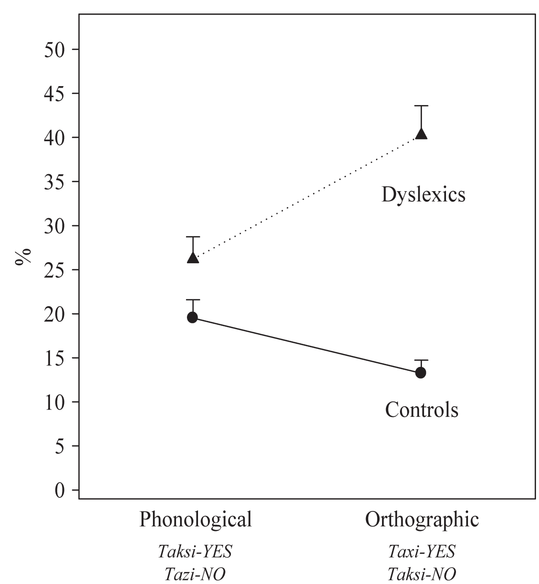

Figure 1. *Means and standard errors of error rates for phonological lexical decisions (pseudohomophone–nonword pairs) and orthographic lexical decisions (word–pseudohomophone pairs).*

larger speed deficit on the orthographic task (nonimpaired readers: 830 ms; dyslexic readers: 1,427 ms; difference: 597 ms) than on the phonological lexical decision task (nonimpaired readers: 1,043 ms; dyslexic readers: 1,568 ms; difference: 525 ms). The interaction between task and group was not reliable, $F(1,\ 38) = 0.50$, $p = .48$, but the main effects of group and task were, $F(1,\ 38) = 36.70$, $p < .001$, and $F(1,\ 38) = 11.87$, $p < .001$, respectively.

Inspection of the phonological lexical decision errors showed that both groups exhibited more erroneous NO responses to pseudohomophones than erroneous YES responses to nonwords (nonimpaired: 12.9% and 7.6%, respectively, dyslexic readers: 15.9% and 12.0%, respectively). Inspection of the orthographic lexical decision errors showed that dyslexic readers were more often misled to respond with YES to the pseudohomophones than with NO to the words (30.1% and 15.4%, respectively). Nonimpaired readers showed each error type about equally often (8.5% and 5.7%). For both groups, orthographic lexical decision performance was substantially associated with spelling test performance, $r(18) = .59$, $p = .010$, and $r(18) = .54$, $p = .021$, for dyslexics and controls, respectively.

A possible concern is that the opposite task effects for dyslexic compared to nonimpaired readers may reflect a difference in sensitivity of the two groups for the effects of response priming. Remember, in the phonological lexical decision task, for half of the word–pseudohomophone pairs, the word item preceded its pseudohomophone so that the YES response to the word (e.g., *Taxi*) may prime the correct YES response to the pseudohomophones (e.g., *Taksi*). The opposite may be the case in the orthographic lexical decision task, where the easy YES response to a preceding word item may interfere with the required NO response to the following pseudohomophone. This response interference could be specifically acute when the orthographic task followed the phonological task (although the tasks did not follow in immediate sequence), because a YES response to a pseudohomophone (e.g., *Taksi*) in the phonological task may interfere with the required NO response to the very same item in the following orthographic task. In short, dyslexic readers may have unduly profited in the phonological and may have unduly suffered in the orthographic task. To examine this concern we limited the analysis to the task presented first (with 10 participants per group), and, for this task, we limited the analysis to only the first occurrence of an item of a word–pseudohomophone pair. Therefore, the "phonological" score combined the percentage of the correct YES responses to the first occurring pseudohomophones and the percentage of the correct NO responses to the first occurring nonwords. Correspondingly, the "orthographic" score combined the percentage of the YES responses to the first occurring words and the percentage of the NO responses to the first occurring pseudohomophones. The error rates for these measures were markedly lower than the error rates for the original measures, but the pattern was close to identical to the original pattern in Figure 1, and the task by group interaction was highly reliable, $F(1,\ 36) = 7.21$, $p = .011$. Again, there was an only small dyslexic deficit on the phonological task with error rates of 12.8% and 9.0% for dyslexic readers and controls, respectively, but a marked dyslexic deficit on the orthographic task with error rates of 18.9% and 5.9%, respectively. Again, as in the original analysis, the error rate of the nonimpaired readers decreased from the phonological to the orthographic task (−3.1%, $p = .21$), but it increased for the dyslexic readers (6.2%, $p = .016$).

Subtyping. A specific accuracy impairment of the lexical route—surface dyslexia—was diagnosed when a dyslexic participant performed worse than 1.64 standard deviations below the mean of the controls on the orthographic task, but in the normal range (not worse than half a standard deviation below the mean of the controls) on the phonological task. The *z*-scores for accuracy of the lexical route were based on the 168 word–pseudohomophone pairs of the orthographic task, and those for accuracy of the nonlexical route on the 84 pseudohomophone–nonword pairs of the phonological lexical decision task. The opposite criteria were used for phonological dyslexia. These strict criteria for pure subtypes identified 7 surface dyslexia cases, but not a single case of phonological dyslexia. A total of 4 cases exhibited deficits on both lexical and nonlexical routes, and 1 case did not reach the impairment criterion for either route. The remaining 8 cases did not exhibit a severe impairment on either route, but lay in between the nonimpairment and impairment criteria. In requiring performance in the normal range for the nonimpaired route we had followed Castles, Bates, and Coltheart (2006). For a less pure diagnosis a standard score worse than 1.64 for the impaired route had to be accompanied by standard score not worse than 1.00. These less pure criteria identified 12 cases of surface dyslexia, but again not a single case of phonological dyslexia. The correlation within the dyslexic group for accuracy of the lexical and the nonlexical route was $r(18) = .57$, $p < .01$.

