Dyslexia in Regular Orthographies: Manifestation and Causation

Heinz Wimmer* and Matthias Schurz

Department of Psychology and Center for Neurocognitive Research, University of Salzburg, Salzburg, Austria

This article summarizes our research on the manifestation of dyslexia in German and on cognitive deficits, which may account for the severe reading speed deficit and the poor orthographic spelling performance that characterize dyslexia in regular orthographies. An only limited causal role of phonological deficits (phonological awareness, phonological STM, and rapid naming) for the emergence of reading fluency and spelling deficits is inferred from two large longitudinal studies with assessments of phonology before learning to read. A review of our cross-sectional studies provides no support for several cognitive deficits (visual–attention deficit, magnocellular dysfunction, skill automatization deficit, and visual–sequential memory deficit), which were proposed as alternatives to the phonological deficit account. Finally, a revised version of the phonological deficit account in terms of a dysfunction in orthographic–phonological connectivity is proposed. Copyright © 2010 John Wiley & Sons, Ltd.

**Keywords:** dyslexia; reading fluency; orthography; phonological awareness; naming

**INTRODUCTION**

The present article deals with two questions. First, what is the nature of the reading difficulties in an orthography (German) with regular grapheme–phoneme relations and, second, what are the perceptual and cognitive deficits, which may cause these difficulties. To answer these questions we

*Correspondence to: Heinz Wimmer, Department of Psychology and Center for Neurocognitive Research, University of Salzburg, Hellbrunnerstr. 34, 5020 Salzburg, Austria. E-mail: Heinz.Wimmer@sbg.ac.at
review our research performed during the last 20 years. The main focus will be on the phonological deficit explanation of dyslexia, which is the dominant account endorsed by organizations such as the World Health Organization, the International Dyslexia Association, or the National Institute of Child Health of the USA. The present review of our German-based research can be seen as an examination of the generality of the largely English-based dyslexia research. Recently, Share (2008) questioned this generality by arguing that ‘the extreme ambiguity of English spelling-sound correspondence has confined reading science to an insular, Anglo centric research agenda, addressing theoretical and applied issues with limited relevance for an universal science of reading’ (p 584). Our review will support Share’s critique, specifically with regard to the manifestation of reading difficulties and in respect of the causal role of phonemic awareness. However, we will also show that the phonological deficit explanation fares better than rival deficit accounts, and in the final section, we propose a modification of this explanation in terms of a deficit in phonological–orthographic connectivity.

**MANIFESTATION**

Obviously, high regularity of an orthography in the reading direction from letters to sounds should have a marked effect in the initial phase of learning to read, when children encounter many new words and have to rely on phonological (i.e. grapheme–phoneme based) decoding for reading these words. Indeed, our German–English comparisons of young readers found an enormous advantage for German (Frith, Wimmer, & Landerl, 1998; Wimmer & Goswami, 1994). This regularity advantage was further documented in studies comparing a substantial number of regular European writing systems with English (Aro & Wimmer, 2003; Seymour, Aro & Eskrine, 2003). Early success with self-reliant phonological decoding is obviously advantageous for orthographic learning, that is, for storing the letter sequences of successfully decoded words or recurring larger parts of words, and for using these orthographic recognition units for fast visual word processing. A side effect of early success with phonological decoding is its positive effect on the acquisition of phoneme awareness. To illustrate, decoding successfully the letter sequence BROT (bread) provides insight that the consonantal onset of ‘bro:t’ is composed of two specific phonemes. In correspondence with this, we found rapid emergence of phoneme awareness in beginning readers who, due to the absence of reading preparation in kindergarten, typically exhibit no or little phoneme awareness before learning to read (Mann & Wimmer, 2002; Wimmer, Landerl, Linortner, & Hummer, 1991).

