The role of orthographic and phonological processing in dyslexia and reading

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Chapter 6 General discussion

First, the main findings of the studies according to the three themes described in the General introduction will be addressed. Subsequently, the implications of these results will be discussed regarding theory, practice, and future research, concerning the role of orthographic processing, the persistence of the problems, and heterogeneity among dyslexics.

6.1 Review of main findings

6.1.1 Orthographic processing as an important predictor

The present thesis dealt with three main themes. The first theme regarded the important role for orthographic processing in addition to phonological processing as a predictor of reading fluency. This thesis demonstrated that in all age-groups, middle childhood, young adolescents, and adults, orthographic processing played an important role in predicting word reading fluency. Chapter 2 considered this in more detail, showing that in the longitudinal study regarding Grade 2 to Grade 4, orthographic processing was an important predictor of polysyllabic word reading fluency, in addition to an increasing role for rapid serial naming, a stable role for phoneme awareness, and initial level of vocabulary. Except the contribution of vocabulary the same was true for predicting pseudoword reading fluency.

In a sample of young adolescents consisting of dyslexics and control readers, a regression analysis on word reading fluency was performed in Chapter 3. Because of moderate correlations and the results of the factor analysis, phoneme awareness and rapid serial naming were treated as a phonological composite factor. First, vocabulary and phonological recoding were entered to serve as control variables, followed by the phonological composite that did not predict word reading fluency in young adolescents. However, orthographic processing, a composite of word-specific

orthographic knowledge in both Dutch (L1) and English (L2), and fast identification of larger orthographic units (brief exposure task) contributed to the prediction. Additionally, important to note is that when phonological recoding was excluded, both phoneme awareness and rapid serial naming explained variance, whereas there still was variance left for orthographic processing. In a similar adult sample a regression analysis to predict word reading fluency was performed (Chapter 4). In this sample, orthographic processing was a composite of word-specific orthographic knowledge (both Dutch L1 and English L2) and the time to perform these tasks. Orthographic processing was an additional predictor after verbal ability, phoneme awareness, and rapid serial naming were partialed out.

6.1.2 Universality of phonological processing deficit

The second theme was to examine the universality and stability of phonological processing deficits across age. Chapter 3 investigated this for young adolescent dyslexics. All young adolescent dyslexics had lower performances on phoneme awareness (i.e., manipulating speech sounds), and rapid serial naming (i.e., fast lexical access and retrieval of well-known symbols). It is important to note that there were no differences on verbal ability and vocabulary of Dutch and English between the dyslexics and control readers. This is also the case for the adult dyslexics, which was discussed in Chapter 4. The dyslexic adults performed inferior compared to the control adults, on all tasks, including phoneme awareness and rapid serial naming. However, on verbal and spatial ability they performed similar to the controls. Even when the adult dyslexics were compared to reading age controls from the second grade of secondary school, who were matched on word reading fluency, they performed worse on phoneme awareness, and rapid serial naming, and on pseudoword reading fluency. Finally, when the core deficit was investigated among poor readers from Grade 4 (primary school) and Grade 7 (first class of secondary school) again a core deficit in phoneme awareness and rapid serial naming emerged, without differences in

vocabulary. When poor readers were compared across four different age-groups, Grade 4, 7, 10, and adults (see Chapter 5) poor readers from mid-primary school (Grade 4) were weaker in phoneme awareness than the older poor readers. The older poor readers performed similar on phoneme awareness. This resulted in relatively stable differences between typical and poor readers in phoneme awareness, because the older typical readers did not progress as well. The poor readers in mid-primary school (Grade 4) and adults were comparable in rapid serial naming, and they performed slower than the secondary school students (Grade 7 and 10), whereas the typical readers did improved into end of secondary school. There was a larger gap between typical and poor readers in reading fluency at later ages independent of frequency, language (words, pseudowords, and English words), and in rapid serial naming.