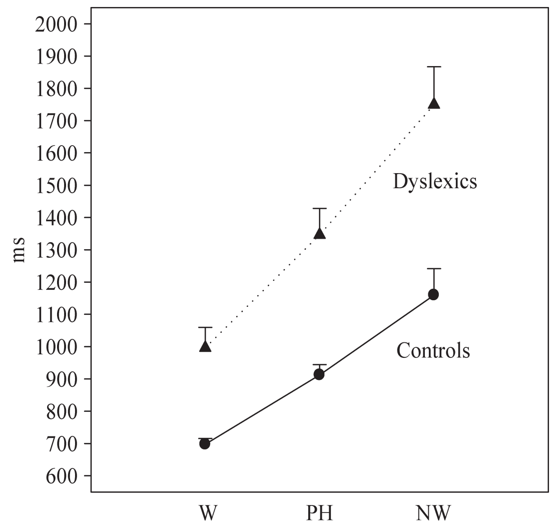

Figure 2. *Means and standard errors of response latencies for correct phonological lexical decisions on words (W), pseudohomophones (PH), and nonwords (NW). Only response latencies of orthographically known words were included (see text).*

Speed of phonological lexical decision

For examining dyslexic speed impairments of the routes from print to sound, we relied on the latencies of phonological lexical decisions. As explained in the Introduction, the comparison between words and pseudohomophones is of particular interest, because the very same phonological word entries are accessed but, potentially, by different routes. Figure 2 shows the latencies of correct phonological decision to the three item types. Only latencies of responses to orthographically known words are included. These are words that were distinguished from their corresponding pseudohomophone in the orthographic lexical decision task. Mean latencies increased from words over pseudohomophones to nonwords and, for all item types, the dyslexic readers responded more slowly. The main effects of item type and group were reliable, $F(1, 38) = 123.64$, $p < .001$, and $F(1, 38) = 21.84$, $p < .001$, respectively. Of main interest are the interactions between item type and group, because from a specific dyslexic impairment of the nonlexical route, a larger speed deficit for pseudohomophones and nonwords than for words is expected. Indeed, reliable interactions with group were found for the word–pseudohomophone contrast and for the word–nonword contrast, $F(1, 38) = 13.95$, $p < .001$, and $F(1, 38) = 8.16$, $p < .01$, respectively. A possible concern is that these interactions are spurious and reflect an over-additivity effect due to the overall higher latencies of the dyslexic readers (Faust, Balota, Spieler, & Ferraro, 1999). To reduce absolute latency differences between the groups, the interaction effects were examined again with log-transformed latency scores and were no longer found to be reliable, Fs < 2, $p > .17$.

Also of interest is that dyslexic readers exhibited faster phonological decisions to orthographically known than to unknown words with means of 997 ms and 1,187 ms, respectively (difference: 190 ms). For nonimpaired readers this difference was smaller with means of 698 ms and 758 ms, respectively (difference: 60 ms) and is based on a small number of orthographically unknown words. The apparent interaction between orthographic familiarity and group was only of borderline significance, $F(1, 38) = 3.77$, $p = .060$. The latency difference between orthographically known and unknown words was highly reliable for dyslexic ($p < .001$) but not for nonimpaired readers ($p = .204$). The main effects of orthographic familiarity and group were reliable, Fs(1, 38) > 14.19, $p < .001$.

Subtyping. A specific speed impairment of the lexical route—surface dyslexia—was diagnosed when, for orthographically known words, a dyslexic participant exhibited a response latency of more than 1.64 standard deviations below the mean of the controls and when his average response latency for pseudohomophones and nonwords was in the normal range (no worse than half a standard deviation below the mean of the controls). The opposite criteria were applied for diagnosing a specific speed impairment of the nonlexical route. In contrast to subtyping based on accuracy, only 1 case of surface dyslexia was identified but again not a single case of phonological dyslexia. A total of 11 cases exhibited a speed impairment of both the lexical and the nonlexical route, and 2 cases did not reach the impairment criterion for either the lexical or the nonlexical route. The remaining 6 cases did not exhibit a severe impairment on either route, but lay in between the nonimpairment and impairment criteria. Application of the less pure criteria (i.e., not worse than 1 standard deviation below the control mean) did not change this finding. The near absence of specific speed impairments for lexical and nonlexical route processes is due to the high correlation between the speed measures for the two routes of $r(18) = .93$, $p < .001$, in the dyslexic sample.

Speed of orthographic lexical decisions compared to phonological lexical decisions

Because the same 84 word–pseudohomophone pairs were presented in both the phonological and the orthographic lexical decision tasks, the speed of correct orthographic lexical decision could be compared to the speed of phonological lexical decision for the same items. The means in Figure 3 show that dyslexic readers exhibited a marked latency increase from phonological to orthographic decision for both words (YES response in both the phonological and the orthographic tasks) and pseudohomophones (YES response in the phonological, NO response in the orthographic task). In contrast, nonimpaired readers exhibited similar phonological and orthographic decision latencies. An ANOVA with task and item type as within- and group as between-subject factors confirmed the interaction between task and group, $F(1, 38) = 7.39$, $p = .01$, which remained reliable for log-transformed latencies, $F(1, 38) = 4.53$, $p < .05$. The main effects of group, item type, and task were also reliable, all Fs(1, 38) > 10, $p < .01$. Importantly, the three-way interaction of task, item type, and group was not reliable, $F(1, 38) = 2.38$, $p = .13$. Averaged over the two item types, the latency increase from phonological to orthographic decisions (256 ms) was large and highly reliable for dyslexic readers ($p < .001$) and small (25 ms) and not reliable ($p = .68$) for nonimpaired readers. Importantly, as evident from Figure 3, the latency increase from phonological to orthographic lexical decisions of the dyslexic readers was similar for words and pseudohomophones. This latency increase for words (with a YES response in both the phonological and the

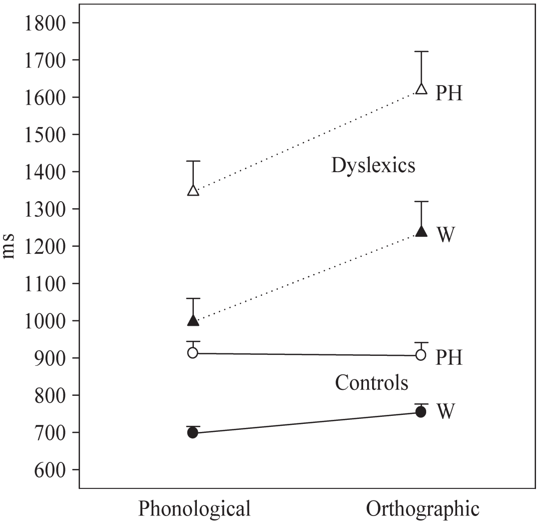

Figure 3. *Means and standard errors of response latencies for words (W) and pseudohomophones (PH) in the phonological lexical decision task and the orthographic lexical decision task.*

orthographic lexical decision tasks) speaks against the possibility that the latency increase for pseudohomophones was due to the change in response from YES in the phonological to NO in the orthographic task, which was the case for half of the 84 items. Furthermore, as noted in the Method section, the two lexical decision tasks were separated by about 20 minutes filled with additional tasks.