If acquisition of self-reliant word decoding is rather easy, then massive difficulties should be rare. Indeed, we found that only about 1% of our samples at the end of Grade 1 exhibited more or less complete reading failure (Landerl & Wimmer, 2008; Mayringer, Wimmer & Landerl, 1998; Wimmer & Hummer, 1990). These children typically knew the letter sounds but were unable to ‘blend’ the sounds into syllables. In less severe cases, assembly of phonemes was performed extremely slowly, with errors due to short-cutting effortful decoding (Wimmer, 1996). After Grade 1, poor readers were found to exhibit primarily a severe reading fluency problem and no marked difficulties with decoding accuracy.
(Wimmer, 1993). This discrepancy to English-based dyslexia research led to a German–English dyslexia comparison (Landerl, Wimmer, & Frith, 1997). The difference in reading accuracy was dramatic. For low-frequency words, accuracy was about 93% correct for German compared with only about 50% for English. Similar results were found in a further German–English dyslexia comparison by Ziegler, Perry, Ma-Wyatt, Ladner, and Schulte-Körne (2003) who elegantly demonstrated an abnormal prolongation of reading onset latencies with increasing word length (i.e. number of letters) for German and English dyslexic children. To illustrate, for each additional letter in monosyllabic words, reading onset latencies increased by about 300 ms for the dyslexic German sample and even more so for the English sample. This abnormal word length effect was also documented impressively by eye-movement and reading time data for Italian dyslexic readers who, similar to German, exhibit little difficulty with reading accuracy (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; Spinelli et al., 2005; Zoccolotti et al., 2005).

The reading fluency deficit of our dyslexic readers was found to be highly persistent (Landerl & Wimmer, 2008) and hard to remediate (Thaler, Ebner, Wimmer, & Landerl, 2004). Furthermore, it was found for all types of reading tasks including silent reading for meaning in an eye-movement study (Hawelka, Gagl, & Wimmer, 2010), reading aloud of lists of words and pseudowords (e.g. Landerl, 2001), and lexical decisions on singly presented items (Bergmann & Wimmer, 2008). A substantial proportion of our speed impaired dyslexic readers also exhibited severe spelling difficulties, but their misspellings tended to be phonetically acceptable (Wimmer & Mayringer, 2002). One may wonder how misspellings can arise in a ‘regular’ orthography. The answer is that German—similar to other orthographies—is quite regular only in the reading direction (from graphemes to phonemes) but not in the writing direction (from phonemes to graphemes). Of interest is that fluency impaired reading was also found in children with about average spelling performance (Moll & Landerl, 2009; Wimmer & Mayringer, 2002). Furthermore, prolonged reading onset latencies were also found for words for which the correct letter sequence was known (Bergmann & Wimmer, 2008). These findings show that impaired reading speed cannot be simply taken to reflect absent orthographic word representations, which are required for fast whole-word recognition.

CAUSATION

In this section, we summarize evidence that speaks to cognitive deficits proposed in causal explanations of dyslexia. Our evidence consists of comparisons between dyslexic and nonimpaired samples and, therefore, cannot provide a definitive evaluation of the causal hypotheses. Specifically, presence of an expected deficit provides only limited support as other causal influences may not be controlled for. Absence of the expected deficit—a common result in our studies—carries a stronger implication as it speaks more definitively against the causal hypothesis that predicted the deficit. We note that cognitive deficits constitute only one level in common causal models of dyslexia. These models, in addition to the cognitive deficit, also include a neuroanatomical and a genetic level of explanation (e.g. Morton, 2004; Ramus, 2004; Snowling, 2000).
The Phonological Deficit Explanation

As already noted, dyslexia is prominently seen as following a difficulty in the acquisition of spoken language, and specifically as resulting from a dysfunction of the phonological component of language. In an authoritative statement summarizing the largely English-based evidence, Lyon, Shaywitz, and Shaywitz (2003) noted: ‘...there is now strong consensus among investigators in the field that the central difficulty in dyslexia reflects a deficit within the language system ... a deficit in phonology represents the most robust and specific ... correlate of reading disability.’ (p 7). In its dominant version, the explanation posits that an impairment of spoken language phonology hinders children to become aware of phonemes as segments of spoken words. Without awareness of phonemes, letters of written words cannot be mapped on their corresponding phonological segments. This affects the extraction of grapheme–phoneme rules, which are critically involved in the acquisition of self-reliant word decoding. The difficulty with decoding of novel letter strings is seen as the main hurdle for dyslexic children in learning to read, and may secondarily affect the build-up of the orthographic word lexicon (Share, 1995). Variants of this account of dyslexia in terms of a causal developmental chain of cognitive deficits are formulated by the mentioned causal explanatory frameworks (Morton, 2004; Ramus, 2004; Snowling, 2000). The critical role of phoneme awareness for difficulties in learning to read an alphabetic orthography was put forward prominently more than 30 years ago by phoneticians with statements such as ‘segmenting the speech wave in discrete terms’ constitutes a ‘fundamental barrier to reading acquisition’ (Gleitman & Rozin, 1977) or ‘...the reader and writer must be something of a linguist—able, at the very least, quite deliberately to divide utterances into the constituent segments that are represented by the characters of the orthography’ (Liberman, 1982).