6.1.3 Heterogeneity among dyslexics

The last major theme of the present thesis concerned the heterogeneity among dyslexics. The first approach was to extend the generally accepted view of a core deficit in phonological processing with variability in orthographic processing within the group of dyslexics, applying the phonological-core variable-orthographic differences (PCVOD) framework. To show this variability, the group of dyslexics was split in half in the sample with young adolescents (Chapter 3) and in three in the sample with adults, to show the more extreme ends of the distribution (Chapter 4). This was done to create a group of dyslexics with inferior orthographic processing ($ORTH^-$) and a group of dyslexics with superior orthographic processing ($ORTH^+$) of which some dyslexics performed similar to control readers. When comparing these two groups, the two young adolescent dyslexic subgroups did not differ in phoneme awareness and rapid serial naming. However, the adult dyslexics with better orthographic processing (word-specific orthographic knowledge, accuracy and speed), did perform better on phoneme awareness, even though they did not differ on rapid serial

naming. The young adolescent (Chapter 3) dyslexics with better orthographic processing ($ORTH^+$) were better in tasks tapping the use of larger orthographic units, such as reading and spelling after a flashed presentation (brief exposure), whereas the type of words (Dutch words, pseudowords, or English words) did not play a role. Also, the $ORTH^+$ subgroup had a better spelling ability. Because the dyslexics did not differ in verbal ability, vocabulary, and reading experience, we concluded that $ORTH^+$ were not simply better readers with better verbal competence, more reading experience, and exposure.

The adult dyslexics with better orthographic processing were better in all reading tasks in comparison to the adult dyslexics with inferior orthographic processing. However, if phoneme awareness was used as a covariate, the differences remained for tasks tapping a brief exposure, and English reading. In these tasks it is assumed that using larger orthographic units is needed. It was ruled out that the $ORTH^+$ had more reading experience and exposure, superior cognitive abilities, and less severe phonological deficits.

The PCVOD framework was also extended to poor readers of Grade 4, as a supplement in Chapter 2. It was shown that when poor readers were divided in two based on orthographic processing, including both word-specific orthographic knowledge and fast identification of larger orthographic units (brief exposure task), the poor readers with better orthographic processing skills performed similar to the poor readers with inferior orthographic processing on phoneme awareness, rapid serial naming, and reading comprehension. However, they were better in polysyllabic word reading and tended to do better in spelling.

These results showed that even among Grade 4 dyslexics, in addition to young adolescent and adult dyslexics, there was variability within the dyslexics in orthographic processing, in addition to confirmation of a phonological core deficit. The variability in orthographic processing resulted in the finding that the $ORTH^+$ benefited from tasks requiring rapid processing by using larger orthographic units, especially in silent reading.

The second approach to examine the heterogeneity was to look for cognitive profiles of poor readers across ages. A comparable variety of persistent problems in a combination of three investigated reading-related processes across ages was found. Phoneme awareness, rapid serial naming, and parallel symbol processing proved to play a role in the variety of weaknesses in the reading-related processes among poor readers.

6.2 Who is dyslexic?

Several issues regarding the group of participants and possible limitations must be addressed. A point of concern is the selection of the participants and subsequently whether the poor reading participants could be called dyslexic. In Chapter 2, the sample consisted of complete classrooms, representing the whole reading distribution. In this chapter poor reading was not a separate issue. In Chapter 3, the young adolescents were selected by school counsellors and verified with a psychometric criterion on word reading fluency (below 25th percentile), which is a broad criterion. The participants in Chapter 4 were the parents of the children who participated in the longitudinal study of the Dutch Dyslexia Program (DDP; see van Herten et al., 2008). The adults applied voluntarily for participation. In the screening for participating in the DDP the dyslexic had to perform poorly on a word and pseudoword reading fluency test (bottom 10% on one of the reading tasks, bottom 25% on both reading tasks). In Chapter 5, a selection of the participants from previous studies were used, to form a representative sample for that age-group, and reselected with the selection criterion of the lowest 25% of the reading distribution per sample, approximately equal to national norms representing below 25%.

It could be argued that when relatively wide criteria are used, it may not be right to call these poor reading participants dyslexic. However, we did not want to rely on clinical certificates of dyslexia, because there were clear differences in the young adolescent sample, between participants that were marked by the school counsellors (and had a dyslexia certificate) and

participants who were marked by psychometric criteria by us. To straighten these criteria some participants were excluded to retain a clear sample of control readers and dyslexics. With respect to the adult sample, they fulfilled strict criteria, because they were selected for DDP (see above). To support the specificity of their reading problems, when the dyslexic young adolescents and adults were compared to the control participants on verbal ability, there were no differences. To select the poor readers of the Grade 4 participants, the 25% poorest readers where selected, with normal vocabulary levels. A similar selection was done in representative samples of Grade 7, Grade 10, and adult readers (see Chapter 5). Using this wide criterion of the lowest 25%, we did not claim that these participants were indeed dyslexic; they were described as poor readers. However, most of these poor readers exhibited reading-related problems which are characteristic of dyslexia. The mean score on word reading fluency of the poor readers belonged to the bottom 12% according to the national norms (see Chapter 5). In sum, we have reasons to assume that clear samples of poor readers were selected with a possible overrepresentation of dyslexics in the adult samples, but less in the younger samples.