Discussion

Accuracy of orthographic versus phonological lexical decisions: Evidence for an orthographic lexicon impairment and an intact grapheme–phoneme system

Corresponding to the well-established findings (mentioned in the Introduction) showing that dyslexic readers in regular orthographies exhibit rather high reading accuracy, the present sample of German adolescent dyslexic readers exhibited an only minor deficit for phonological lexical decisions. The dyslexic error rate for phonological decisions (based on number of correctly judged pseudohomophone–nonword pairs like *Taksi* and *Tazi*) was enhanced by only 6% in relation to nonimpaired readers. In contrast, the dyslexic error rate for orthographic decision (based on the number of correctly judged word–pseudohomophone pairs like *Taxi and Taksi)* was enhanced by 27% compared to nonimpaired readers. Furthermore, for dyslexic readers, the error rates increased from phonological to orthographic lexical decisions (from 26% to 40%), whereas, for nonimpaired readers, the error rates decreased from phonological to orthographic lexical decisions (from 20% to 13%). This pattern speaks for a seriously impoverished orthographic lexicon (required for correct orthographic lexical decisions) in dyslexic readers. In contrast, for nonlexical route processes, that is, grapheme–phoneme conversion and access to the phonological lexicon (required for phonological lexical decisions), they exhibited an only minor deficit. A specific orthographic lexicon deficit of our dyslexic readers was evident not only from the high error rate for orthographic lexical decisions, but also from their poor spelling test performance.

Unexpectedly, our phonological lexical decision task led to substantial error rates in both nonimpaired and dyslexic readers (20% and 26%, respectively). At first sight, this seems inconsistent with our claim that in regular orthographies highly accurate functioning of the nonlexical route is expected. However, a substantial number of the erroneous phonological lexical decision may have been due to task-specific problems. We note that the majority of the erroneous phonological lexical decisions were NO responses to pseudohomophones such as *Taksi.* When only correct negative decisions on nonwords are considered, then the error rates were small with 8% and 12% for nonimpaired and dyslexic readers, respectively. For nonwords, which were not derived from the word items of the present task, error rates were even smaller—that is, 6% and 10% for nonimpaired and dyslexic readers, respectively. Some of the erroneous phonological NO decisions on pseudohomophones may have resulted from a failure to suppress the NO that would result from an automatic orthographic lexical decision, and others may have resulted from overly accurate phonetic readings. For example, reading of *Prot* (intended to sound like the reading of *Brot*–*bread*) with an overly plosive /p/ may have resulted in a NO response because of the deviation from the phonological lexicon entry. Similarly, erroneous phonological lexical YES responses to nonwords may have resulted from similarities with entries in the orthographic or phonological lexicon. We further note that rather accurate reading of nonwords was observed for young German dyslexic readers even under speed instruction (e.g., Wimmer, 1993). These findings suggest that the erroneous phonological lexical decisions of both nonimpaired and dyslexic readers stem primarily from specifics of the task and that the core component of the nonlexical reading route—that is, the grapheme–phoneme rule system—is well established in German dyslexic readers.

The high error rate of dyslexic readers in the orthographic lexical decision task corresponds to their high error rate on the spelling test. The orthographic lexical decision errors resulted primarily from YES responses to pseudohomophones. Both the frequent acceptance of pseudohomophones as orthographically correct and the high rate of misspellings reflect a severely underdeveloped orthographic lexicon in the sense that for a substantial number of words, orthographic lexicon entries were completely missing or did not contain all letters. The underdeveloped orthographic lexicon is remarkable, because even poor readers (diagnosed by slow laborious reading) from about Grade 2 onwards read words quite accurately (e.g., Wimmer, 1993). Therefore, they should experience many self-teaching opportunities (sensu Share, 1995) for storing the letter sequences of successfully decoded words. A striking demonstration of poor orthographic learning by dyslexic children with direct relevance for reading speed was provided by Reitsma (1983). In a learning phase, dyslexic third-graders gained speed by reading repeatedly a number of novel Dutch words. Reading accuracy was not a problem as Dutch shares with German high regularity in the reading direction. Three days after the learning phase, reading latency for the trained words was contrasted with reading latency for corresponding pseudohomophones. The critical finding was that normally reading first-graders were sensitive to the change of letters, whereas the dyslexic third-graders were not. A specific difficulty in storing the letter sequences of words is also suggested by the limited success of studies from our lab that attempted to improve the spelling performance of dyslexic children by inducing the use of spelling pronunciations (Landerl, Thaler, & Reitsma, 2008; Thaler, Landerl, & Reitsma, 2008).

The present German-based dyslexic performance pattern with little deficit for phonological and a major deficit for orthographic lexical decision is exactly the opposite of what was found in English-based studies that, similar to the present study, directly contrasted phonological and orthographic processing of dyslexic children (Manis, Szeszulsky, Holt, & Graves, 1990; Olson et al., 1985; Siegel, Share, & Geva, 1995). An approach, similar to the present one, was used by Olson et al. (1985) who contrasted performance on an orthographic and a phonological choice task. In the orthographic task, the correct alternative of two simultaneously presented items of a word–pseudohomophone pair (e.g., *room–rume*) had to be selected. In the phonological choice task, the alternative sounding like an existing word had to be selected from a pseudohomophone–nonword pair (e.g., *baik–bape*). The large original study by Olson et al. showed that dyslexic readers (age: 9–16 years) committed more errors on the phonological than on the orthographic choice task (33% vs. 18%), and the difference to nonimpaired readers (18% vs. 11%) was larger for phonological than for orthographic choice. In addition, 15-year-old dyslexic readers committed more phonological choice errors than did younger 10-year-old reading-level controls with similar orthographic choice performance. A similar pattern of findings with somewhat different phonological and orthographic tasks was presented by Siegel et al. (1995) as evidence for relatively superior orthographic skills in dyslexic children.