The mentioned findings on the manifestation of dyslexia in German raised doubts about the validity of this version of the phonological deficit explanation, as the rather accurate decoding of our dyslexic readers is difficult to reconcile with a phoneme awareness deficit affecting extraction of grapheme–phoneme rules and acquisition of decoding. Our alternative suggestion was that phonological impairments may specifically affect the speed with which sublexical or lexical phonology can be accessed during visual word processing (Wimmer, 1993). Sticking to the phonological framework, we coined the term phonological speed dyslexia for the typical German manifestation of the reading difficulties.

Longitudinal Studies on the Influence of Phonological Awareness (PA) and Rapid Automatized Naming (RAN) Deficits on Reading and Writing Difficulties

In the following, we summarize results from two large longitudinal studies that assessed deficits of PA and RAN as part of a larger screening at school entrance, and reading and spelling performance about 3 years later (for details see Wimmer, Mayringer, & Landerl, 2000). The inclusion of RAN in the screening battery was based on the extension of the phonological deficit explanation by Wolf and Bowers (1999) who proposed a deficit in rapid naming as reflecting an
an additional causal factor in the emergence of reading difficulties. Obviously, a visual–verbal speed deficit seemed quite plausible, given the ‘German’ manifestation of dyslexia.

The first study included 530 children (only boys) and the second one included about 300 children (boys and girls) from regular classrooms. Our phonological awareness tasks had to be simple, because—due to the absence of reading preparation with letters in kindergarten—our children tend to exhibit floor effects on traditional phoneme awareness tasks, such as phoneme deletion before school (for a comparison with American children see Mann & Wimmer, 2002). In the first study, we relied on the detection of onsets and rhymes, as awareness of these segments precedes awareness of phonemes (Goswami & Bryant, 1990). To illustrate, a typical rhyme item was ‘What rhymes with Feld: Gold or Geld?’ In the second longitudinal study, each item of our PA task presented a word and its phonemic segments (e.g. ‘Fee -/f/-/e/’) and children had to repeat the word and its phonemes. The idea was that children with a nascent sensitivity for phonemes would be better on this task. Obviously, these PA tasks also make demands on verbal short-term memory, which in addition to PA is assumed to be compromised in children with a general phonological deficit. The RAN task presented five highly familiar pictured objects in the RAN format.

Figure 1 is based on the results of Wimmer et al. (2000) and informs to what extent deficits at school entrance affected reading and spelling acquisition. Following Wolf and Bowers (1999), we distinguished between three subtypes.

![Diagram showing reading fluency and spelling deficits in Grade 3 of children with single or double phonological deficits at school entrance (Study 1: 530 boys and Study 2: 301 boys and girls).](image_url)