6.3 Orthographic processing

The central issue in the present thesis concerned orthographic processing. As mentioned in the General introduction orthographic processing is an umbrella term. The focus on orthographic processing in reading science has increased the last decades. For instance, the self-teaching mechanism, in which phonological recoding serves as a self-teaching mechanism to form an orthographic lexicon (Share, 1995), has gained increased attention. In this theory, orthographic processing is a secondary important source of information in word recognition, i.e., orthographic learning. The dual route framework of Coltheart (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) proposes two routes for word recognition, the first a sublexical, phonological, route, and the second a lexical, orthographic, route. As

another example, the mapping of phonological representations and orthographic representations is the crucial mechanism in the model of word identification of Perfetti (1992).

However, whereas there is remarkable consensus in the conceptualization of phonological processing (I will return to this point in a later section), the term orthographic processing and what is meant by it, is still not a clear. Throughout the literature several concepts are employed and are used indifferently, for instance orthographic competence (e.g., Deacon, Wade-Woolley, & Kirby, 2009; van der Leij & Morfidi, 2006), orthographic coding (e.g., Berninger et al., 1992; Stanovich & Siegel, 1994; Vellutino, Scanlon, & Tanzman, 1994), orthographic knowledge (Barker, Torgesen, & Wagner, 1992) and orthographic processing. Even within the context of this thesis, the term used to refer to orthographic processing has evolved. Focusing on a possible compensatory mechanism, we called it orthographic competence (Chapter 3). However, to stress that orthographic processing involves both lexical and sublexical representations, orthographic coding was used as a counterpart to phonological coding (following Berninger et al., 1992 and Vellutino et al., 1994) (Chapter 4). Moreover, we used the term word-specific orthographic knowledge to refer to a representation of the script version of a word, which involves "all the letter information in a word (the specific letters and their order)" (Barker et al., 1992, p. 345). However, if it also involves access and retrieval and using parts of this knowledge, this actually implies sublexical processing. Therefore we used orthographic processing, probably the most neutral term (Chapter 2).

Furthermore, important in the terminology about orthographic processing is the distinction of the lexical and sublexical level of processing. Orthographic processing is often conceptualized as the access and retrieval of word-specific orthographic knowledge stressing the lexical aspect. Share (2008b, p. 43) refers to this as "crystallized orthographic ability". However, in orthographic processing also the sublexical aspect should be accounted for, for several reasons. First, in mapping phonological and orthographic representations, both sublexical and lexical information is of importance (Perfetti, 1992). Second, in reading words, the neighbourhood effect can

facilitate word identification, in which words with more neighbours are recognized faster (e.g., Andrews, 1997; Marinus & de Jong, 2010). This indicates that sublexical information of the word is of importance, suggesting the use of larger orthographic units. Third, orthographic processing involves access and retrieval of this representation that can include the whole word, but also parts of the word in a single letter or letter cluster, involving sublexical representations (Berninger et al., 1992). Fourth, even in beginning readers it is known that the frequency of letterclusters is important in developing higher-order orthographic representations (Geudens & Sandra, 2002) and that information about the orthographic structure of the words is helpful in obtaining reading fluency (Reitsma, 1983). Fifth, even orthographic knowledge at the most elementary level, i.e., letter knowledge, has successfully been used as an operationalization of initial orthographic processing (Badian, 2001; Boets, Wouters, van Wieringen, de Smedt, & Ghesquière, 2008). Boets et al. constructed a preschool measure of orthographic processing consisting of letter knowledge in which they statistically removed variance due to phonological processing. This measure was a good predictor of reading and spelling development.