The choice tasks introduced by Olson et al. (1985) may be easier than the single-item lexical decision tasks used in the present study. For example, the present dyslexic participants, who were often misled to accept a pseudohomophone as orthographically correct, may have chosen the correct alternative from simultaneously presented word–pseudohomophone pairs such as *Taxi–Taksi*. However, one would also expect that our single-item phonological lexical decision task is more difficult than the corresponding phonological choice task. Therefore, it is unlikely that opposite result patterns of the present German study and the English studies are due to the different tasks. The difference in grapheme–phoneme regularity between German and English is a more plausible explanation. We further note that the present German result pattern (little deficit for phonological, large deficit for orthographic lexical decision) corresponds to the typical finding that—as a group—German dyslexic readers (identified by abnormally slow reading speed) exhibit a little deficit with respect to correct word readings, but a large deficit with respect to correct word spellings (e.g., Klicpera &

Schabmann, 1993). The reading versus spelling difference most plausibly reflects the asymmetric regularity of German with high regularity in the reading direction, but low regularity in the writing direction. A quantification of this asymmetry (J.C. Ziegler, personal communication, February 20, 2001) used body–rime consistency and found 84% of German monosyllabic words to be consistent in the reading direction from body (all letters of a word starting with the vowel) to rime, whereas only 47% of these words were consistent in the direction from rime to body. To illustrate, each of the different bodies in *Wahl*, *Wal*, and *Saal* maps onto /a:l/, and these mappings are fully consistent but, as obvious from the examples, the rime /a:l/ maps onto three different bodies. For English the corresponding measures for body–rime and rime–body consistency are 69% and 28%, respectively (Ziegler, Stone, & Jacobs, 1997).

Given the result for the whole dyslexic sample (i.e., little deficit for phonological, large deficit for orthographic decision), it is not surprising that our subtyping results are different from the English- and French-based studies mentioned in the Introduction. The mentioned studies found roughly similar proportions of phonological and surface dyslexia cases when subtyping was based on deficits in relation to age-matched controls and a near absence of the surface pattern in relation to younger reading-level-matched controls. Of interest is the comparison of our subtyping findings with those of Castles et al. (2006) because we adopted their criteria, and our dyslexic sample was of similar age to that of their older sample. To repeat, for surface dyslexia, a participant had to perform at least 1.64 standard deviations below the mean of the controls on the orthographic lexical decision task, but had to exhibit close to normal accuracy on the phonological lexical decision task. The converse criteria were used for pure phonological dyslexia. We found 30% and 0% to exhibit surface and phonological dyslexia profiles, respectively, whereas Castles et al. found 12.5% and 9.0%, respectively. The most striking finding is the absence of the phonological dyslexia pattern in our German sample, which, again, most plausibly reflects the high regularity of German grapheme–phoneme correspondences. However, as is shown next, different results were obtained when subtyping was based on speed.

To summarize:

1. German dyslexics were more accurate for phonological than for orthographic lexical decisions and exhibited less of a deficit on the former than on the latter. This is the opposite of findings with English dyslexics.
2. Subtyping of the dyslexic sample based on the error rates for orthographic and phonological lexical decisions found a substantial number of pure surface dyslexia cases but not a single case of pure phonological dyslexia. For English, similar proportions of surface and phonological dyslexia cases were found, and the phonological dyslexia pattern is considered to be the more pervasive problem.
3. In terms of the dual-route model, the present findings were taken to reflect an impoverished orthographic lexicon, but an intact grapheme–phoneme rule system.

Speed of phonological lexical decisions: Dyslexic impairments of both the lexical and the nonlexical route from print to sound

Because slow laborious reading constitutes the hallmark of the reading problem of dyslexic readers in regular orthographies, the speed impairments on the phonological lexical decision task were of specific interest. Several findings are relevant. First, dyslexic readers similar to nonimpaired readers responded faster to orthographically known words than to pseudohomophones, and, similarly, they responded faster to orthographically known words than to orthographically unknown words. In absolute terms, these orthographic familiarity effects were larger for dyslexic than for nonimpaired readers and show that dyslexic readers for familiar letter strings rely on the lexical route from print to phonology. Second, and of main interest, is the finding that, despite this reliance on the lexical route for words, dyslexic readers exhibited much slower phonological lexical decision responses to orthographically known words. (For a similar conclusion based on eye-movement measures see Moll, Hutzler & Wimmer, 2005.) In previous studies with German dyslexic readers, one of us had coined the term “phonological speed dyslexia” to refer to slow serial grapheme–phoneme conversion as specific locus of the reading problem and had assumed that—due to the regularity of German—both nonimpaired and dyslexic readers rely predominantly on the nonlexical route even for high-frequency words (Wimmer, 1993; Wimmer & Mayringer, 2002). The findings of the present study provide evidence for a different characterization. First, the regularity of German does not lead to an overreliance on the nonlexical route as both nonimpaired and dyslexic readers gave clear evidence for reliance on the lexical route for orthographically known words. Second, and of main importance, the phonological speed deficit of the dyslexic readers was not limited to grapheme–phoneme conversion of the nonlexical route. It was similarly present for the lexical route—that is, for accessing existing phonological word entries from orthographic word entries. We note that the same conclusions were reached for Italian dyslexic readers by Barca, Burani, Di Filippo, and Zoccolotti (2006). The Italian dyslexic readers, similar to controls, exhibited a negative effect of context-dependent grapheme–phoneme relations on naming latency for low-frequency words (taken to reflect reliance on the nonlexical reading route), and, again similar to controls, they exhibited no such negative effect for high-frequency words (taken to reflect reliance on the lexical route). However, despite the absence of a grapheme contextuality effect, dyslexic readers exhibited markedly impaired reading speed for high-frequency words.

A further finding was that the dyslexic speed impairment was not limited to phonological lexical decisions on words, but, in absolute terms, was increased for decisions on pseudohomophones and nonwords. This corresponds to the finding from studies that used naming latency measures and found a larger dyslexic deficit for nonwords than for words (e.g., Wimmer, 1996). However, these interactions between lexicality (word–nonword) and reading level may be spurious due to the overall longer reaction times of the dyslexic readers (Faust et al., 1999), and reducing this potential problem for the present study by log transforming response times indeed eliminated the reliability of the item type by reading level interactions. A similar control for overall reaction time differences in an Italian dyslexia study (Di Filippo et al., 2006) also eliminated the lexicality by reading level interaction, but not the word length by reading level interaction. Therefore, we cautiously conclude that the speed impairment of the dyslexic readers was roughly similar for the lexical route (reflected in delayed phonological decision latencies to words) and the nonlexical route (reflected in delayed decision latencies to pseudohomophones and nonwords). This interpretation finds support in the subtyping findings. The speed impairment of the lexical route was based on latencies of phonological lexical decisions on orthographically known words, and the speed impairment of the nonlexical route was based on latencies of phonological lexical decisions on pseudohomophones and nonwords. Based on the same criteria as those for accuracy, only one case was identified with a pure surface profile, and not a single case exhibited a pure phonological dyslexia profile. The majority of the sample exhibited slow speed on both the lexical and the nonlexical route, and the correlation between the *z*-scores for lexical and nonlexical speed impairments in the dyslexic sample was very high. A similar speed deficit of both the lexical and the nonlexical reading route is also suggested by findings with French dyslexic children by Ziegler et al. (2008). This study found reading speed deficits for regular and irregular words and for nonwords with the deficit being largest for irregular words.

