Word-recognition processes in normal and dyslexic readers

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Reading, the ability to convert written into spoken word forms, has become an increasingly crucial prerequisite to functioning adequately in modern society. However, up to 10% of all school-age children are estimated to experience difficulties in learning to read (Vellutino, Fletcher, Snowling, & Scanlon, 2004). In The Netherlands, the prevalence of specific reading disabilities, or dyslexia, is estimated to be between 4% to 8% (Blomert, 2005; van der Leij et al., 2004).

Although a century of scientific studies on reading has resulted in a remarkable accumulation of knowledge (Snowling & Hulme, 2007), the reading process is still not fully understood, and there is certainly no standard cure for dyslexia. Therefore, the aim of the current thesis was to further expand the understanding of visual word-recognition processes in normal and dyslexic readers. In particular, I focused on the causes that might underlie the slow and laborious reading that is commonly observed in dyslexic children.

In this thesis, computational models of skilled word-reading (e.g., the Dual-Route Cascaded (DRC) model, Coltheart et al., 2001, and the Connectionist Dual Process (CDP+) model, Perry, Ziegler, & Zorzi, 2007) were taken as a framework for formulating hypotheses about and for examining proximal causes of word-recognition problems in dyslexic readers. Because, and in contrast to developmental theories like the phase theory of Ehri (1992; 1998) and the self-teaching hypothesis (Share, 1995), these models are very explicit in describing the processes that precede the recognition of a word.

Within the DRC and CDP+ models a distinction is made between a lexical and sublexical route in word and pseudoword recognition. In the sublexical route, letters or graphemes are processed one-by-one in a sequential left-to-right fashion. Therefore, extra reading time will be required for each additional letter or grapheme in a word or pseudoword. In contrast, in the lexical route, all letters of a word are processed in parallel and immediately trigger the orthographic representation of the word in the orthographic lexicon. As a result, the number of letters in a word, or word length, does not affect the reading time.

The lion’s share of the current thesis (Chapters 2 to 5) focused on sublexical processes in word recognition in normal and dyslexic readers. Important issues
concerned the size of the functional units in word recognition and potential differences between normal and dyslexic readers in the use of these units. Finally, in Chapter 6, differences in lexical processing were examined. Below I will describe the separate studies and their outcomes.

The study in Chapter 2 examined the use of sublexical clusters in normal and dyslexic readers. The main focus was on consonantal-onset clusters (e.g., the *st* in *stop*), however, the use of rimes (e.g., the *op* in *stop*) and digraphs (e.g., the *ou* in *soup*) were also considered. A segmentation paradigm, the separation of two adjacent letters in a word by a nonletter symbol, was used to investigate whether children used letter clusters in reading (e.g., *s#top*). The hypothesis was that the effect of this distortion on reading would be larger if two adjacent letters functioned as a cluster. In the first part of the study, naming and lexical decision tasks were administered to 24 normal reading and 24 dyslexic grade-4 children. In the second part of the study, the same tasks were administered to 24 skilled adult readers. The results did not support the use of consonantal onsets and rimes during reading. However, it was found that digraphs were used, because their distortion (e.g., *so#up*) had a relatively large effect on reading speed. This effect was found to be similar in normal and dyslexic readers.

In Chapter 3, the special status of digraph units and possible differences between normal and dyslexic readers was further examined with a letter-detection task. Both normal and dyslexic readers were found to be slower in detecting a letter within a vowel digraph (e.g. the *a* in *peach*) than in detecting a letter of a single-letter grapheme (e.g. the *a* in *spark*). In addition, and in line with the findings in Chapter 2, the dyslexic children were slowed down to a similar degree as the normal readers when detecting a letter embedded in a digraph. Finally, the slower response to target letters embedded in a digraph was position-independent in both reading groups (i.e., the children were equally fast in detecting an *e* in *boek* or *beuk*). Together with the findings in Chapter 2, these results indicate that both normal and dyslexic readers process vowel digraphs as perceptual units.

As there appeared to be no differences between normal and dyslexic readers in the earlier processing of digraphs, the focus was shifted towards a later step in the word-recognition process, namely the subsequent linking of the digraph unit to the corresponding phoneme. The assumption that digraphs are visually parsed as perceptual units before they are mapped onto their corresponding phonemes, is also relevant for the nature of the length effect. The length effect refers to the finding that longer words and pseudowords are read more slowly than shorter ones. If digraphs are treated as perceptual units, then the length effect should be based on grapheme length instead of on letter length. This hypothesis was addressed in the next chapter.

The study in Chapter 4 aimed to disentangle the effects of length and digraph presence. Normal, beginning and dyslexic readers completed a word and pseudoword reading task consisting of items varying in length (3 to 5 letters) with
and without digraphs. In line with previous studies, it was found that dyslexic and younger readers showed stronger length effects than normal readers. Interestingly, however, these length effects indeed seemed to be based on the number of graphemes, and not on the number of letters. This implies that both normal reading and dyslexic children decode words and pseudowords grapheme by grapheme and not letter by letter, and provides further support for the assumption that graphemes, and therefore also digraphs, are the functional units of print. In addition, it was found that the presence of a digraph causes an extra delay on top of the grapheme-length effect in all reading groups, but only in pseudoword naming. Interestingly, this effect was stronger in beginning and dyslexic readers than in normal reading children. Hence, it was concluded that dyslexic children do experience difficulties in mapping the corresponding phoneme onto a digraph, explaining, in part, their slower reading speed.