Concluding from the above, in addition to word-specific orthographic knowledge, which we may call "crystallized" orthographic processing, fast access and retrieval of sublexical units, i.e., all levels beneath whole word level, are also important. We suggest calling this involvement of the sublexical units "fluid" orthographic processing, which I will discuss in the next paragraph.

In this thesis mainly two kinds of orthographic processing are incorporated. The first kind of orthographic processing is word-specific orthographic knowledge. This is measured with an orthographic choice task (*rane - rain* paradigm of Olson, Forsberg, Wise, & Rack, 1994), also called orthographic verification (Hagiliassis, Pratt, & Johnston, 2006). This was used with two choices in the young adolescents and adults (Chapter 3 and 4) and with three choices in primary school (Chapter 2). Because the sublexical level is not included, it is a clear example of "crystallized" orthographic processing. Since the chance level of a two-choice task is higher than a

three-choice task, the psychometric quality of the orthographic three-choice task is better.

The second kind of orthographic processing involves fast identification of larger orthographic units, measured with a brief exposure task. A brief exposure task with the flashed presentation of words, prevents a reader from a slow laborious grapheme-to-phoneme decoding strategy, and increases reliance on larger orthographic units. Brain imaging studies supports that recognition of larger orthographic units take place within the first 200 ms (e.g., Bolger, Perfetti, & Schneider, 2005; Maurer, Brem, Bucher, & Brandeis, 2005; Wolf, 2007). Furthermore, eye-movement studies support the use of syllable information during (silent) reading (Asby & Rayner, 2004), which could stress the importance of reliance on larger orthographic units. Especially when pseudowords in addition to words are presented in a brief exposure of 200 ms, using larger orthographic units is stressed. This is because direct word recognition is impossible in pseudowords and complicated in polysyllabic words. Also the brief exposure restricts the use of a grapheme-phoneme decoding strategy. Related to their slow rate of parallel symbol processing, dyslexics show large deficits on this task (Yap & van der Leij, 1993a). Because in performing this task both lexical and sublexical levels are included, we suggest to call this "fluid" orthographic processing. The orthographic choice task and the fast identification of larger orthographic (in a brief exposure) task tap orthographic processing, because factor analyses demonstrated that these tasks loaded on the same factor across all ages (see Chapter 2, 3, and 4). This finding is similar to Hagiliassis et al. (2006) who found a single orthographic processing factor existing of recognizing the correct orthographic pattern, word-specific representations, and orthographic awareness which relates to the legality of the sublexical clusters. It could be suggested that the orthographic awareness part of this factor is more "fluid" orthographic processing, in which the sublexical level is stressed, beside word-specific orthographic knowledge ("crystallized" orthographic processing).

Operationalizing "fluid" orthographic processing in addition to "crystallized" orthographic processing can be a response to the criticism that

orthographic processing is often measured as an outcome of the learning process, instead of including more on-line processing (Burt, 2006). Using tasks applying to "fluid" orthographic processing, involving the sublexical level as well, rather than stressing word-specific orthographic knowledge ("crystallized" orthographic processing) might be helpful in investigating on-line processing.

Moreover, "fluid" orthographic processing, including word-specific orthographic knowledge is important in polysyllabic word reading fluency. Although Dutch is a relatively transparent language, there are irregularities especially in polysyllabic words (open/closed syllables). Orthographic processing (both sublexical and lexical level) is important to identify polysyllabic words (Verhoeven & van Leeuwe, 2009). The present thesis takes this into account as well, following the more recent focus in reading theories on polysyllabic words (Ans, Carbonnel, & Valdois, 1998), instead of single syllable words as, for example is done in the dual route framework.

6.3.1 Orthographic processing in relation to other reading-related processes

In addition to the conceptual differences of the view of orthographic processing, there is also no consensus how orthographic processing specifically relates to other reading-related processes. Two reading-related processes that were used in the present thesis could relate to orthographic processing, rapid serial naming and parallel symbol processing. First, the relation between rapid serial naming and orthographic processing has to do with the underlying cognitive processes of rapid serial naming. Both involve intermodal processing of mapping a visual symbol to a speech sound and require access and retrieval from the memory. It is suggested that rapid serial naming serves as a marker for orthographic processing (Bowers, Sunseth, & Golden, 1999; Wolf, Bowers, & Biddle, 2000) in which rapid serial naming reflects precise and rapid timing requirements, which keeps the child from obtaining information about the orthographic patterns.

