The role of orthographic and phonological processing in dyslexia and reading

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THE ROLE OF ORTHOGRAPHIC AND PHONOLOGICAL PROCESSING IN DYSLEXIA AND READING

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Faculteit der Maatschappij- en Gedragswetenschappen
You can't help respecting anybody who can spell TUESDAY, even if he doesn't spell it right; but spelling isn't everything. There are days when spelling Tuesday simply doesn't count.

A. A. Milne
The house at Pooh corner
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Summary

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Biography
Chapter 1  General introduction

1.1  Reading fluency development

One goal in reading development is to become a fluent reader, which involves accuracy and automaticity. Automaticity implies fast, effortless, autonomous, and not consciously aware processing. This automaticity enables the reader to shift attention to more higher-order tasks such as reading comprehension (Kuhn & Stahl, 2003; LaBerge & Samuels, 1974; Logan, 1997).

In order to develop automatic and efficient visual word recognition Perfetti (1992) proposes two sublexicons to acquire a lexical representation system: the functional and the autonomous lexicon. In the functional lexicon the representations are not yet fully specified, whereas the autonomous lexicon is characterized by fully specified representations. The autonomous lexicon refers to precise (accurate) orthographic and phonemic connections and redundant orthographic and phonemic connections on the sublexical and lexical level, in which the lexical representation becomes “encapsulated” (Perfetti, 1992, p.162). This implies accurate direct word recognition. Fluency is thought to be reached when the representations increase in quality and, as a byproduct, the access to these representations increases.

Reaching reading fluency involves efficient processing of words on a continuum of high to low frequency. At the same time, reading experience leads to the transition of words from unfamiliar to familiar (Share, 2008a). To establish the transition and improve the quality of the lexicons, experience is needed, which involves shifting the words from the functional to the autonomous lexicon (Perfetti, 1992). In reading development, phonological recoding, which is the print-to-sound conversion, is of major importance in word identification. Phonological recoding forms the key to acquire orthographic representations (Share, 1995), since each time after a successful decoding of a (new) word, word-specific information is obtained. This forms the basis of the self-teaching mechanism which allows a child to
develop its own orthographic lexicon. The forming of a large autonomous lexicon (i.e., acquiring word-specific knowledge) is a requirement for reading fluency. In parallel, this knowledge may be used to identify unfamiliar words which are still part of the functional lexicon. Therefore, children are helped achieving reading fluency through information about the orthographic structure of the words and using these larger orthographic units in word identification (Reitsma, 1983). For example, there is evidence that larger orthographic units of known words are used to identify equal parts in other words (so called orthographic neighbour words, e.g., Andrews, 1997; Marinus & de Jong, 2010).

Necessary prerequisites and important predictors for the development of reading fluency are at least phoneme awareness, rapid serial naming, and orthographic processing. The first step before establishing a functional lexicon is to grasp the alphabetic principle that a phoneme maps a grapheme (Snowling & Hulme, 2005). In this process phoneme awareness is of importance, the understanding and awareness that spoken words exist of a sequence of sounds and the ability to manipulate those sounds (Bowey, 2005, Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1987). Another important phonological processing variable is rapid serial naming, the quick retrieval of symbolic information from the long term memory, involving intermodal processing between a visual symbol and a speech sound (Jorm & Share, 1983; Wagner & Torgesen, 1987). Rapid serial naming represents in particular the fast access and retrieval of well-known symbols from memory. However, it is not reading-specific, it is also related to arithmetic fluency (van der Sluis, de Jong, & van der Leij, 2007).

Besides phonological processing, orthographic processing is another important source in predicting word identification, even when phonological processing, including phonological recoding, is controlled for (Cunningham, Perry, & Stanovich, 2001; Morfidi, van der Leij, de Jong, Scheltinga, & Bekebrede, 2007). Orthographic processing is an umbrella term which includes the accuracy and speed of access and retrieval of word-specific orthographic knowledge, representing crystallized orthographic ability (Share, 2008b) and is often measured with lexical decision tasks (e.g., *rane* -
General introduction

rain paradigm of Olson, Forsberg, Wise, & Rack, 1994). In addition to the lexical level, the sublexical level of single letters, letter clusters, and syllables (Berninger et al., 1992) is involved as well. This information is already available in the functional lexicon, but does not involve a fully specified representation (Perfetti, 1992). The sublexical level includes orthographic awareness, which refers to the awareness of legal letter strings (wordlikeness), how letters are organized in words and statistical regularities of letter sound combinations (Siegel, Share, & Geva, 1995; Stanovic & Siegel, 1994; Vellutino et al., 2004). However, the role of orthographic processing in word identification is still debated (see reviews of Burt, 2006; Castles & Nation, 2006; see also Chapter 6 of the present thesis).

1.2 Reading-related processes and reading difficulties

Unfortunately, not all persons develop into fluent readers. Some encounter major difficulties in reaching adequate levels of accuracy and/or fluency. Around 10% of the children experiences difficulties with learning to read (Vellutino et al., 2004). In a transparent orthography like Dutch estimates are somewhat lower. Approximately 9% of the children have severe difficulties in the accurate and quick identification of written words and 4% is diagnosed as dyslexic (Blomert, 2006). This difference could be related to the transparency of the orthography under study. English is an opaque orthography, in which many irregularities in the one-to-one mapping of graphemes to phonemes exists (Seymour, Aro, & Erskine, 2003), whereas Dutch is a relatively transparent orthography. Transparent orthographies are characterized by the finding that poorly reading children already early in reading development reach relatively adequate accuracy levels. In contrast, they have persistent problems with developing adequate levels of reading fluency to obtain automaticity (see Landerl & Wimmer, 2008; Seymour et al., 2003; Share, 2008a; van der Leij & van Daal, 1999; Verhoeven & van Leeuwe, 2009).
Chapter 1

There is consensus that the main deficit in developmental dyslexia is a deficit in phonological processing (see for a review Vellutino et al., 2004). Phonological processing is a universal and stable core characteristic of dyslexia independent of orthography and age. This is characterized by problems with phoneme awareness and rapid serial naming. Problems with phoneme awareness are found in all alphabetic languages and in all ages, provided that task demands are adapted to the developmental level of the dyslexic (e.g., English: Bruck, 1992; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Swanson & Hsieh, 2009; Czech: Caravolas, Volín, & Hulme, 2005; Dutch: de Jong & van der Leij, 2003; Morfidi et al., 2007). Problems with rapid serial naming are also commonly found in all alphabetic languages, which persist into adolescence and adulthood (e.g., English: Swanson & Hsieh, 2009; Vukovic, Wilson, & Nash, 2004; Dutch: de Jong & van der Leij, 2003; Morfidi et al., 2007; Vaessen, Gerretsen, & Blomert, 2009; German: Wimmer, Mayringer, & Landerl, 2000).