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The phonological subtype exhibited a deficit on the PA tasks (below percentile 16), but not on the RAN tasks. The naming deficit subtype exhibited the opposite pattern, and the double-deficit subtype scored poorly on both the PA and the RAN tasks. Figure 1 contrasts the deficit on the defining measures for each subtype (for Study 1 only) with the deficit for text reading speed and for orthographic spelling about 3 years later (for both Study 1 and 2). Because text reading accuracy was generally close to ceiling, it is not included in Figure 1. The results are presented in terms of effect sizes, that is, Cohen’s $d$ (Cohen, 1988). A $d$-score of $-1$ implies that the mean of the deficit sample was about 1 SD (combined SDs of deficit and control samples) below the mean of the control sample. A first observation from Figure 1 is that a substantial number of children exhibited single deficits on either the PA or the RAN task. For example, in Study 1, more than 60 children exhibited such a single deficit and only 25 children exhibited both a PA and a RAN deficit. It should be further noted that the single deficit groups could be clearly separated. To illustrate, the single PA deficit subtype of Figure 1 exhibited absolutely no RAN deficit, and the same applies to the single-RAN-deficit group. However, the main observation from Figure 1 is that the very large deficits (effect sizes of about $-3$) on the PA and/or the RAN tasks at school entrance were followed by comparatively small deficits for reading fluency and spelling. Even the double-deficit group exhibited effect sizes only of about $-1$, suggesting that only about half the children exhibited reading fluency and/or poor spelling performance in the range below percentile 16. Specifically, disappointing from the perspective of the phonological deficit explanation of dyslexia is the very limited effect of the phonological awareness deficit. The majority of children with a single PA deficit exhibited no subsequent reading or writing deficit. Furthermore, an early PA deficit, in addition to the RAN deficit, did not substantially increase the size of the moderate reading and spelling deficits shown by the group with a single RAN deficit.

Figure 2 is based on Wimmer and Mayringer (2002) who retrospectively examined, for the two longitudinal studies, precursors of reading and/or spelling deficits. Again three subgroups were distinguished. The single reading deficit group exhibited poor reading fluency (below percentile 16) but not a marked spelling deficit. The single spelling deficit group exhibited the opposite pattern and the reading and spelling deficit group scored below percentile 16 on both measures. Figure 2 shows how the three reading/spelling subgroups performed on the precursor measures at school entrance. In addition to the already mentioned PA and RAN tasks of Study 1 and 2, Figure 2 also presents results from phonological STM tasks that were included in the school entrance screening. The STM task of Study 1 asked for repetition of pseudowords that consisted of three syllables and required distinction between similar consonants (e.g. ‘bowiba’ or ‘fiwofi’). In Study 2, children had to repeat sequences of two or three monosyllabic pseudowords (e.g. ‘tes-bof’ or ‘gat-fos-hap’).

The results of the retrospective analyses correspond to the results of the predictive analyses. The main finding, evident from Figure 2, is that the large deficits on the reading and/or spelling measures were preceded by comparatively small deficits on the school entrance measures. Specifically surprising was the finding that the single reading deficit subgroups of both Study 1 and Study 2 exhibited neither a preceding PA deficit nor a preceding phonological STM deficit and exhibited a mild RAN deficit only. In contrast, the
subgroups suffering from a single spelling deficit or from a double reading and spelling deficit exhibited PA and phonological STM deficits of moderate size with effect sizes of around $-1$ and below $-1$, respectively. As expected, the reading and spelling deficit subgroups also consistently exhibited RAN deficits of about $-1$. (For a recent replication and extension of these dissociations between reading rate and spelling deficits on the one hand and cognitive deficits on the other, see Moll & Landerl, 2009).

In summary, the longitudinal findings summarized in Figure 1 and 2 show that many children with PA and/or RAN deficits at the beginning of reading instruction did not exhibit any serious reading and spelling problems about 3 years later and, conversely, many children with reading fluency and/or spelling difficulties did not exhibit preceding phonological and RAN deficits. This summary based on effect size measures finds further support in a classificatory analysis performed by Mayringer, Wimmer, and Landerl (1998) for Study 1. In this analysis, we used the school entrance measures (including prominently PA, phonological STM, and RAN) to select at-risk groups for dyslexia. An assessment at the end of Grade 1 was used to select a group with early difficulties in the acquisition of phonological recoding in reading and writing. This poor
reading/writing group at the end of Grade 1 included 9% of the total sample of more than 500 boys. We found that only about 40% of the poor reading/writing group came from the at-risk group, even when risk rate was doubled compared with case rate. When the risk rate was equal to the case rate, then about 30% of the phonological at-risk children were among the poor reading/writing group. This rate is more than tripled compared with the case rate of 9%, but still implies that the large majority of the children with phonological and rapid naming deficits at school entrance did not exhibit early difficulties with the acquisition of phonological reading and writing.