Following this line, Manis, Seidenberg, and Doi (1999) suggested that rapid serial naming reflects learning the arbitrary relationship between a symbol and a sound. In addition, rapid serial naming is important in predicting tasks with a heavy load on orthographic processing. However, it has been argued that rapid serial naming is not an independent marker of orthographic processing, but reflects speed and efficiency in intermodal mapping (Moll, Fussenegger, Willburger, & Landerl, 2009, p. 22). Rapid serial naming represents lexical access and retrieval of well-known symbols, involving intermodal processing (Jorm & Share, 1983; Wagner & Torgesen, 1987). Important in this aspect is that rapid serial naming implies using representations from the memory. This process is not necessarily linked to reading alone, but reflects elementary speed of processing of symbols. This interpretation is supported by the study of van der Sluis, de Jong, and van der Leij (2007) which suggest that rapid serial naming is also related to fluency of arithmetic ability. Moreover, this thesis gives additional evidence that orthographic processing is something different than rapid serial naming. Although both require access and retrieval of representations from the memory, rapid serial naming indicates elementary access and retrieval (rate of elementary symbol processing), whereas orthographic processing involves the access and retrieval of knowledge on both the lexical and sublexical level, which is reading-specific. Orthographic processing explains additional variance in predicting word reading fluency after the influence of rapid serial naming was controlled for in middle childhood, as well as in young adolescents and adults. Therefore, rapid serial naming is not seen as an orthographic marker, but reflects elementary rate of symbol processing.

The second reading-related process that needs to be elucidated with its possible close relation to orthographic processing, is the parallel symbol processing measure from Chapter 5. To measure speeded parallel symbol processing, the visual attention task of Bosse, Tainturier, and Valdois (2007) was adopted. Visual attention span is seen as the number of symbols that can be processed in parallel. Bosse et al. interpreted problems with this parallel symbol processing in the connectionist multi-trace model of

polysyllabic word reading (Ans et al., 1998). In this model there are two ways for word identification and both ways differ in the amount of visual attention span that is needed. However, Hawelka, Huber, and Wimmer (2006) replicated findings of a symbol string processing deficit, and did not find evidence for a smaller visual attention window among dyslexics as was suggested by Ans et al. and Bosse et al.. Because the visual attention window is not impaired if only visual detection is necessary without the connection to a verbal code (Hawelka & Wimmer, 2008). This symbol string processing deficit is mainly specific to alphanumeric processing, not for non-alphanumeric processing (Bergmann & Wimmer, 2008). Therefore it is questionable whether this parallel symbol processing task does represent general visual attention. Because this speeded parallel symbol processing task involves letters, it could be used as some kind of orthographic processing measure. In producing a symbol string of capital letters, it could be argued that in order to perform this task, the capital letters are transformed to syllables using mapping of orthographic and phonemic representations which could suggest a heavy load of orthographic processing. To investigate the correlations between parallel symbol processing and word-specific orthographic knowledge (orthographic choice task – "crystallized" orthographic processing) data of the present studies[6] reveal moderate correlations (adults $r = .56$, young adolescents (Grade 10) $r = .45$, Grade 4 $r = .52$). The correlations between parallel symbol processing and "fluid" orthographic processing in brief exposure tasks (flashed word identification / flashed word production) revealed relatively higher correlations (adults $r = .66/.72$, young adolescents (Grade 10) $r = .58/.63$, Grade 4 $r = .32/.53$). Future research should focus on the relationship between orthographic processing and parallel symbol processing because these findings support the view that parallel symbol processing as measured by the task of Bosse et al. (2007) may be part of "fluid" orthographic processing.

[6] These data are not presented in the present thesis. The data are available on request.

6.4 Persistent problems

Besides orthographic processing, the second theme of this thesis consisted of examining the stability and universality across age of the phonological core deficit. Confirming the finding of Vellutino, Fletcher, Snowling, and Scanlon (2004) that phonological processing qualifies as the universal and stable core characteristic of dyslexia across languages with alphabetic writing, the present thesis found persistent problems in phonological processing across ages in Dutch dyslexics. The stable core phonological deficit, resulting in problems with phoneme awareness and rapid serial naming compared to control readers was found in middle childhood and also among young adolescents and adults. A phoneme awareness deficit is found to be persistent if sensitive enough measures are used.