1.3 Heterogeneity of dyslexia

Reading acquisition is a complex process which involves large individual differences in the reading-related processes (Share & Stanovich, 1995). As a consequence the group of dyslexics is not a homogeneous group (e.g., Beaton, 2004). Even among adult dyslexics, this group is still characterized by a large heterogeneity (e.g., Lyytinen, Leinonen, Nikula, Aro, & Leiwo, 1995; Ramus et al., 2003; Vukovic et al., 2004; Zabell & Everatt, 2002). The consensus about the core phonological processing deficit in dyslexia (Vellutino et al., 2004) suggests a single cause of dyslexia. However, this line of reasoning contradicts the evidence about heterogeneity in cognitive profiles. A probabilistic multifactorial model forms a better explanation for the heterogeneity than a deterministic single cause (Pennington, 2006), including orthographic, visual, and rapid serial naming deficits, next to phoneme awareness deficits.
The question is whether heterogeneity of cognitive profiles of poor readers is determined by intraindividual variation of reading-related subskills in the phonological domain (in particular phoneme awareness and rapid serial naming), or whether more reading-specific subskills account for additional variance. In order to solve this issue and investigate the heterogeneity in dyslexia, one solution is the development of sub-classifications within the group of dyslexics. It is important to note that subtypes are not naturally occurring, but are imposed (Rispens, van der Stege, & Bode, 1994). Subtypes entail different underlying processes that lead to the same problem at the surface. Studying subtypes in dyslexia implies that multiple causes should be considered and that there is not a single processing deficit accounting for the problem (Licht, 1994). There are various subtypes considered based on reading-related processes. For instance, subtypes based on the double deficit theory (Wolf & Bowers, 1999) and based on the multiple-trace memory model for polysyllabic word reading (ACV98 model; Ans, Carbonnel, & Valdois, 1998) are suggested.

The double deficit hypothesis proposes a single phoneme awareness deficit, a single rapid serial naming deficit, and a combination of both deficits (Wolf & Bowers, 1999) underlying dyslexia. The subtypes based on the ACV98 model advocate a distinction between phoneme awareness and visual attention span (Bosse, Tainturier, & Valdois, 2007). Moreover, there are also subtypes thoroughly investigated that are based on specific processes in reading, as the dual route model with two routes for word identification: the sublexical and lexical route (DRC model; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Derived of these two routes are the phonological and surface subtypes (e.g., Castles & Coltheart, 1993), in which the phonological subtype represents a deficit in the sublexical route leading to problems with pseudoword reading and the surface subtype has a deficit in the lexical route leading to problems with irregular words. It should be noted that the term phonological subtype may be somewhat misleading because it does not relate to reading-related subskills such as phoneme awareness and rapid serial naming, but to reading-specific processes only.
However, these subtype distinctions have been criticized (Share, 2008a; Vellutino et al., 2004; Ziegler et al., 2008; see also the General discussion). Although subtypes should entail multiple causes (Licht, 1994), most subtypes are seen as deterministic single “opposite” causes, leaving no room for the multiplicity and complex patterns in cognitive profiles (Pennington, 2006). This is supported by Ziegler et al. (2008) who imply that the causes of dyslexia must not be investigated as a unitary disorder, but at individual levels, since there is no single cause of dyslexia.

An alternative way to solve the problem of a phonological core deficit on the one hand and additional variables that may play a role on the other, is expressed in the phonological-core variable-differences (PCVD) framework of Stanovich (1988). This framework embraces the phonological core deficit, implicating that all poor readers exhibited a core phonological processing deficit. The heterogeneity elicits in the aspect of possible differences in other, mainly general, cognitive skills. This is not a subtype model, in which two reading-related processes are contrasted. Stanovich’s framework was proposed to account for the differences found between IQ-discrepant dyslexics and non-IQ-discrepant (“garden variety”) poor readers in measures outside the phonological core domain, which indicate differences in their general cognitive abilities. This was followed by the suggestion that dyslexic readers were relatively less disadvantaged in orthographic processing compared to phonological processing than non-discrepant poor readers (Stanovich & Siegel, 1994).

1.4 **Variability in orthographic processing**

The PCVD framework (Stanovich, 1988) stresses the need to look for variable differences outside the phonological core domain. In addition to cognitive abilities, orthographic processing was mentioned (Stanovich & Siegel, 1994). To further investigate the heterogeneity within dyslexics and to deviate from the aptitude achievement discrepancy, variability in orthographic processing within dyslexics is a promising possibility. As was
shown by Cunningham and colleagues (2001), orthographic processing explained additional variance in word recognition. Moreover, individual variability among the group of dyslexics was found (Miller-Guron & Lundberg, 2000; van der Leij & Morfidi, 2006). Among Swedish college students there was a subgroup of dyslexics who were better in English reading and had a preference for English instead of Swedish, although the latter has a transparent orthography (Miller-Guron & Lundberg, 2000). In a Dutch study with dyslexic adolescents, van der Leij and Morfidi (2006) also found a dyslexic subgroup that was better in English reading. This subgroup had superior orthographic skills in both English and Dutch contrasted to another dyslexic subgroup. Both dyslexic subgroups had equal phonological processing deficits. It was suggested that the subgroup with better orthographic skills that performed better in English had a preference for larger orthographic units.

Therefore, van der Leij and Morfidi (2006) extended the PCVD model of Stanovich (1988 and Stanovich & Siegel, 1994) to individual variability within the group of dyslexics, resulting in the phonological-core variable-orthographic differences model (PCVOD). The PCVOD model assumes that all dyslexics suffer from a core phonological processing deficit whereas there are large individual differences in orthographic processing. This model predicts that some dyslexics may have orthographic processing skills in the normal range, whereas other dyslexics have deficits in both phonological and orthographic processing leading to less compensatory potential in orthographic processing. One of the central issues in the present thesis is to investigate whether there is larger individual variability within dyslexics in orthographic processing than in phonological processing, testing the PCVOD-model.

### 1.5 Themes and outline of this thesis

The present thesis involves three main themes. Firstly, the role of orthographic processing in addition to phonological processing as a
Chapter 1

predictor of reading fluency is investigated. This was examined in three different age groups: middle childhood (mean age 7;10 in Grade 2), young adolescents (mean age 15;7), and adults (mean age 37;3) (see Chapter 2, 3, and 4).

The second theme considers the universality and stability of deficits in phonological processing across age, the cornerstone of causal theories of dyslexia. Deficits in phoneme awareness and rapid serial naming are known to be present in poor readers in middle childhood (Chapter 5). The hypothesis is extended to Dutch dyslexic young adolescents (Chapter 3 and 5) and Dutch dyslexic adults (Chapter 4 and 5). The fact that most evidence comes from studies investigating readers in the acquisition phase or from more opaque orthographies, mostly English studies, whereas the Dutch language is a more transparent orthography, supports the relevance of this choice.

The third major theme is to investigate the heterogeneity among dyslexics by highlighting two different ways to look at the heterogeneity. In the first approach the variability within dyslexics in orthographic processing is considered by examining the PCVOD model in Dutch young adolescents (Chapter 3) and adults (Chapter 4). The second approach (Chapter 5) is to examine the cognitive profiles using multiple case studies across different ages (Ramus et al., 2003, Sprenger-Charolles, Colé, Kipffer-Piquard, Pinton, & Bilard, 2009; White et al., 2006). Multiple case studies serve as a possibility to address the heterogeneity of cognitive profiles at the individual level, because they search for possible combinations of deficits in individuals. This is without restrictions of reading theories about different routes and subtypes, and without restrictions in contrasting reading-related processes to form subtypes. The methodology is to select variables that have shown to differentiate between poor and typical readers and combine them in one design.