Cross-Sectional Studies on Cognitive Deficits

In this article, we present results of a number of cross-sectional studies from our lab, which measured the cognitive deficits at the same time as the reading deficits. Again we measured deficits in phonological awareness, phonological memory, and in rapid naming. However, several of our studies were devoted to the measurement of deficits proposed by alternative explanatory accounts of dyslexia (see below). Different from measurements of cognitive deficits at school entrance, concurrent measures may be affected by reduced reading experience of the dyslexic readers, and therefore, may overestimate cognitive deficits.

The youngest samples were tested at the end of Grade 2 (Wimmer, Mayringer, & Landerl, 1998) and the oldest in Grade 7 (Kronbichler, Hutzler, & Wimmer, 2002). The main inclusion criterion for selecting the dyslexic samples was a score below percentile 16 on a reading test measuring primarily speed (e.g. number of sentences correct within 3 min). A substantial proportion of the dyslexic readers, identified by a reading speed impairment, also suffered from poor spelling. The main exclusion criterion was a nonverbal IQ score below 85. For three studies, the data from dyslexic subgroups were combined (Moll & Landerl, 2009; Wimmer, 1993; Wimmer & Mayringer, 2001). Further details on sample selection and on tasks are given in the original studies.

Figure 3 illustrates, for one of our cross-sectional studies, the large size of the reading speed deficit (resulting from the inclusion criterion) and also shows that the size of the accompanying spelling deficit was similar to the size of the reading rate deficit. The first section includes data from a variety of traditional PA tasks. The rhyme task asked for identification of the odd one in sequences of four words with items such as ‘Grube, Stube, Hupe, Tube’. Items for the phoneme deletion tasks were ‘Mond without/n/’ (word item) or ‘gulst without/l/’ (pseudoword item). The vowel substitution task asked for replacement of the vowels with/i/, for example, ‘Rosine’ resulting in ‘Risini’. The spoonerism task asked for exchange of initial consonants in items such as ‘Gold–Silber’ resulting in ‘Sold–Gilber’.

The main observation from Figure 3 is that the size of the concurrent PA deficits varied from small for rhyme oddity detection to substantial for the spoonerism task. For an additional assessment of phoneme awareness, dyslexic participants had to write pseudowords (Landerl & Wimmer, 2000; Wimmer, 1993). The writing task has several advantages compared with some of the traditional phoneme manipulation tasks such as spoonerism. The task format is highly familiar and problems of working memory and executive control are
reduced. On the other hand, correct phonetic transcription of pseudowords involves not only phonemic analysis but also recoding of phonemes into graphemes. The results from these tasks are not included in Figure 3 because nonimpaired samples scored at ceiling (with minimal SDs), and even the dyslexic samples scored close to ceiling. To illustrate, Landerl and Wimmer found that their dyslexic sample wrote about 90% of the pseudowords correctly with each of the pseudowords containing two consonant clusters (e.g. 'gluwisp' and 'flamont'). The close to ceiling performance for transcribing pseudowords stood in marked contrast to an accuracy of only 30% correct on the spoonerism task of Landerl et al. (1997). We will come back to dyslexic deficits on difficult PA tasks.

Figure 3. Cognitive deficits of dyslexic children compared with age-matched controls. (1) Wimmer (1993); (2) Landerl, Wimmer, and Frith (1997); (3) Wimmer, Mayringer, and Landerl. (1998); (4) Landerl (2001); (5) Wimmer and Mayringer (2001); (6*) Kronbichler, Hutzler, and Wimmer (2002); (7*) Hawelka and Wimmer (2005); (8) Hawelka and Wimmer (2006); (9*) Hutzler, Kronbichler, Jacobs, and Wimmer (2006); (10*) Hawelka and Wimmer (2008); (11) Moll and Landerl (2009). *Participants are drawn from our longitudinal studies.
tasks in the final section and offer a potentially interesting interpretation in terms of a deficit in orthographic–phonological connectivity. The section on phonological STM deficit exhibits a rather consistent pattern of only small deficits.