To summarize:

1. Dyslexic readers, similar to controls, exhibited faster decision on orthographically known words than on orthographically unknown words and pseudohomophones. This was interpreted as reliance on the lexical route from print to phonology for orthographically known words.

2. A dyslexic speed impairment of the lexical route was inferred from markedly slower responses to orthographically known words. In absolute terms, the dyslexic speed deficit was increased for pseudohomophones and for nonwords that are processed via the nonlexical route.
3. Subtyping based on lexical and nonlexical speed impairments found the majority of cases exhibiting speed impairments on both routes.

An additional finding was that dyslexic readers, different from nonimpaired readers, exhibited markedly prolonged latencies of orthographic lexical decisions compared to phonological lexical decisions. This finding corresponds to the accuracy data by showing a specific difficulty of dyslexic readers with orthographic lexical decision.

For a graphical summary of the interpretations of the present findings, Figure 4 presents the functional architecture of the dual-route model for the present tasks. The close to normal ability of our dyslexic readers to distinguish between pseudohomophones and nonwords in the phonological lexical decision was taken to reflect a fully developed grapheme–phoneme rule system, whereas their marked problem in distinguishing between words and pseudohomophones in the orthographic lexical decision task (together with their poor performance on the spelling test) was taken to reflect an impoverished orthographic lexicon. The speed impairment of dyslexic readers with phonological lexical decisions was traced to three loci in the dual-route model. One is the impoverished orthographic lexicon, which has the effect that dyslexic readers for a comparatively small number of words can rely on the lexical route, which is generally faster than the nonlexical route. The second source is slow access from orthographic word entries to phonological entries. The specific claim is that even for words that find an entry in the orthographic lexicon, access from the activated orthographic entry to the corresponding phonological entry is prolonged. The third source is located in the grapheme–phoneme conversion module of the nonlexical route, and, here, it is specifically the speed with which grapheme–phoneme conversion can be performed. As already explained the high accuracy of nonword reading and the small difference between nonimpaired and dyslexic readers on the phonological lexical decision task speaks against an incomplete or error prone grapheme–phoneme rule system.

In Figure 4, the standard dual-route architecture for reading is extended and includes an orthographic evaluation component to account for the finding that orthographic lexical decisions were as time consuming as phonological lexical decisions (nonimpaired readers) or more time consuming (dyslexic readers). To illustrate the function of this component, let us assume that *Taksi* is presented for orthographic lexical decision. The processing assumptions incorporated in Figure 4 are that the NO response is not resulting from immediately matching the letter string against orthographic lexicon entries, but that the nonlexical route activates the corresponding phonological word entry, which in turn activates the corresponding orthographic word entry, against which the letter string is matched with a resulting NO response. The idea here is that the automatic response of the reading system, when presented a letter string, is to access a phonological word before doing any extras such as checking orthographic correctness. We take the slow orthographic lexical decisions of dyslexic readers as reflection of a more general difficulty with the rapid activation of orthographic lexicon entries from phonological lexicon entries. However, a more natural assessment of such a phonology-to-orthographic speed deficit would be to measure the latency of the writing response to spoken words.

Potential distal cognitive deficits affecting dual-route components

In this section we provide a short review of findings that speak to the issue of distal cognitive deficits in German dyslexic readers that may affect dual-route components. Of relevance is the proposal by Valdois and collaborators that dyslexic readers suffer from a narrow visual-attentional window, which limits the number of letters that can be processed in parallel (e.g., Valdois,