In line with this lay-out, the study in Chapter 2 describes the role of orthographic processing in predicting word and pseudoword reading fluency and spelling ability in the fluency-acquisition phase in primary school in a longitudinal design (from Grade 2 to Grade 4). In this chapter, the influence
of orthographic processing as a predictor in addition to phoneme awareness and rapid serial naming is investigated in children across the whole reading distribution.

The first part of Chapter 3 examines orthographic processing as a predictor for word reading fluency and spelling ability after controlling for phonological processing among young adolescents with and without dyslexia. Secondly, the core deficit in phonological processing is investigated. Finally, the variability within dyslexics in orthographic processing is considered with the PCVOD model.

While Chapter 4 addresses the same topics as in the previous chapter, the participants are a different age-group: adults with and without dyslexia. Also in this age group, the influence of orthographic processing in predicting word reading fluency is investigated. Secondly, the persistence of the phonological core deficit is examined by comparing the adult dyslexics both with control adult readers and secondary school students as a reading-level match group. Third, the variability within dyslexics in orthographic processing is investigated within the framework of the PCVOD model.

In Chapter 5 the cognitive profiles of poor readers from four different age groups (mid-primary school, beginning and end of secondary school, and adults) are investigated and compared to typical readers. This was accomplished by using multiple case studies investigating the possible multiplicity in weaknesses in reading-related processes. Comparisons are made between poor and typical readers and age groups on reading fluency and three reading-related processes: phoneme awareness, rapid serial naming, and parallel symbol processing.

Finally, in Chapter 6 the main findings in this thesis are discussed. First a review of the findings according to the three themes is given, followed by the implications for reading theories, practice and future research, regarding the role of orthographic processing, the persistence of the problems, and the heterogeneity among dyslexics.
Chapter 2   Predicting word reading fluency in Dutch children in a longitudinal study: The role of phonological and orthographic processing*

Abstract

The present study investigated the role of orthographic processing in gaining Dutch reading fluency and spelling ability in the period from Grade 2 to 4 in a sample of 129 children, controlling for the influence of phoneme awareness, rapid serial naming, and initial levels of vocabulary. Orthographic processing, defined as word-specific orthographic knowledge and fast identification of larger orthographic units, was expected to be important in the fluency phase, when readers need to read polysyllabic words. By using multilevel modeling with an autoregressive structure, the results revealed that in predicting (polysyllabic) word and pseudoword reading fluency orthographic processing was an important predictor. This was in addition to phoneme awareness and the increasing influence of rapid serial naming. In predicting spelling ability the use of word-specific orthographic knowledge was an important predictor, in addition to the increasing role of phoneme awareness. Therefore, all components are needed to increase precise and redundant orthographic and phonemic connections in order to develop automatic and efficient visual word recognition and efficient spelling ability.

* Bekebrede, J. I., van der Leij, A., Oort, F. J., & Share, D. L.
2.1 Introduction

This study aims to investigate the role of orthographic processing in the acquisition of word reading fluency. This was motivated by two observations. First, although the role of orthographic processing is acknowledged within reading research (e.g., Badian, 2001; Barker, Torgesen, & Wagner, 1992; Bowey & Muller, 2005; Burt, 2006; Cunningham, Perry, & Stanovich, 2001; Hagiliassis, Pratt, & Johnston, 2006; Olson, Forsberg, Wise, & Rack, 1994; Share, 1995; Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Wood, 2009), its contribution to the development of reading fluency is not thoroughly investigated in a relative transparent language like Dutch, the language under study. None of the Dutch longitudinal prediction studies has addressed this question during the years of reading acquisition (Grade 1 - 4) (e.g., Aarnoutse, van Leeuwe, & Verhoeven, 2005; Bast & Reitsma, 1998; de Jong & van der Leij, 1999; Verhagen, Aarnoutse, & van Leeuwe, 2008; Verhoeven & van Leeuwe, 2009).

The second observation is that findings of previous studies suggest that orthographic processing is important in predicting reading fluency after the years of reading acquisition, in adolescents and adults (Bekebrede, van der Leij, Plakas, Share, & Morfidi, 2010; Morfidi, van der Leij, de Jong, Scheltinga, & Bekebrede, 2007). In addition, it has been established that there are individual differences among older dyslexics in orthographic processing. Dyslexics in the age range of adolescents and adults all have phonological problems but combine them with relatively large individual orthographic differences (in Dutch: Bekebrede, van der Leij, & Share, 2009; Bekebrede et al., 2010; van der Leij & Morfidi, 2006; see for a Swedish example: Miller-Guron & Lundberg, 2000). In fact, substantial subgroups of dyslexics have word-specific orthographic knowledge in the normal range which is far better than expected based on their overall reading skill. These two observations led us to the question whether the foundations of these differences may emerge at an earlier stage. That is, whether there are early signs of the impact of the role of orthographic processing on gaining reading
fluency, especially in the period when the development of reading fluency is at its peak (the period from Grade 2 to 4).

### 2.1.1 The role of orthographic processing in word identification

To become a fluent reader automaticity in decoding must be reached, which implies fast, effortless, autonomous, and not consciously aware processing of words independent of familiarity. Automaticity enables the reader to shift attention to higher-order tasks (Logan, 1997). To develop automatic and efficient visual word recognition processes, Perfetti (1992) has argued that the precision and redundancy of orthographic and phonemic connections at the sublexical and lexical level have to be increased in order to be used in a flexible and rapid way. This process, which will be called orthographic processing throughout this chapter, implies “crystallized” orthographic ability (Share, 2008b, p.43), i.e., connections at the lexical level (word-specific knowledge), and at the sublexical level of single letters, letter clusters, and syllables (Berninger et al., 1992).

It has been suggested that using word-specific knowledge is less important in a relative transparent orthography (Ziegler & Goswami, 2005), because fast efficient phonological recoding is all the reader needs to identify the word. However, experience with words may establish orthographic knowledge ranging from lexical to sublexical knowledge relatively early to be used to recognize not only the specific words (Reitsma, 1983), but also other words with equal parts, e.g., their orthographic neighbours (e.g., Andrews, 1997; Marinus & de Jong, 2010). There is an “interactive convergence of orthographic and phonological representations when reading” (Booth, Perfetti, & MacWhinney, 1999, p.17). It may be assumed that the role of orthographic processing may increase when the reader has to read words of two or more syllables. As is tentatively suggested in a recent Dutch study, knowledge of larger orthographic units may be necessary to overcome both the consistency problem (orthographic units may have different pronunciations) and the granularity problem (grain
The size and complexity of orthographic units may vary (Verhoeven & van Leeuwe, 2009; see also Ziegler & Goswami, 2005). The consistency and granularity problem both exist in Dutch. For example, the pronunciation of en is different in the first and second syllable of *dennen* (firs), and the VC-cluster op is connected to one syllable in *stop*, but splits up in two in *open*. The use of (sub)lexical orthographic knowledge gains influence as an independent source of information when words with a complex orthographic structure have to be recognized, which is the case from third grade onwards when polysyllabic Dutch words, which contain many inconsistencies, have to be learned (Verhoeven & van Leeuwe, 2009). This belongs to the idea of a continuous process from print to sound conversion to automatic whole word recognition (Share, 1999; 2008a), in which larger orthographic units – sublexical orthographic knowledge – are important (Wesseling & Reitsma, 2000).