In addition to difficulties in the processes as phoneme awareness and rapid serial naming, another major characteristic of dyslexics is that they have difficulties with phonological recoding, measured with pseudoword reading (Herrmann, Matyas, & Pratt, 2006; Landerl & Wimmer, 2000; Miller-Guron & Lundberg, 2000; Rack, Snowling, & Olson, 1992; Yap & van der Leij, 1993a). Van den Broeck, Geudens, and van den Bos (2010) recently have argued that poor identification of unfamiliar words is not caused by a nonword reading deficit but, alternatively, the consequence of normal developmental differences in word-specific knowledge between disabled readers and younger normal readers. In the view of van den Broeck et al., the nonword reading deficit is an artifact of the reading-level-match design (which is based on familiar word reading).

Specific deficit or not, the differential power of pseudoword reading as a relatively pure measure of word decoding which excludes familiarity at the lexical level, has received substantial support in the present thesis. By showing that young adolescents (both beginning and end of secondary school) and adult dyslexics read both words and pseudowords at a level normal for Grade 4 (whereas the adults even read pseudowords at a level normal for Grade 3). In contrast, typical readers still improve with age in word and pseudoword reading fluency (see Chapter 5). The poor readers

exhibited severe speed limitations, which is corroborated by an increasing gap between typical and poor readers in reading fluency at later ages. Although there are no indications of an increasing gap in primary school (the so called Matthew effect; Stanovich, 1986) (Aarnoutse, van Leeuwe, Voeten, & Oud, 2001; Bast & Reitsma, 1998; Scarborough & Parker, 2003), our findings suggest that it may apply to the period from secondary school onwards. This could be due to more differentiation in instruction from this age onwards and differentiation in choices at education and reading experience.

With respect to phonological recoding, measured with pseudoword reading excluding familiarity at the lexical level, it should be questioned if phonological recoding should be adopted in the phonological processing concept. Because phonological recoding is a reading-specific process and not a reading-related process. This is in contrast to the reading-related processes as phoneme awareness and rapid serial naming.

6.4.1 Remediation

By showing the persistence of the reading difficulties and the problems in the reading-related processes in this thesis, the question rises whether these core problems can be remediated, although this was not investigated in the present thesis. Because dyslexia in a relative transparent language like Dutch is characterized by slow and laborious reading (de Jong & van der Leij, 2003), the main aspect of intervention programs is to enhance the speed of reading. As many treatment studies show, it is difficult to speed up word reading fluency to normal levels (e.g., Gijsel, 2009; Marinus 2010; Torgesen, 2000). It is shown that the effects of the treatment depend on the severity of the problem and the age at entry of the treatment (van der Leij, 2006). There are large individual differences in response-to-intervention (Scheltinga, van der Leij, & Struiksma, 2010; Torgesen, 2000). Scheltinga et al. showed that if differences in initial reading performances are taken into account, the differences in response-to-intervention are predicted by

rapid serial naming and not by orthographic knowledge. By predicting individual differences in responsiveness, rapid serial naming establishes the important role of elementary intermodal access and retrieval for reading fluency. It should be noted that Scheltinga et al. did not use "fluid" orthographic processing. Future research should take this into account. In addition, these individual differences in response-to-intervention emphasize the heterogeneity among dyslexics.

In addition to the individual differences in response-to-intervention in reading-related processes, intervention studies demonstrate that remediation of spelling ability is more successful. This can even lead to normal spelling levels (Gijsel, 2009; Tijms, Hoeks, Paulussen-Hoogeboom, & Smolenaars, 2003). Spelling is mapping from phonology to orthography, which is basically a much slower process than reading (Bosman & van Orden, 1997). Spelling does not require the fast visual identification of letters. This is also indicated by low correlations between rapid serial naming and spelling ability (Nikolopoulos, Goulandris, Hulme, & Snowling, 2006), which confirms that speed is not (yet) essential in spelling. The present thesis corroborates with this finding in showing no additional role for rapid serial naming in predicting spelling ability (see Chapter 2 for children and Chapter 3 for young adolescents). Because spelling does not involve the rapid identification of visual symbols and because spelling shows more improvement after invention, it could be suggested that the fast identification of orthographic units is more difficult than the production of these orthographic units. This has to do with the fact that fast recognition implies speed. In the preceding it was argued that the fast access and retrieval in intermodal mapping is the bottleneck for dyslexics. Therefore, fast identification can give more problems and is harder to remediate than producing orthographic units. This line of reasoning could be misinterpreted by claiming that orthographic processing is not important for spelling. It is important in spelling ability, in addition to phoneme awareness (see Chapter 2) (see also Hilte, 2009 for "crystallized" orthographic processing). However, the fast identification of orthographic units is of minor

importance, because spelling involves the mapping from phonology to orthography, which is a relatively slow process.