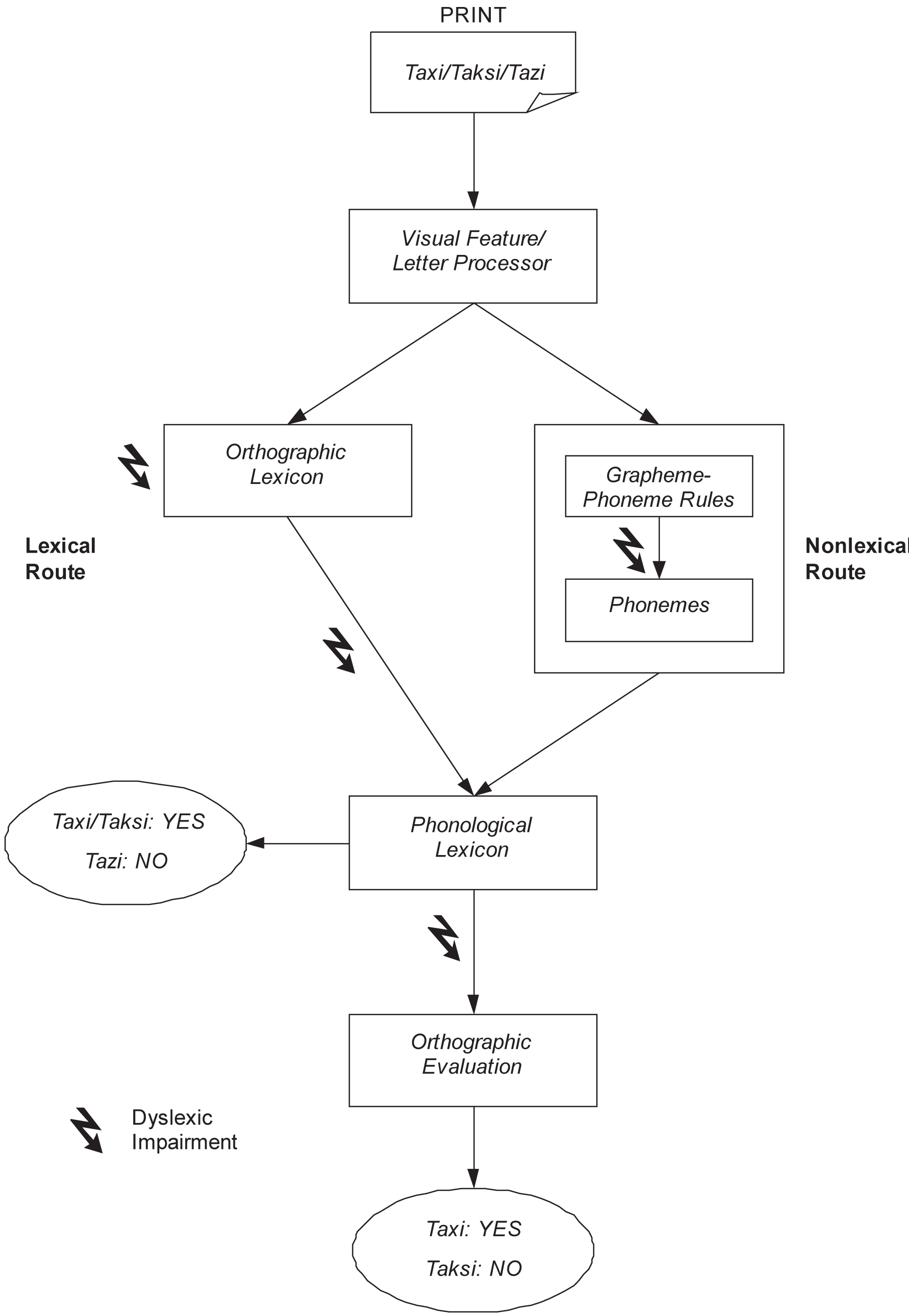

Figure 4. *Functional architecture of the dual-route model for the present tasks including loci for dyslexic impairments.*

Bosse, & Tainturier, 2004, for a review). In this account, the slow speed of both the lexical and the nonlexical route (Figure 4) is due to inefficient functioning of the letter processor, which provides the input both to the orthographic lexicon (lexical route) and to grapheme–phoneme coding (nonlexical route). In two studies inspired by this hypothesis, we indeed found longer presentation time thresholds for dyslexic readers on tasks that presented strings of digits or consonant letters and asked participants to name a single item in response to a position cue after string presentation and a mask (Hawelka, Huber, & Wimmer, 2006; Hawelka & Wimmer, 2005). However, when the naming response requirement was deleted, and participants simply had to detect the presence of a specific letter form in strings, then dyslexics tended to perform faster than nonimpaired readers (Hawelka & Wimmer, 2008). Several further studies from our lab provided negative findings on visual processing impairments of German dyslexic readers (Hutzler, Kronbichler, Jacobs, & Wimmer, 2006; Kronbichler, Hutzler, & Wimmer, 2002; Wimmer & Mayringer, 2001). Based on these negative findings, it seems implausible that the speed impairment of the lexical and the nonlexical route can be traced to a visual-attentional dysfunction.

An alternative distal deficit would be a general speed impairment in accessing phonological representations from visual representations. This would affect the lexical route (i.e., the speed of access from the orthographic to the phonological lexicon) and the speed of grapheme–phoneme coding. There is behavioural and functional neuroanatomical support for this visual–verbal dysfunction. The previously mentioned studies from our lab (Hawelka et al., 2006; Hawelka & Wimmer, 2005, 2008) found a dyslexic deficit on string-processing tasks only when a naming response was required, but not when detection of a letter form was required. Further support for slow access to phonology comes from the large number of studies that found a dyslexic deficit on the rapid "automatized" naming (RAN) tests introduced by Denckla and Rudel (1976), which require rapid naming of long sequences of single digits, letters, pictured objects, or colours (for review see Wolf & Bowers, 1999). Converging evidence from brain-imaging studies speaks for dysfunction of a left occipitotemporal brain region, which is thought to efficiently connect abstract visual-orthographic representations with phonological representations (for a review see McCandliss & Noble, 2003). For German dyslexic readers we found both functional and structural abnormalities in the left occipitotemporal cortex (Kronbichler et al., 2006; Kronbichler et al., 2008). The critical involvement of this brain region for fluent reading is evident from findings showing that lesion of the left occipitotemporal cortex results in letter-by-letter reading of formerly fluent readers (Gaillard et al., 2006).

The rapid naming deficit of dyslexic readers is often subsumed under a general phonological deficit account of developmental dyslexia (e.g., Snowling, 2000). However, the correlations of rapid naming measures with phonological awareness (e.g., phoneme deletion) and phonological memory (e.g., pseudoword repetition) measures are low (Wolf & Bowers, 1999). A recent study from our lab with three large samples found correlations between phoneme deletion and rapid naming to range from .18 to .40, and, importantly, rapid naming was specifically associated with reading fluency, whereas phoneme deletion was specifically associated with spelling (Moll, Fussenegger, Willburger, & Landerl, in press). Similar findings were found in longitudinal studies that used preschool measures of phonological awareness and rapid naming (Landerl & Wimmer, 2008; Wimmer & Mayringer, 2002; Wimmer et al., 2000). An isolated early specific rapid naming deficit (without a phonological awareness deficit) affected the acquisition of both reading fluency and spelling, whereas an isolated phonological awareness deficit affected mainly the acquisition of spelling. A negative effect of phonological awareness deficits on the build-up of orthographic word representations is expected from Ehri (1992) and Perfetti (1992) who suggest that stable orthographic word representations depend on multiple-redundant associations between graphemes and letter clusters of orthographic word representations and sublexical segments of corresponding phonological representation. With respect to the components of the dual-route model of Figure 4 our review of distal cognitive deficits of dyslexic readers suggests that the component labelled visual feature/letter processor is not negatively affected by a distal deficit. The build-up of an orthographic lexicon should be affected by a phonological awareness deficit, and the speed of access from the orthographic to phonological word entries and from graphemes to phonemes should be affected by a general visual–verbal speed deficit.