### 2.1.2 The role of orthographic processing in spelling ability

Orthographic processing is also very relevant for spelling ability. In order to spell a word, the speech sounds have to be transposed into corresponding letters, that is mapping phonology to orthography. All different kinds of phonological units are vital in spelling: single phonemes, onsets, rimes, speech-sound clusters, and whole words (e.g., Ziegler, Stone, & Jacobs, 1997). These phonological units have to be matched to graphemes, grapheme clusters, and words. Besides knowledge about the phoneme-grapheme correspondences (Treiman & Bourassa, 2000), the quality of the lexical representation in the mental lexicon is important. Both phonological and orthographic information is needed to form this representation (Perfetti, 1992; Perfetti & Hart, 2002). As in most alphabetic languages, in Dutch the phoneme-grapheme correspondences needed for spelling are less regular than the grapheme-phoneme correspondences needed for reading. Due to these differences in irregularities there are often more ways to spell a word.
than to read a word. Therefore, spelling is more difficult to acquire than reading (Bosman & van Orden, 1997).

2.1.3 The need to control for phoneme awareness and rapid serial naming as independent predictors

The goal of the present study is to shed light on the role of orthographic processing in predicting reading fluency and spelling ability. In order to investigate the unique contribution of orthographic processing, other predictors have to be controlled for. Two phonological processing variables that are not part of the process of word identification but have strong correlations to the process of reading acquisition, phoneme awareness and rapid serial naming, are used to control for their independent contribution to reading fluency and spelling ability (de Jong & van der Leij, 1999; Vaessen & Blomert, 2010).

There is abundant evidence that phoneme awareness is one of the strongest predictors of reading acquisition, irrespective of language (e.g., Bowey, 2005; Cardoso-Martins & Pennington, 2004; Holopainen, Ahonen, & Lyytinen, 2004; Ziegler & Goswami, 2005). However, the period during which phoneme awareness affects typical reading development appears to be different across languages with differences in orthographic depth. Especially in relative transparent languages phoneme awareness is one of the strongest predictors of early reading, but it is only a longitudinal predictor during a short period of time in the early stages (de Jong & van der Leij, 1999; Landerl & Wimmer, 2008; Leppänen, Aunola, Niemi, & Nurmi, 2008; Lervåg, Bråten, & Hulme, 2009; Verhagen et al., 2008). As a concurrent predictor phoneme awareness has a strong influence until Grade 4. However, the influence declines as a function of word frequency (Vaessen & Blomert, 2010). However, in the perspective of the discussion about the importance of phoneme awareness in predicting reading fluency, sensitivity to individual differences in the period when the development of reading fluency is at its fastest, is important (Caravolas, Volín, & Hulme,
2005; de Jong & van der Leij, 2003), next to the distinction between longitudinal and concurrent predictors (Lervåg et al., 2009; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). With respect to spelling acquisition phoneme awareness is a key element (e.g., Bosman & van Orden, 1997; Frith, 1985; Treiman & Bourassa, 2000). In order to spell a word correct, it is essential to segment the spoken word into separate phonemes. Phoneme awareness is an important predictor of spelling ability in both relative transparent orthographies, such as German and Czech, as in a deep orthography as English (Caravolas et al., 2005; Cardoso-Martins & Pennington, 2004; Moll, Fussenegger, Willburger, & Landerl, 2009; Wimmer & Mayringer, 2002).

In contrast to phoneme awareness, which essentially is a subskill within the auditory modality, rapid serial naming involves intermodal processing, i.e., the fluency of naming of colors, pictures, or symbols (letters or digits). The naming of symbols implies lexical access and retrieval of well-known information. It requires the mapping of a visual symbol to a speech sound, a syllable with a meaning. This mapping, as in all mappings with larger units than the phoneme, involves suprasegmental phonology, in contrast to segmental phonology as used in phoneme awareness. Furthermore, the relationship between word reading fluency and alphanumeric naming grows stronger during development (van den Bos, Zijlstra, & lutje Spelberg, 2002).

Although both phoneme awareness and rapid serial naming are strong predictors at the start of reading acquisition, it has been suggested that the role of phoneme awareness diminishes after the early grades, whereas the role of rapid serial naming is increased (Kirby, Parrila, & Pfeiffer, 2003), because laborious phonological recoding processes are gradually replaced by fluency of word reading. Especially in relative transparent languages rapid serial naming is the most influential predictor of reading (e.g., de Jong & van der Leij, 1999; 2003; Georgiou, Parrila, & Papadopoulos, 2008; Holopainen et al., 2001; Moll et al., 2009; Vaessen & Blomert, 2010; Vaessen, Gerretsen, & Blomert, 2009; Wimmer & Mayringer, 2002; Wimmer, Mayringer, & Landerl, 2000). Whereas rapid serial naming is important in predicting reading fluency, the role in spelling is less clear. In
prediction studies the role of phoneme awareness is more influential, rapid serial naming may be additive in explaining spelling ability (Cardoso-Martins & Pennington, 2004; Compton, DeFries, & Olson, 2001; Moll et al., 2009; Savage, Pillay, & Melidona, 2008). However, there is also evidence that rapid serial naming has not an additive role in predicting spelling (Nikolopoulos, Goulandris, Hulme, & Snowling, 2006).

In addition to phoneme awareness and rapid serial naming, the semantic aspect could be of importance in predicting reading fluency. However, with regard to letter knowledge it can be assumed that letter knowledge is already acquired in Grade 1 (Aarnoutse et al., 2005). Furthermore, the meaning component is especially important for reading comprehension, less for word reading fluency and spelling, and not at all for pseudoword reading fluency (e.g., Frost, Madsbjerg, Niedersøe, Olofsson, & Sørensen, 2005; Wood, 2009). The focus in the present study was not on letter knowledge, nor on semantic knowledge. However, vocabulary was included in this study to serve as a cognitive control variable to control for possible semantic effects (Wood).