6.5 Heterogeneity

The third theme of this thesis is to investigate the heterogeneity in dyslexia. Whereas there is consensus about the phonological core deficit, this does not imply that there is one cause underlying dyslexia, as described in the General introduction. To understand the issue of heterogeneity, theories containing subtypes based on reading and reading related processes have been proposed and often used as a way to describe the heterogeneity, such as the subtypes based on the double deficit theory (Wolf & Bowers, 1999) and the dual route theory (Coltheart et al., 2001; see General introduction). However, recently these subtype theories are under debate.

Vellutino et al. (2004) and Vukovic and Siegel (2006) criticized the double deficit subtypes on theoretical, interpretive, and methodological points. The finding that both phoneme awareness and rapid serial naming contribute to predict reading performances, does not necessarily mean that this automatically involves the double deficit hypothesis with two relatively unrelated skills. And it does not necessarily challenge the phonological processing account (Wagner & Torgesen, 1987). The question remains whether phoneme awareness and rapid serial naming are independent predictors. If there is a relation between both predictors, there will be individuals that have a deficit in both, not because of the double deficit hypothesis, but because the underlying predictors are related. Furthermore, in examining studies investigating the double deficit hypothesis, the double deficit group (with both phoneme awareness and rapid serial naming deficits) had lower phonological awareness than the phonological deficit group. Having a lower phonological awareness was also more related to reading skills than having higher phonological awareness, which suggest a curvilinear relationship with reading (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). Combining this with the finding that most

dyslexics with a naming speed deficit exhibited also other phonological processing difficulties or even orthographic difficulties, and that there were few dyslexics with only a rapid serial naming deficit with intact phonological skills (Vukovic & Siegel, 2006), this subtype distinction can be criticized.

A second often used subtype distinction comes from the dual route perspective and is a distinction between phonological and surface dyslexics (Castles & Coltheart, 1993). In phonological dyslexics the sublexical route is hampered, resulting in mainly pseudoword reading problems. In surface dyslexics the lexical route is hampered resulting in mainly irregular word reading problems (Bailey, Manis, Pedersen, & Seidenberg, 2004; Castles & Coltheart, 1993; Stanovich, Siegel, & Gottardo, 1997). This phonological and surface subtype distinction has also been questioned. For instance, it is difficult to find discrete subgroups. Instead, all dyslexics exhibit both irregular and pseudoword reading problems, which means that the dyslexics differ in severity but not in quality of the reading deficit (Murphy & Pollatsek, 1994). Furthermore, the dual route framework is typically based on the English orthography with many irregularities. These two routes could be different in other, more transparent, orthographies (Share, 2008a). Moreover, the strict distinction in the two routes, based on regularity has been criticized (Share, 2008a). Another criticism comes from Ziegler et al. (2008) who question the single cause of dyslexia, which is underlying a subtype. Similarly to Hulme, Snowling, Caravolas, and Carroll (2005), they propose a multiplicity of underlying deficits. Therefore, instead of a categorical view using subtypes to encounter the heterogeneity in dyslexia, a dimensional view is proposed, emphasizing the multiplicity of underlying deficits (Pennington, 2006; Ziegler et al., 2008). This multiplicity relates to the sense of more reading-related processes underlying, and individual variety in these underlying processes. This view emphasizes the need to look for individual variation, rather than one single cause. In addition to the multiplicity, the dimensional view also emphasizes the relative position in strengths and weaknesses of the reading-related processes.