The section on visual–verbal deficits shows dyslexic performance on RAN tasks, paired-associate learning tasks and on letter string processing tasks which required a verbal response. The common feature of all these tasks is that both visual and verbal processing is involved. Figure 3 shows that the deficits on RAN tasks ranged from small for colour naming to substantial for digit naming, with a clustering around an effect size of $-1$, implying that about half of the samples exhibited poor RAN performance. For the RAN deficits it is important to note that they result primarily from prolonged gaps between the articulations and not from a prolongation of the articulations (Jones, Obregón, Kelly, & Branigan, 2008). In the visual–verbal paired-associate learning task, children were asked to learn pseudonames for pictured fantasy animals over a sequence of learning and test trials (Wimmer, Landerl, & Mayringer, 1998; see also Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Mayringer & Wimmer, 2000). The dyslexic deficit on this paired-associate learning task was larger than the deficits on the short-term pseudoword repetition tasks in the preceding section of Figure 3. Finally, the section on visual–verbal deficits presents the results from two visual string processing studies which employed a partial report task (Hawelka & Wimmer, 2005; Hawelka, Huber, & Wimmer, 2006). These studies presented strings of digits or consonant letters in a word-like format and, following a short mask, cued one of the positions for verbal report. The critical measure was the presentation time threshold required for reliable report of a single digit or letter. Figure 3 shows substantial deficits on these string processing tasks with verbal response.

Our string processing studies with verbal response were inspired by the visual–attentional span deficit hypothesis of Valdois, Bosse, and Tainturier (2004). This proposal assumes that dyslexic readers are limited in the number of letters that can be processed in parallel. This proposal is of interest as it quite nicely accounts for the generally impaired reading speed of our dyslexic readers, and specifically for the abnormal prolongation of reading time with increasing word length (i.e. number of letters). However, we were concerned that the dyslexic deficits on our tasks may arise from difficulties with the verbal demands of the partial report paradigm, that is, with quick activation of the names of the digits/letters and keeping the names and their sequence in short-term memory. To avoid this potential confound of visual attention and speed of name retrieval, we eliminated the verbal component in a further study (Hawelka & Wimmer, 2008) which presented a target (letter or pseudoletter) together with a five-element string and measured target detection time. Results from this string-processing tasks with target detection are shown at the beginning of the section on visual–attentional tasks in Figure 3. In contrast to the substantial deficits on the string processing tasks with partial report, no deficit was found for target detection. This pattern is difficult to reconcile with a visual–attentional span deficit and speaks more for a difficulty with the verbal demands of the partial report tasks. This negative conclusion on a visual–attentional deficit finds further support in the near absence of a dyslexic deficit on a variety of visual string-processing tasks, which are also shown in the section on visual–attentional tasks in Figure 3. The identity task measured the time to decide whether or not the unfamiliar (Greek) letters in singly presented strings were all the same. The letter search task of an eye-movement
study required a decision whether, in strings of consonant letters, two adjacent letters were identical. The absence of deficit on these visual tasks is of general importance. It seems inconsistent with other visual deficit assumption such as visual magnocellular deficit hypothesis prominently formulated by J. Stein (e.g. Stein & Walsh, 1997) or the sluggish visual attention hypothesis of Facocetti, Turatto, Lorusso, & Mascetti (2001). The absence of a dyslexic deficit on the mentioned visual speed tasks speaks against a general deficit of processing speed as proposed by Kail, Hall, and Caskey (1999) and it also rules out that the dyslexic deficit on the RAN tasks is due to the visual component of the task. Finally, the section on visual-attention includes the finding from a visual short-term memory task, which did not include a speed component. Each trial of the task presented the sequential build-up of a sequence of unfamiliar Greek letters (item length 3–5 letters) and the task was to reproduce the sequence by pointing to the letters in a correct order. As evident from Figure 3, dyslexic readers exhibited no deficit on this task, which seems inconsistent with a deficit of visual short-term memory (e.g. Romani, Olson, and Ward, 1999). Such a visual-memory deficit would have plausibly accounted for the difficulties of our dyslexic readers with the formation of orthographic word representations (i.e. with storing the letters of specific words).