2.2 The present study

To investigate the role of orthographic processing in a relative transparent orthography, the present study examined the predictors of fluency of Dutch (polysyllabic) word and pseudoword reading, and spelling ability in Grade 2, 3, and 4 in a longitudinal design, which controlled for the influence of phoneme awareness and rapid serial naming. Both orthography to phonology mapping (reading), and phonology to orthography mapping (spelling) was included. To ensure a broad vision on reading development, the unfamiliar to familiar framework (Share, 2008a) was included by using both words and pseudowords. The focus was on reading fluency because in a relative transparent language like Dutch, high levels of accuracy are obtained fairly early (Seymour, Aro, & Erskine, 2003; Verhoeven & van Leeuwe, 2009).
As described in the introduction, our primary interest was the development of reading and spelling in Grade 2 to 4 when children show an increased fluency in word reading and a large progress in spelling skills. Our main hypothesis was that orthographic processing at the sublexical and lexical level explains additional variance above phoneme awareness and rapid serial naming. With regard to polysyllabic word reading fluency, it was expected that the role of phoneme awareness with its emphasis on segmental phonology (Goswami, 2000) would diminish over the grades (e.g., de Jong & van der Leij, 1999; Wimmer & Mayringer, 2002). In addition, it was expected that the role of rapid serial naming would become more important in predicting word reading fluency (e.g., Moll et al., 2009). Because it has been suggested that the relationship between alphanumerical rapid serial naming and word reading fluency becomes stronger during development (van den Bos et al., 2002), indicating the increasing influence of speed of lexical access and retrieval of over-learned intermodal connections. At the same time, orthographic processing would gain influence (e.g., Reitsma, 1983; Share, 1995), stressing the increasing use of large orthographic units at the lexical and sublexical level (Perfetti, 1992). Furthermore, it was expected that vocabulary plays a role in predicting word reading fluency at this age, because the semantic aspect affects the acquisition of word reading fluency (de Jong & van der Leij, 2002; Wood, 2009).

In addition, pseudoword reading fluency is incorporated as a dependent variable. This will shed light on the issue whether or not the predictors are independent of familiarity at the lexical level. It was hypothesized that the role of phoneme awareness, in contrast to the predictions of word reading fluency, remained stronger, because non-existing words were involved. In identifying pseudowords there can be no direct word identification, so phonological processes at the phoneme level remain important. It was also expected that rapid serial naming was an important predictor of pseudoword reading fluency, because in typical reading development, progress in fluency tends to become increasingly independent of familiarity (van den Broeck, Geudens, & van den Bos, 2010) and the increasing influence of
speed of access and retrieval also applies to sublexical units. With regard to orthographic processing it may be argued that word-specific (lexical) orthographic knowledge does not predict pseudoword reading fluency, because whole word identification is impossible in reading pseudowords. However, representations from other known words may facilitate identification of sublexical parts of the pseudowords, using familiar larger orthographic units, which is also seen in the neighbourhood effect (that is, pseudowords with more neighbours were read faster (Andrews, 1997; Marinus & de Jong, 2010)). Furthermore, in contrast to word reading fluency, the role of vocabulary is absent, because it involves non existing words.

In predicting spelling ability it was expected that phoneme awareness was important across Grade 2 to 4, because segmental phonology is of importance in spelling acquisition (Goswami, 2000; Treiman & Bourassa, 2000). In contrast to fluency of (pseudo)word reading, the influence of rapid serial naming would be less important, because the speed of lexical access and retrieval of phonological labels of well-known symbols from memory is of minor importance in the relatively slow and elaborate process of spelling. Moreover, rapid serial naming involves suprasegmental phonology and in spelling it was expected that segmental phonology was more crucial, therefore phoneme awareness was expected to play a critical role (e.g., Savage et al., 2008). In addition, it was expected that orthographic processing predicts spelling ability, because lexical representations are necessary in the process of mapping of phonology to orthography (Bekebrede et al., 2009; Cardoso-Martins & Pennington, 2004; Perfetti, 1992).

### 2.2.1 Considerations of how to operationalize the theoretical concepts

To investigate the predictors of (pseudo) word reading fluency and spelling in second to fourth grade, the issue of sensitivity and equivalence of measures had to be resolved to correctly operationalize the theoretical
concepts. Because this was a longitudinal study, the content and format of the measures used in the three years should, as much as possible, be the same for all grades to enable comparison across grades. The measures needed to be easy enough to avoid floor effects at second grade and difficult enough to avoid ceiling effects at the later grades. Designing the study, six decisions were made.

Firstly, in order to operationalize orthographic processing we wanted to include both the lexical and the sublexical level and speed of processing. In addition to a three-choice task measuring processing of word-specific orthographic knowledge that has showed differentiating value amongst good and poor readers in earlier studies (Horsley, 2005), another measure was designed which required flexible and rapid processing of orthographic representations at the sublexical and lexical level (Booth et al., 1999). This orthographic processing task existed of words and pseudowords with one and two syllables and involved a brief presentation (200 ms) on a computer screen that stresses the need for fast processing and use of larger orthographic units (Yap & van der Leij, 1993a) in both words and pseudowords.

Secondly, in the operationalization of phoneme awareness we incorporated two different phoneme awareness tasks. First a deletion task, a commonly used task which has proven its value as a good representative of a phonological task that distinguishes between good and poor readers (e.g., Hagiliassis, et al., 2006; Messbauer & de Jong, 2003). Second, a task that involves the manipulation of phonemes, a word reversal task, which was successfully used in a sample of young adolescents and adults (Bekebrede et al., 2009; 2010).

Third, to specify rapid serial naming, only the digit card was used in all grades. Using digits is a solid condition for the speed of cross-modal matching. We did not use letters for a possible confounding effect, because in reading letters there is more ambiguity, i.e., naming the sound or the letter. Besides, letters are involved in word reading fluency, even though levels of letter knowledge are mastered at this age. Moreover, previous studies showed that rapid serial naming of digits is a good predictor of
Predicting word reading fluency

reading and differentiates between reading levels (e.g., Caravolas et al., 2005; de Jong & van der Leij, 2003; Denckla & Rudel, 1974; Morfidi et al., 2007; van den Bos et al., 2002; Wimmer et al., 2000).

Fourth, passive vocabulary in Grade 2 was measured because vocabulary predicts word reading fluency at a younger age (e.g., de Jong & van der Leij, 2002). Fifth, to specify word and pseudoword reading fluency, the same standardized timed reading aloud tasks were used in all the grades, measuring how many polysyllabic words or pseudowords are read in one or two minutes. We chose for polysyllabic words, because the need for orthographic processing, using larger orthographic units, is stressed in reading polysyllabic words (Verhoeven & van Leeuwe, 2009). These tasks are commonly used to measure reading fluency in Dutch in first to sixth grade (van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994; Verhoeven & van Leeuwe, 2009).

Lastly, because of the fast increasing mastery of spelling categories ranging from simple one-syllabic words to complex polysyllabic words in Grade 2 to 4, it is difficult to use exactly the same spelling task covering second to fourth grade. Therefore, dictation tasks from the Dutch pupil monitoring system were used to measure spelling ability, which adapt spelling categories to grade level. In this monitoring system the scores of each dictation task are transformed into ‘scale scores’ to compare the scores over grades.