These considerations suggest a somewhat different role of phonological awareness for learning to read English and for learning to read more typical alphabetic orthographies such as German with rather high regularity in the reading direction. For English, a phonological awareness deficit may be more detrimental as it presumably affects both acquisition of the complex grapheme–phoneme rules of the nonlexical route and the build-up of the orthographic lexicon with the result that dyslexic readers tend to exhibit a massive problem with reading accuracy. For German, a phonological awareness deficit is less detrimental as the rather straightforward grapheme–phoneme relations (required for the nonlexical reading route) can be directly taught. Here a phonological awareness deficit may exert its effect on reading speed and spelling via the orthographic lexicon. Support for the different effects of phoneme awareness and visual–verbal speed on early phases in learning to read English and German was provided by Mann and Wimmer (2002).

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APPENDIX

Items of the phonological lexical decision task

First column: words; second column: pseudohomophones; third column: nonwords; fourth column: English translation. For the orthographic lexical decision task only words and pseudohomophones were used.

Set A

Bad	Baad	Bud	*bath*
Bahn	Baan	Buhn	*railway*
Bart	Bard	Barl	*beard*
Beere	Bere	Blere	*berry*
Biber	Bieber	Bober	*beaver*
Bild	Bilt	Bilb	*picture*
Blatt	Bladt	Blakt	*leaf*
Blech	Plech	Bluch	*sheet*
Blut	Plut	Blit	*blood*
Brand	Brant	Branf	*fire*
Braut	Praut	Zraut	*bride*
Brei	Prei	Krei	*mash*
Brille	Prille	Frille	*glasses*
Dachs	Dax	Damst	*badger*
Draht	Traht	Fraht	*wire*
Fahne	Fane	Fahme	*flag*
Fäule	Feule	Frule	*decay*
Feige	Faige	Fauge	*fig*
Fliege	Flige	Flimge	*fly*
Flöte	Flöhte	Flöme	*flute*
Föhre	Före	Föbre	*pine*
Fuchs	Fux	Funts	*fox*
Fuß	Fus	Fum	*foot*
Gärung	Gerung	Girung	*fermentation*
Geiz	Gaiz	Gniz	*stinginess*
Geld	Gelt	Gelk	*money*
Glätte	Glette	Glutte	*slickness*
Glocke	Klocke	Plocke	*bell*
Grat	Graht	Grak	*ridge*
Grille	Krille	Zrille	*cricket*
Grube	Krube	Frube	*cavity*
Hälfte	Helfte	Hulfte	*half*
Hieb	Hib	Hirb	*hit*
Jux	Juks	Jug	*hoax*
Kaiser	Keiser	Kauser	*emperor*
Keks	Keex	Kels	*cookie*
Kerze	Kertse	Kerpe	*candle*
Kiesel	Kisel	Kirsel	*pebble*
Kind	Kint	Kinf	*child*
Kino	Kieno	Kiro	*movies*
Kitz	Kits	Kutz	*fawn*
Klee	Kleh	Kles	*clover*

Kleid	Gleid	Fleid	*skirt*
Klon	Klohn	Klof	*clone*
Komet	Komeht	Komes	*comet*
Kraft	Graft	Praft	*force*
Krokus	Grokus	Trokus	*crocus*
Leiter	Laiter	Lerter	*ladder*
Luxus	Luksus	Lurus	*luxury*
Malz	Maltz	Malk	*malt*
Mohn	Mon	Mihn	*poppy seed*
Mord	Mort	Morb	*homicide*
Nerz	Nerts	Nerm	*mink*
Pfand	Pfant	Pfank	*deposit*
Plage	Blage	Slage	*plague*
Plan	Blan	Plon	*plan*
Planet	Blanet	Slanet	*planet*
Plasma	Blasma	Klasma	*plasma*
Platz	Plats	Plalz	*place*
Prinz	Brinz	Trinz	*prince*
Prost	Brost	Krost	*cheers*
Pult	Puld	Pulm	*console*
Reh	Ree	Rel	*deer*
Reisig	Raisig	Rensig	*brushwood*
Ritt	Ridt	Rutt	*ride*
Rohr	Ror	Rehr	*pipe*
Rot	Roht	Rof	*red*
Satz	Sats	Sanz	*phrase*
Schlot	Schloht	Schlob	*chimney*
Schule	Schuhle	Schute	*school*
Schutt	Schudt	Schumt	*rubbish*
Sieger	Siger	Sirger	*winner*
Span	Spaan	Spag	*splinter*
Stein	Stain	Staun	*stone*
Stuhl	Stul	Stuhn	*chair*
Teer	Ter	Trer	*tar*
Truppe	Druppe	Fruppe	*troop*
Tumor	Tuhmor	Tugor	*tumour*
Tür	Tühr	Tar	*door*
Vogel	Fogel	Wogel	*bird*
Wärme	Werme	Wirme	*warmth*
Wiese	Wise	Wieme	*meadow*
Zehn	Zeen	Zuhn	*ten*
Zimt	Zimd	Zims	*cinnamon*