In the final section of Figure 3, we present findings from studies that examined sensory and motor deficits. Sluggish visual attention (Hari & Renvall, 2001, and similarly Facocetti et al., 2001) was examined by a precedence detection task which asked which of two horizontal bars (left and right of fixation point) had arrived first, and measured the minimally required gap for correct detection. A visual magnocellular dysfunction (Stein & Walsh, 1997) was assessed by a coherent motion detection task. For assessment of an auditory magnocellular dysfunction, we relied on the illusory sound movement task of Hari and Kiesilä (1996). Figure 3 shows that our dyslexic readers exhibited no deficit on any of these perceptual tasks. Consistent with the absence of an auditory dysfunction are results of Wimmer, Mayringer, and Landerl (1998) who found no dyslexic deficits on natural speech perception tasks. One task required repeating short sentences, which were masked by increasing levels of background party-noise. A second task presented two different sentences simultaneously by a male and a female voice. One of the voices was cued, and participants had to repeat the sentence from the speaker. Finally, Figure 3 further shows no dyslexic deficit on the balancing tasks used by Nicolson and Fawcett (1990) to measure a general dyslexic deficit in skill automatization due to a cerebellar dysfunction. In this article, we should add that a deficit was found for a subgroup of children suffering from both dyslexia and ADHD (Raberger & Wimmer, 2003).

Conclusions on Causation by Cognitive Deficits

As evident from the final section of Figure 3, our findings are negative on proposals postulating sluggish visual attention, generally impaired processing speed, magnocellular dysfunctions, or a deficit of skill automatization as causal factors for the emergence of developmental dyslexia. The result pattern was clear-cut: our dyslexic samples exhibited severely impaired reading speed (and accompanying spelling deficits) but performed similarly to nonimpaired readers on the tasks measuring the mentioned deficits. This is not the final verdict on the
mentioned proposals, but our negative findings must raise doubts about the
generality of the proposed distal deficits as causes of dyslexia. There are no
obvious reasons for explaining the discrepancy between our negative results and
the positive results of the original studies.

Our findings are less negative with respect to the validity of the phonological
deficit explanation, which is positing a phoneme awareness problem, and of the
double-deficit explanation of Wolf and Bowers (1999), which is positing a rapid
naming deficit in addition to a phoneme awareness deficit. However, support for
these explanations is limited in the sense that the deficits accounted for the
difficulties of not more than maximally about half the dyslexic dyslexic samples.
Even the double-deficit subgroups with both the PA and the RAN deficits at
school entrance exhibited only moderate reading and spelling deficits (effect sizes
around −1) 3 years later. Similarly, the subgroup with both a reading rate and a
spelling deficit after about 3 years in school, exhibited only moderate deficits on the
phonological and rapid naming measures at school entrance. Furthermore, only
about 30–40% of phonological at-risk groups at school entrance exhibited poor
reading/writing performance at the end of Grade 1. This conclusion of a limited
causal influence of phonological deficits on the emergence of reading and spelling
difficulties has to be qualified. It may only apply when circumstances are quite
favourable for learning to read and to write. By favourable, we mean that the
orthography offers rather simple and regular grapheme–phoneme correspondences,
and that a systematic synthetic phonics teaching approach aims at inducing self-
reliant word reading via assembled pronunciations. Furthermore, accessing stored
word phonology by assembled pronunciations may be optimal for rapid acquisition
of high-level phoneme awareness. The argument would be that under such
favourable circumstances even many children with some forms of a phonological
deficit may have a successful start into reading and writing.

A New Hypothesis: Dyslexia Resulting from Reduced Orthographic–Phonological
Connectivity

The field of dyslexia research obviously does not suffer from a paucity of
explanatory hypotheses. Nevertheless, we would like to add an additional one. It
is based on the findings of very substantial deficits of dyslexic readers on tasks
such as spoonerism in both German and English dyslexic children (see Figure 3).
Recently, a high error rate and very slow performance on a spoonerism task was
also documented for Italian dyslexic readers (Menghini et al., 2010). As already
noted, we do not consider these difficulties as reflecting a problem of phoneme
awareness, as commonly assumed by phonological deficit theorists. Against this
interpretation, we pointed out that dyslexic children with poor performance on
tasks such as spoonerism have no difficulty with phonemically correct
transcriptions of complex pseudowords with consonant clusters.