2.3 Method

2.3.1 Participants

Participants were 129 children (60 boys, 69 girls) from six different schools for regular education in the Netherlands across different regions in the Netherlands (urban/rural population). The children were tested in Grade 2, 3, and 4. The mean age in Grade 2 was 7 years and 10 months (SD = 6 months, range 6;11 – 9;3). Based on a norm referenced reading task (three
minutes test, see below), our sample was quite similar distributed compared to the national norms in Grade 2 (25% top reading level, our study 30.8%; 50% average readers, our study 44.6%; 15% poor readers, our study 13.1%; and 10% very poor readers, our study 11.5%). Hence, our sample was a representative sample of the Grade 2 population. Eight children repeated a class (five in Grade 2 and three in Grade 3). These children remained in the sample in the grade they were supposed to be, to preserve the reading distribution. All children learned to read with a phonics based - letter and word level - program called ‘Veilig Leren Lezen’ [Learning to Read Safely] (Mommers, Verhoeven, van der Linden, Stegeman, & Warnaar, 1990), which is the most commonly used reading program in the Netherlands.

2.3.2 Phoneme awareness

Word reversal. A computerized word reversal task (Bekebrede et al., 2009) was used to measure phoneme awareness. The children heard two pseudowords using headphones (e.g., ket – tek). They had to indicate on the computer keyboard whether the second word was the reverse of the first. The word reversal task consisted of 6 examples and 30 items in Grade 2 and 40 items in Grade 3 and 4, all monosyllabic pseudowords with one or two consonants at the beginning or at the end of the word. The internal consistency (Cronbach’s $\alpha$) was found to be .72, .81, and .82 for Grade 2, 3, and 4, respectively.

Sound deletion. Secondly, a sound deletion task was used to measure phoneme awareness (see also de Jong & van der Leij, 2003; Messbauer & de Jong, 2003). The experimenter auditively presented 27 pseudowords to the participant. First the children had to repeat the pseudoword, subsequently they were required to delete a given sound from the word (e.g., what is /grar/ without /g/) and sound out what was left. The first nine items consisted of one syllable, the following nine items consisted of two syllables, and the last nine items consisted of two syllable words where the
sound that had to be deleted occurred twice. The internal consistency (Cronbach’s $\alpha$) was found to be .88, .82, and .84 for Grade 2, 3, and 4, respectively.

2.3.3 Rapid serial naming

*Rapid serial naming.* Rapid naming of digits (Denckla & Rudel, 1974) was used. A card with 50 digits ($1, 3, 5, 6, 8$) was presented to the children. They were asked to name the digits as quickly and accurately as possible. The time to name the digits was recorded. Test-retest reliability was found to be .79.

2.3.4 Orthographic processing

*Orthographic choice.* The orthographic choice task with three choices of Horsley (2005) was used to measure word-specific orthographic knowledge. The children saw 70 items on printed pages, each item consisted of three words. These words were homophones, e.g., *tijd*-teid-tijt [time]. The participants were required to choose the correctly spelled word (*tijd*). The accuracy score was the number of correctly chosen words in 10 minutes. Internal consistency (Cronbach’s $\alpha$) was found to be .98, .91, and .87 for Grade 2, 3, and 4, respectively.

*Flashed word and pseudoword production.* This task (Bekebrede et al., 2009) required flexible and rapid processing of orthographic representations at the sublexical and lexical level to be used to identify familiar and unfamiliar words. Silent reading and spelling of words and pseudowords was needed to perform the task. A word or pseudoword was flashed on a computer screen for 200 ms and was then masked. The participant was asked to type the flashed (pseudo)word. There were three examples followed by three blocks of ten words. The first block consisted of 10
CCVC words, the second block consisted of 10 CVCC words, and the last block contained 20 CVCV and CVCCVC words. In Grade 2 the last block consisted of only 12 words. In each block half the words were pseudowords. In Grade 4 seventy-five participants performed this test. The internal consistency (Cronbach’s $\alpha$) was found to be .96, .95 and .92 for Grade 2, 3 and 4, respectively.

2.3.5 Reading and spelling measures in Dutch

Word reading fluency. The Drie Minuten Test (DMT) [Three Minute Test] (Verhoeven, 1995) consists of three word cards of increasing difficulty. The third card was administered in all grades. It consists of 120 words with multiple syllables. The child has to read aloud as many words as possible in one minute. The test score was the number of words read correctly in one minute on the third word card. Reliabilities were reported to be over .86 (Moelands, Kamphuis, & Verhoeven, 2003).

Pseudoword reading fluency. The Klepel (van den Bos et al., 1994) is a single pseudoword reading task, which requires phonological recoding. It consists of 116 pseudowords of increasing difficulty. The child is required to read aloud as many words as possible in two minutes. Parallel test reliabilities were reported to be over .89 (van den Bos et al., 1994).

Spelling ability. Scores from the schools were obtained for spelling ability. Spelling ability was measured with a spelling dictation test from the Dutch pupil monitoring system (from the Dutch National Institute for Measurement in Education, Cito). Different dictation tests were used for each grade (M4, M5, and M6; van den Bosch, Gillijns, Krom, & Moelands, 1997). All the spelling tests consist of mono- and polysyllabic words with orthographic patterns of various complexities. Scores were reported into ‘scale-scores’ to compare over grades. Reliability (accuracy of measurement (MAcc)) was reported to be above .86 (Moelands & Kamphuis, 2001).
2.3.6 Vocabulary

Receptive vocabulary. Receptive vocabulary (Verhoeven, 1993) scores in Grade 2 were obtained from the schools from the Dutch pupil monitoring system (Cito). The test consisted of 50 items of four pictures. The teacher named a word and the children had to mark the correct picture which belonged to the word. This task was used for practical reasons. Reliability is reported by the author to be over .90.

2.3.7 Procedure

All students from the six schools were tested in January – February in three consecutive years. The tasks were administered in two sessions. One individual session included all the paper and pencil tests and the other session the computerized tasks. Dependent on how many computers were available, one to ten children were tested at the same time. For practical reasons, all children received the same fixed order of the tests: word reversal and flashed (pseudo)word production. In a separate session the paper and pencil tests were administered in the following order: three minutes test (Card 3), sound deletion, Klepel, and rapid naming digits. The orthographic choice task was administered in class. The scores of the vocabulary task and spelling task were retrieved from the school (Dutch pupil monitoring system). These tasks were administered by the classroom teacher.

2.3.8 Analyses

To investigate the predictors of (pseudo)word reading fluency and spelling ability we used multilevel (or mixed) modeling. This statistical technique has a number of advantages over repeated measures ANOVA, with its restrictive assumptions, or structural equation modeling, that requires a much larger ratio of sample size over the number of variables in the
analysis. First, multilevel modeling has the advantage that it is possible to take different patterns of missingness into account while still making use of all available data. Second, it is possible to consider various longitudinal (autoregressive) structures in addition to compound symmetry. Third, it is possible to simultaneously investigate the effect of fixed predictors (e.g., sex) and a number of time-varying predictors (e.g., repeatedly administered reading related tasks). Fourth, it is possible to simultaneously investigate the effects on reading fluency and the effects on changes in reading fluency.