In Chapter 5, the series of studies on sublexical processing was concluded with a training study that aimed to improve the reading speed of poor grade-2 readers. The training consisted of eight sessions in which four consonantal onset clusters (\(st\), \(gr\), \(bl\) and \(tr\)) were explicitly taught as blended units. The rationale behind this approach was that still a potential alternative explanation for the finding that the children in the first study (Chapter 2) only seemed to use digraphs and not consonantal onset clusters and rimes as functional units in reading had to be ruled out. Namely, it might have been the case that consonant clusters are not used as functional units because they are not explicitly taught as units in Dutch education. Therefore, 99 poor grade-2 readers were selected and divided among three training conditions: a cluster-training condition, a letter-training condition and a no-training control condition. Although the children of the cluster-training condition made significantly more progress on the rapid naming of the trained consonantal onset clusters than the other two groups, their increase in word-recognition speed was not superior to that of the letter-training condition. This implies that even explicit training of consonantal onset clusters does not result in faster reading and provides further evidence that the use of sublexical clusters does not seem to be a causal mechanism in the development of word recognition speed.

Finally, in Chapter 6, potential differences in lexical processing in normal and dyslexic readers were examined by measuring the influence of orthographically similar candidates on word and pseudoword naming performance. A useful metric for the number of such candidates is orthographic neighbourhood size (N-size). The orthographic neighbourhood of a given word represents all existing words that can be created by replacing one of its letters for another one (Coltheart, Davelaar, Jonasson, & Besner, 1977). Examples of orthographic neighbours of \(sand\) are \(land\), \(hand\), but also \(send\), \(said\) and \(sang\). In skilled readers, the joint activation of these visually similar words in the orthographic lexicon generally speeds up the reading of a target word.

In the study in Chapter 6 the dyslexic readers were found to be equally sen-
sitive to orthographic neighbourhood size in both word and pseudoword naming as the normal readers, that is, they responded less accurately and more slowly to pseudowords from a low neighbourhood size and equally fast to words from a low and high neighbourhood size. This finding suggests that lexical processing is intact in dyslexic readers. However, in contrast to the normal grade-4 readers, it was also found that the naming speed of the dyslexic and beginning readers was significantly slowed down if a word had a high-frequent neighbour. These results suggest that the orthographic representations of dyslexic children are less strongly specified or insufficiently distinct from similar candidates in the mental lexicon. Additional evidence for problems in lexical processing was found in Chapter 4.

In this study, dyslexic readers’ intra-individual variability in word recognition was found to be larger than that of both chronological-age as reading-age controls. Interestingly, the largest difference in variability with the normal readers was found for short words. Such higher intra-individual variability also suggests that the retrieval of lexical or orthographic knowledge is less stable in dyslexic children.

In Chapter 7, the implications of the results of the current thesis for theories on reading development and computational models of reading were discussed. In addition, it was evaluated what the current thesis has taught us about differences in visual word-recognition processes in normal and dyslexic readers. Finally, it was stressed that the results of the current thesis are not only of theoretical, but also of practical importance. Based on the results of the studies in Chapters 2 and 5 as well as previous studies (Das-Smaal, Klapwijk, & van der Leij, 1996; Hintikka, Landerl, Aro, & Lyytinen, 2008; Huemer, Landerl, Aro, & Lyytinen, 2008; Levy, 2001; Thaler, Ebner, Wimmer, & Landerl, 2004; van Daal, Reitsma, & van der Leij, 1994), it may be concluded that stimulating the use of sublexical clusters is not a fruitful way to increase word-reading speed in children learning to read in languages with a transparent orthography. In addition, the finding that both beginning and dyslexic readers are hampered by the presence of high-frequent neighbours (Chapter 6), also questions the feasibility of practicing words in a context of highly similar words, which is typically done with “word-family lists”. Word family lists are a popular educational method in Dutch and English classrooms. Word family lists consist of words that are blocked by, for instance, onset cluster (e.g., stop, step, stuff, still) or rime (e.g., ban, fan, pan, ran). It might be that children need to practice highly similar words together in order to finetune their orthographic representations. However, in the case of dyslexic and beginning readers it might also be that the subsequent presentation of highly similar words interferes with the development of orthographic representations.

The joint results of the studies in the current thesis have advanced our knowledge about what does and does not explain the slow and laborious reading in dyslexic readers. On the one hand, dyslexic readers do not seem to have specific problems in early visual-parsing processes. In other words, they are equally proficient as their normal reading peers in processing digraphs as perceptual units,
and just like normal readers they do not use consonantal onset clusters and rimes as units in reading. Based on the latter result and the results of the cluster training study it was concluded that stimulating the use of sublexical clusters has no value in increasing reading speed. On the other hand, dyslexic children do seem to have specific problems in mapping earlier parsed digraphs onto their corresponding phonemes. This finding may partly account for their slower word-recognition speed. In addition, dyslexic readers are hampered by the presence of a high-frequent neighbour and their word-recognition performance for the simplest three-letter words was found to be more variable than in normal younger readers. These findings suggest that the orthographic representations of dyslexic readers are less stable, less strongly specified and probably less distinct from similar candidates in the orthographic lexicon than in normally developing readers.