The difficulty of tasks like spoonerism for dyslexic children may offer a clue to
an overlooked deficit, which may have to do with reduced neurocognitive
connectivity between orthographic representations and phonological ones. Let us
illustrate the role of orthographic–phonological connectivity for the performance
on the spoonerism task. We assume that this task is rather easy when for an item
such as ‘exchange the initial sounds of gold and silver’, orthographic images of
the critical words get automatically activated (followed by exchange of the initial letters and by reading out of the result). In contrast, the task poses serious difficulties when performed without imagined orthographic word representations. The critical difference may be how tightly orthography and phonology is integrated, so that hearing a word in this task context automatically activates its orthography.

The evidence for tight orthographic–phonological integration in competent readers is impressive. Rhyme judgements on spoken words were shown to be misled when items such as ‘pitch’ and ‘rich’ do not share identical rhyme spellings (Seidenberg & Tanenhaus, 1979). Similarly, phoneme counting is misled by the number of letters with more phonemes counted for ‘pitch’ than ‘rich’ (Ehri & Wilce, 1980). Phoneme deletion was found to be misled by orthography as, for example, competent readers were found to respond with ‘hot’ when asked to delete the first sound of ‘what’ (Landerl, Frith, & Wimmer, 1996). Further evidence for tight orthographic–phonological integration is the finding that orthographic intrusions occur automatically, and competent readers were found to have little control over avoiding such intrusion (Castles, Holmes, Neath, & Kinoshita, 2003).

To our knowledge, there are only two studies that examined orthographic intrusions into phonological judgements of dyslexic readers (Bruck, 1992; Landerl et al., 1996). Both found that dyslexic readers were less misled than competent readers although the dyslexic readers knowledge of the correct spellings of the critical words was controlled. For example, in Landerl et al.’s (1996) study dyslexic readers less often responded with ‘hot’ or ‘hat’ when deleting the first sound of ‘what’ and they less often responded with ‘lin’ when deleting the final sound of ‘line’. Consistent with the present proposal, both Bruck (1992) and Landerl et al. (1996) interpreted their finding of infrequent orthographic intrusions shown by dyslexic readers in PA tasks as reflection of reduced integration of orthographic and phonological representations.

The hypothesis of poor phonological–orthographic integration is of interest for functional and structural neuroanatomical brain research, as it suggests impaired neural connectivity between regions engaged by orthographic processes and regions engaged by phonological processes. The idea of a disconnection between otherwise intact brain areas for vision and language in dyslexic readers was first put forward by Geschwind (1965). Recently, diffusion tensor imaging has become a tool, which allows non-invasive assessment of structural brain connectivity in terms of white-matter tract integrity. There are first reports suggesting abnormalities of the left hemisphere tracts that connect occipito-temporal brain regions engaged by visual-orthographic processes with temporo-parietal and the left inferior frontal areas engaged by phonological processes (e.g. Beaulieu et al., 2005; Deutsch et al., 2005; Richards et al., 2008). Consistent with impaired phonological–orthographic connectivity in dyslexic readers are functional imaging findings—some with German dyslexic readers (Kronbichler et al., 2006; van der Mark et al., 2009; Wimmer et al., in press)—which showed reduced reading-related activation in a left ventral occipito-temporal brain region, which is assumed to function as interface between high-level visual orthographic codes and phonology and meaning. Reduced reading-related activation in the left occipito-temporal cortex was also found in a quantitative review of functional imaging studies on dyslexia (Richlan, Kronbichler, & Wimmer, 2009). Also
consistent with the impaired orthographic–phonological connectivity in dyslexic readers are studies by the group around Leo Blomert in Maastricht, who found reduced modulation of left temporal regions when letter sounds were presented simultaneously with corresponding or non-corresponding letters (Blau, van Atteveldt, Ekkebus, Goebel, & Blomert, 2009).

In conclusion, the proposal that an impairment of orthographic–phonological connectivity may constitute a core deficit of dyslexia has advantages. With appropriate elaboration, it will allow integrating the somewhat diverse manifestations of dyslexia in regular and less regular orthographies, and it offers theoretical linkages to brain research. Last, but not the least, it provides coherence to the field, as it does not give-up basic insights of the phonological deficit explanation.

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