To investigate change in reading fluency and predictors of change, we conducted a four-step multilevel analysis (procedure Mixed from the Statistical Package for the Social Sciences version 15.0) in which the measurement occasions were treated as nested within pupils. For each of the three dependent variables (word reading fluency, pseudoword reading fluency, and spelling ability), we first fitted a model with a random intercept, representing mean baseline scores at Time 1, and two fixed regressions representing deviations from baseline at Time 2 and Time 3. With this so-called “fixed occasion” model (Snijders & Bosker, 1999) we used likelihood-ratio tests to investigate which longitudinal covariance structure provided the best fit: compound symmetry, autoregressive structure or unstructured. In the second step, we added predictor variables with fixed effects. After stepwise removal of insignificant effects, only predictors with significant effects were retained in Model 2. In the third step, we added interaction effects between predictor variables and time to investigate predictors of change. Only the significant effects were retained in Model 3. In the fourth and final step, we checked for random effects, to investigate whether the effects varied among children. Again, we only retained random effects that improved model fit significantly.
2.4 Results

When a principal component analysis with oblique transformation (because of possible correlations between the factors) was performed on all measures (except the dependent (pseudo)word reading fluency and spelling ability), a four factor solution was extracted that explained 75% of the variance (see Table 2.1 for the factor loadings). The first factor with an eigenvalue of 7.99 consisted of the orthographic processing tasks (i.e., orthographic choice and flashed (pseudo)word production) of the three years (factor loadings between .64 - .91). The second factor with an eigenvalue of 1.71 consisted of rapid serial naming of digits of all years (factor loadings between .67 - .88). The third factor with an eigenvalue of 1.27 consisted of both phoneme awareness tasks (i.e., word reversal and sound deletion) of all years (factor loadings between .51 - .87). The last factor existed of only Grade 2 vocabulary (eigenvalue 1.04, factor loading .98).

Table 2.1
Principal component loadings on all independent variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word reversal G4</td>
<td>.51</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Deletion G4</td>
<td></td>
<td>.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthographic choice G4</td>
<td>.86</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Flashed production¹ G4</td>
<td>.92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid serial naming G4</td>
<td></td>
<td>.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reversal G3</td>
<td></td>
<td></td>
<td>.70</td>
<td></td>
</tr>
<tr>
<td>Deletion G3</td>
<td></td>
<td></td>
<td>.87</td>
<td></td>
</tr>
<tr>
<td>Orthographic choice G3</td>
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<td></td>
</tr>
<tr>
<td>Rapid serial naming G3</td>
<td></td>
<td></td>
<td>.88</td>
<td></td>
</tr>
<tr>
<td>Word reversal G2</td>
<td></td>
<td></td>
<td>.56</td>
<td>.83</td>
</tr>
<tr>
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<tr>
<td>Rapid serial naming G2</td>
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<td>.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary G2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Accounted for 75% of the variance.

G4 = Grade 4; G3 = Grade 3; G2 = Grade 2.

¹Flashed production = Flashed (pseudo)word production.
2.4.1 Word reading fluency

Parameter estimates for the word reading fluency model are given in Table 2.2. The longitudinal covariance structure was best described by a first-order autoregressive structure with an autocorrelation of .84 - .91, where the variance over time was the same, but the covariance depended on the time interval (Hox, 2002). In Model 1 significant effects for Time 2 (20.69) and Time 3 (32.64) indicated significant improvement in word reading fluency. In Model 2, orthographic choice, flashed (pseudo) word production, rapid serial naming, phoneme awareness (both deletion and word reversal), and Grade 2 vocabulary contributed significantly to the explanation of word reading fluency.

Model 3 showed that the effect of rapid serial naming changed over time. The effect was significantly larger on Time 2 (Grade 3) and Time 3 (Grade 4) than in Time 1 (Grade 2). The effect of the other predictors remained the same throughout the grades. As an aside we note that when only orthographic choice was added to the model, there was an interaction with time: the effect for Time 3 was larger than for Time 1. However, when other predictors were entered this interaction effect disappeared. The model fit including this interaction effect of orthographic choice did not improve significantly ($\chi^2 = 1.44, df = 2, p > .05$).

In the final model (Model 4 in Table 2.2) a random effect of orthographic choice was added. It improved the model fit significantly ($\chi^2 = 10.25, df = 1, p = 0.0014$), indicating that the effect of orthographic choice on word reading fluency varied across children. After inclusion of interaction effects in Model 3 and random effects in Model 4, the fixed effect of word reversal on word reading fluency was no longer significant. When the predictors were added (Model 2) in comparison with the model with only the three measurement occasions of word reading fluency (Model 1), 80% of the variance between the children was explained. In addition, 2% was explained by including interaction effects between Time and rapid serial naming, and an additional 11% (93%) was explained by including a random effect of orthographic choice.
Table 2.2
Parameter estimates (regression coefficients and standard errors) for multilevel models of word reading fluency

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>(1.71)</td>
<td>-14.21</td>
<td>(9.64)</td>
</tr>
<tr>
<td></td>
<td>20.69**</td>
<td>(.74)</td>
<td>-2.31</td>
<td>(1.57)</td>
</tr>
<tr>
<td></td>
<td>32.64**</td>
<td>(1.02)</td>
<td>-1.83</td>
<td>(2.09)</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>.66**</td>
<td>(.20)</td>
<td>.63**</td>
<td>(.19)</td>
</tr>
<tr>
<td>Deletion</td>
<td>.31**</td>
<td>(.12)</td>
<td>.24*</td>
<td>(.11)</td>
</tr>
<tr>
<td>Word reversal</td>
<td>.30**</td>
<td>(.11)</td>
<td>.20</td>
<td>(.11)</td>
</tr>
<tr>
<td>RAN</td>
<td>-.58**</td>
<td>(.11)</td>
<td>-.26**</td>
<td>(.14)</td>
</tr>
<tr>
<td>Ortho choice¹</td>
<td>.51**</td>
<td>(.07)</td>
<td>.49**</td>
<td>(.07)</td>
</tr>
<tr>
<td>Flashed (pseudo)word production</td>
<td>.74**</td>
<td>(.09)</td>
<td>.85**</td>
<td>(.09)</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time2*ran</td>
<td>-.48**</td>
<td>(.17)</td>
<td>-.47**</td>
<td>(.17)</td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time3*ran</td>
<td>-1.20**</td>
<td>(.27)</td>
<td>-1.08**</td>
<td>(.26)</td>
</tr>
<tr>
<td>Between pupil</td>
<td>372.82**</td>
<td>(42.46)</td>
<td>101.14**</td>
<td>(10.25)</td>
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<td>variance</td>
<td></td>
<td></td>
<td>93.10**</td>
<td>(9.16)</td>
</tr>
<tr>
<td>Autoregression</td>
<td>.91**</td>
<td>(.01)</td>
<td>.59**</td>
<td>(.06)</td>
</tr>
<tr>
<td>coefficient</td>
<td></td>
<td></td>
<td>.57**</td>
<td>(.06)</td>
</tr>
<tr>
<td>Random Ortho</td>
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</tr>
<tr>
<td>choice¹</td>
<td></td>
<td></td>
<td></td>
<td>.02**</td>
</tr>
<tr>
<td>-.2log likelihood (df)</td>
<td>2920.80 (5)</td>
<td>2359.13 (11)</td>
<td>2338.90 (13)</td>
<td>2328.65 (14)</td>
</tr>
<tr>
<td>AIC²</td>
<td>2930.80</td>
<td>2381.13</td>
<td>2364.90</td>
<td>2356.65</td>
</tr>
<tr>
<td>Explained variance within pupils</td>
<td>.72</td>
<td>.75</td>
<td>.86</td>
<td></td>
</tr>
<tr>
<td>Explained variance between pupils</td>
<td>.80</td>
<td>.82</td>
<td>.93</td>
<td></td>
</tr>
</tbody>
</table>

Note. ¹ Ortho = Orthographic; ² AIC=Akaike’s Information Criterion.
Model 1: predicted by time; Model 2: predicted by time and main effects; Model 3: predicted by time, main effects, and interaction effects; Model 4: predicted by time, main effects, interaction effects, and random effect.