Set B

Beet	Beht	Bemt	*patch*
Bett	Bedt	Beft	*bed*
Blase	Plase	Flase	*bubble*
Blitz	Plitz	Klitz	*flash*
Blüte	Plüte	Klüte	*bloom*
Brett	Prett	Krett	*board*
Brief	Brif	Brinf	*letter*
Brise	Briese	Bruse	*breeze*
Bruder	Pruder	Truder	*brother*
Brut	Prut	Krut	*brood*
Bühne	Büne	Bäne	*stage*
Drama	Trama	Grama	*drama*
Feile	Faile	Frile	*rasp*
Feld	Felt	Felb	*field*
Floh	Flo	Flom	*flea*
Friede	Fride	Frinde	*peace*
Fuhre	Fure	Fuber	*load*
Gel	Geel	Gil	*gel*
Gier	Gihr	Gner	*greed*
Gigant	Gigand	Gigank	*giant*
Glück	Klück	Flück	*luck*
Gras	Graas	Gres	*grass*
Grotte	Krotte	Protte	*grotto*
Grund	Krund	Prund	*ground*
Gruß	Grus	Bür	*greeting*
Haare	Hare	Haure	*hair*
Hase	Hahse	Hane	*rabbit*
Hemd	Hemt	Hemf	*shirt*
Herz	Herts	Herk	*heart*
Jäger	Jeger	Juger	*hunter*
Juli	Juhli	Jufi	*July*
Käfig	Kefig	Kofig	*cage*
Kehre	Kere	Kihre	*loop*
Klang	Glang	Flang	*sound*
Klo	Kloh	Klob	*toilet*
Kohle	Kole	Kohne	*coal*
König	Köhnig	Kunig	*king*
Kot	Koot	Kob	*dirt*
Kram	Krahm	Krar	*stuff*
Kritik	Gritik	Fritik	*critique*
Kropf	Gropf	Bropf	*struma*
Kult	Kuld	Kulb	*cult*
Lachs	Lax	Larts	*salmon*
Lanze	Lantse	Lanfe	*lance*
Lehrer	Lerer	Lahrer	*teacher*
Mehl	Mel	Merl	*flour*
Mixer	Mikser	Miber	*mixer*
Moos	Mos	Mols	*moss*
Mund	Munt	Munk	*mouth*
Nixe	Nikse	Nibe	*mermaid*
Papst	Pabst	Pamst	*pope*
Pferd	Pfert	Pferk	*horse*
Pilot	Piloht	Pilut	*pilot*
Pirat	Piraht	Pirut	*pirate*
Planke	Blanke	Glanke	*plank*
Preis	Breis	Treis	*price*
Probe	Brobe	Trobe	*sample*
Propan	Bropan	Dropan	*propane*
Rätsel	Retsel	Rutsel	*riddle*
Ruder	Ruhder	Fakur	*rudder*
Saal	Sal	Sool	*hall*
Saat	Saht	Saut	*seed*
Säbel	Sebel	Subel	*sword*
Säure	Seure	Säute	*acid*
Schund	Schunt	Schunf	*trash*
Sold	Solt	Solk	*pay*
Sprint	Sprind	Sprant	*sprint*
Sprit	Spritt	Spril	*spirit*
Stahl	Staal	Staul	*steel*
Stand	Stant	Stanf	*stand*
Stiege	Stige	Stinge	*stairs*
Sturz	Sturtz	Sturp	*downfall*
Taifun	Teifun	Trifun	*typhoon*
Tatze	Tatse	Tatre	*paw*
Taxi	Taksi	Tazi	*taxi*
Trafo	Drafo	Krafo	*transformer*
Träne	Dräne	Präne	*tear*
Trieb	Trib	Trerb	*drive*
Vater	Fater	Mafer	*father*
Vier	Fier	Lier	*four*
Wald	Walt	Walb	*wood*
Wiesel	Wisel	Wirsel	*weasel*
Zelt	Zeld	Zelk	*tent*
Zug	Zuhg	Zeg	*train*

Additional nonwords of the phonological lexical decision task

Bensch	Fopf	Laft	Pfub	Schulf	Törper
Berme	Frital	Lampf	Pisch	Schuni	Tresam
Bift	Fütte	Lerbe	Plirn	Solka	Waspel
Bleik	Galp	Loo	Premme	Sot	Wieb
Botz	Gause	Mabrik	Priege	Spau	Wips
Broch	Grein	Maub	Prohn	Spee	Worf
Brug	Hage	Mee	Prupe	Spoppel	Wotel
Dack	Hürze	Melm	Pultur	Spuf	Wucker
Dapier	Karkt	Micht	Rafik	Stinn	Zacht
Darze	Keber	Mirma	Ras	Stuch	Zasser
Dater	Kelpe	Mopf	Ropf	Sube	Zau
Delt	Ketall	Nurm	Runk	Taus	Zose
Ferk	Knoker	Päge	Sahr	Tenf	Zwad
Fesse	Knuch	Päune	Schäte	Thoden	Zwiff

Additional words and pseudohomophones of the orthographic lexical decision task

Bier	Bir	*beer*	Hose	Hohse	*trousers*	Pute	Puhte	*turkey*
Blau	Plau	*blue*	Huf	Huuf	*hoof*	Rad	Raad	*wheel*
Blei	Plei	*lead*	Hupe	Huhpe	*horn*	Rahmen	Ramen	*frame*
Boden	Bohden	*floor*	Kalk	Kalck	*lime*	Reis	Rais	*rice*
Boot	Boht	*boat*	Kater	Kahter	*tomcat*	Riemen	Rimen	*belt*
Bräune	Breune	*tan*	Keiler	Kailer	*boar*	Säge	Sege	*saw*
Brezel	Prezel	*pretzel*	Kiesel	Kisel	*pebble*	Schuft	Schufd	*villain*
Brösel	Prösel	*crumb*	Klotz	Klots	*log*	Schuld	Schult	*guilt*
Brot	Prot	*bread*	Kluppe	Gluppe	*clip*	Silo	Sielo	*silo*
Brust	Prust	*chest*	Knolle	Gnolle	*lump*	Sitz	Sits	*seat*
Bub	Buhb	*boy*	Koma	Kohma	*coma*	Skalp	Skalb	*scalp*
Bude	Buhde	*booth*	Krieg	Krig	*war*	Sohn	Son	*son*
Bug	Buhg	*bow*	Kur	Kuhr	*cure*	Sport	Spord	*sport*
Dieb	Dib	*thief*	Kurve	Kurfe	*curve*	Strahl	Stral	*beam*
Diesel	Disel	*diesel*	Leiste	Laiste	*strip*	Streik	Straik	*strike*
Dotter	Dodter	*yolk*	Liebe	Libe	*love*	Stück	Stükk	*piece*
Fahrt	Faart	*trip*	Lücke	Lükke	*gap*	Tee	Teh	*tea*
Fehler	Feler	*error*	Meißel	Maißel	*chisel*	Thema	Tema	*theme*
Fliese	Flise	*tile*	Mütze	Mütse	*cap*	Therme	Terme	*hot springs*
Frack	Frakk	*tailcoat*	Netz	Nets	*net*	Trafik	Drafik	*tobacconist*
Fuge	Fuhge	*seam*	Paar	Pahr	*pair*	Tropf	Dropf	*drip*
Führer	Fürer	*leader*	Pelz	Peltz	*fur*	Vieh	Vih	*cattle*
Gala	Gahla	*gala*	Pilz	Pilts	*fungus*	Wand	Want	*wall*
Gen	Geen	*gene*	Pizza	Pitza	*pizza*	Zahl	Zal	*number*
Gift	Gifd	*poison*	Plombe	Blombe	*plumb*	Zierde	Zirde	*ornament*
Glas	Glaas	*glass*	Pratze	Pratse	*claw*	Zone	Zohne	*zone*
Gott	Godt	*god*	Praxis	Braxis	*practice*	Zoo	Zoh	*zoo*
Hefe	Heefe	*yeast*	Prunk	Brunk	*pomp*	Zucker	Zukker	*sugar*