The present thesis explores this individual variety in two approaches. In addition to the core deficit, variability in orthographic processing within dyslexics is confirmed, in accordance with the PCVOD framework. Before this individual variety in orthographic processing was explored, it was established that orthographic processing was an additional independent predictor of word reading fluency after phonological processing was controlled for. In most previous studies orthographic processing and heterogeneity in dyslexics has been related to print exposure (Cunningham, Perry, & Stanovich, 2001; Stanovich et al., 1997). In the view of "crystallized" orthographic processing, this orthographic processing is often seen as an outcome measure on which print exposure has a major influence. This major influence of print exposure relates more to environmental influences, whereas phonological processing relates more to genetic influences (Samuelsson et al., 2005). Since the present thesis emphasizes the role of reading fluency and investigates "fluid" orthographic processing, it may be assumed that the genetic influences instead of environmental influences become increasingly important. This is supported by findings of common genetic influences on both phonological and orthographic processing (Olson, Byrne, & Samuelsson, 2009). The present thesis did not investigate the heritability, but we did show that the variability within the dyslexics is not related to differences in print exposure, because the two subgroups of dyslexics that differed in orthographic processing skills had similar reading experience and exposure.

Applying the PCVOD framework, this thesis demonstrated that the dyslexics with better orthographic processing ($ORTH^+$ subgroup) benefitted from tasks appealing to larger orthographic units, such as English (see also van der Leij & Morfidi, 2006) and when reading and spelling in a flashed presentation (brief exposure) was used. There were even indications that the dyslexics with better orthographic processing had better spelling skills and benefited in polysyllabic word reading (among Grade 4 $ORTH^+$ subgroup). The better orthographic processing skills were not due to differences in verbal ability, spatial ability, reading experience, reading exposure, or levels of phoneme awareness (see this thesis). Moreover, this $ORTH^-$ subgroup

was found across all ages. Because this thesis found evidence for a possible compensating mechanism, it is important to investigate this "orthographic talent" further.

The importance of investigating a remediation program is stressed by indications that the adult dyslexics with better orthographic processing had a better educational attainment than the dyslexics with lower orthographic processing. This might indicate that the dyslexics with better orthographic processing have a better future perspective. It could be that with specific remediation for the $ORTH^+$ group, directed to their ability to benefit from tasks appealing to the use of larger orthographic units, reading and spelling could be improved. Additionally, further research is also needed to investigate if it is possible to train orthographic processing in the group that had inferior orthographic processing ($ORTH^-$ subgroup). In emphasizing larger orthographic units, remediation programs should give attention to exercises and training in which the use of larger orthographic units is stimulated. For instance, brief exposure tasks can force the dyslexics to use their better orthographic processing. Silent reading and text reading, instead of reading aloud and single word reading could be supportive for these dyslexics (see also Barker et al., 1992). In silent reading and in brief exposure (flashed presentation), there is a less than maximal load on phonological processing, the core deficit. This could be because there is no reading aloud involved, in which there is a burden on phonological processing.

Also loanwords can help them benefit from larger orthographic units. Loanwords are words that come from another language such as French or English and have been adopted in the Dutch language (e.g., *team*, *aubergine* [eggplant]). The Dutch phoneme-grapheme correspondence rules cannot be applied in these words. Larger orthographic units or whole-word representations are necessary. In this line of thinking it should be considered to incorporate more English in the primary school curriculum. It has been shown that orthographic knowledge ("crystalized" orthographic processing) and reading comprehension can be influenced by a bilingual primary school

curriculum (van der Leij, Bekebrede, & Kotterink, 2010). This could be beneficiary for the ORTH^{+} subgroup.

Moreover, in order to support the dyslexics, and comply with the heterogeneity, the individual profiles have to be investigated and used. This provides information about the possible combinations of deficits in reading-related processes such as phoneme awareness, rapid serial naming, and speeded parallel symbol processing. This would provide possible starting points for treatment. To emphasize the importance of investigating orthographic processing skills in the individual profile and operationalize "fluid" orthographic processing, we developed, in collaboration with other researchers, a diagnostic instrument for dyslexia in secondary school (Interactive Dyslexia test Amsterdam-Antwerpen (IDAA) and for vocational education (IDAA-mbo) (see Bekebrede et al., 2010; van der Leij et al., 2010).

Furthermore, future research to investigate the heterogeneity in dyslexics should incorporate a dimensional view, in which the multiplicity and complex patterns in cognitive profiles, at individual level, are accounted for, resulting from evidence from e.g., Hulme et al. (2005), Pennington (2006), Ziegler et al. (2008), and the present thesis.