2.4.2 Pseudoword reading fluency

Parameter estimates for the pseudoword reading fluency model are given in Table 2.3. The longitudinal covariance structure was best described by a heterogeneous first-order autoregressive structure where the variances for the three times were different, but the covariances depended on the time...
interval (Hox, 2002). The variances appeared to be larger further in time (i.e., at a later age). There was an autocorrelation of .84–.89.

In Model 1, significant effects of Time 2 (12.20) and Time 3 (20.68) indicated growth in pseudoword reading fluency. In Model 2, orthographic choice, flashed (pseudo)word production, rapid serial naming, and phoneme awareness (both deletion and word reversal) contributed significantly to the prediction of pseudoword reading fluency. Grade 2 vocabulary had no single effect on predicting pseudoword reading fluency, not even a contribution when no other predictors were entered. Therefore, this predictor was not added in the final model.

Model 3 showed that the effect of rapid serial naming changed over time. The effect was significantly larger in Time 2 (Grade 3) and Time 3 (Grade 4) than in Time 1 (Grade 2). The effect of orthographic choice of Time 3 being larger than in Time 1 just missed significance. The effect of the other predictors remained the same throughout the grades. In the final model (Model 4 in Table 2.3) a random effect of orthographic choice was added. It improved the model fit significantly ($\chi^2 = 8.02, df = 1, p = 0.005$) indicating that the effect of orthographic choice on pseudoword reading fluency varied across children. After inclusion of the interaction effects, the interaction effect for orthographic choice Time 3 just missed significance ($p = .055$). However, it improved the fit of the final model, therefore this interaction effect did appear in the third and fourth model ($\chi^2 = 6.18, df = 2, p = 0.046$).

When the predictors were added (Model 2) in comparison with the model with only the three measurement occasions of pseudoword reading fluency (Model 1), 70% of the variance between the children was explained. By including interaction effects between Time and rapid serial naming and orthographic choice 4% was added, and an additional 19% (in total 93%) was explained by including a random effect of orthographic choice.
Table 2.3
Parameter estimates (regression coefficients and standard errors) for multilevel models of pseudoword reading fluency

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>36.38**</td>
<td>22.43**</td>
<td>15.77**</td>
<td>16.52**</td>
</tr>
<tr>
<td></td>
<td>(1.44)</td>
<td>(4.66)</td>
<td>(4.97)</td>
<td>(4.84)</td>
</tr>
<tr>
<td>T2</td>
<td>12.20**</td>
<td>-5.20**</td>
<td>15.06**</td>
<td>15.55**</td>
</tr>
<tr>
<td></td>
<td>(.75)</td>
<td>(1.54)</td>
<td>(6.09)</td>
<td>(6.18)</td>
</tr>
<tr>
<td>T3</td>
<td>20.68**</td>
<td>-5.88**</td>
<td>-73.00</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>(1.04)</td>
<td>(2.16)</td>
<td>(13.45)</td>
<td>(11.76)</td>
</tr>
<tr>
<td>Deletion</td>
<td>.47**</td>
<td>.40**</td>
<td>.38**</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>(.11)</td>
<td>(.11)</td>
<td>(.11)</td>
<td>(.11)</td>
</tr>
<tr>
<td>Word reversal</td>
<td>.30**</td>
<td>.24*</td>
<td>.24*</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>(.11)</td>
<td>(.11)</td>
<td>(.11)</td>
<td>(.11)</td>
</tr>
<tr>
<td>RAN</td>
<td>-.59**</td>
<td>-.34**</td>
<td>-.33**</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>(.11)</td>
<td>(.12)</td>
<td>(.12)</td>
<td>(.12)</td>
</tr>
<tr>
<td>Ortho choice¹</td>
<td>.32**</td>
<td>.30**</td>
<td>.27**</td>
<td>.07</td>
</tr>
<tr>
<td></td>
<td>(.06)</td>
<td>(.07)</td>
<td>(.07)</td>
<td>(.07)</td>
</tr>
<tr>
<td>Flashed (pseudo)word</td>
<td>.47**</td>
<td>.59**</td>
<td>.57**</td>
<td>.08</td>
</tr>
<tr>
<td>production</td>
<td>(.08)</td>
<td>(.08)</td>
<td>(.08)</td>
<td>(.08)</td>
</tr>
<tr>
<td>Interaction</td>
<td>-.65**</td>
<td>-.63**</td>
<td>-.71**</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>(.16)</td>
<td>(.16)</td>
<td>(.27)</td>
<td>(.13)</td>
</tr>
<tr>
<td>Interaction Time2*ran</td>
<td>-.77*</td>
<td>-.71**</td>
<td>.27</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>(.30)</td>
<td>(.15)</td>
<td>(.15)</td>
<td>(.13)</td>
</tr>
<tr>
<td>Interaction Time2*ortho</td>
<td>-.05</td>
<td>-.05</td>
<td>.26</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>(.06)</td>
<td>(.06)</td>
<td>(.13)</td>
<td>(.13)</td>
</tr>
<tr>
<td>Interaction Time3*ortho</td>
<td>.27</td>
<td>.26</td>
<td>.26</td>
<td>.26</td>
</tr>
<tr>
<td></td>
<td>(.15)</td>
<td>(.13)</td>
<td>(.13)</td>
<td>(.13)</td>
</tr>
<tr>
<td>Variance T1</td>
<td>268.24**</td>
<td>85.66**</td>
<td>82.20**</td>
<td>45.19**</td>
</tr>
<tr>
<td></td>
<td>(33.20)</td>
<td>(11.56)</td>
<td>(10.93)</td>
<td>(8.61)</td>
</tr>
<tr>
<td>Variance T2</td>
<td>335.98**</td>
<td>122.05**</td>
<td>105.90**</td>
<td>42.21**</td>
</tr>
<tr>
<td></td>
<td>(41.83)</td>
<td>(17.10)</td>
<td>(14.78)</td>
<td>(13.55)</td>
</tr>
<tr>
<td>Variance T3</td>
<td>357.39**</td>
<td>154.96**</td>
<td>131.98**</td>
<td>43.24**</td>
</tr>
<tr>
<td></td>
<td>(44.10)</td>
<td>(24.73)</td>
<td>(20.63)</td>
<td>(16.43)</td>
</tr>
<tr>
<td>Autoregression coefficient</td>
<td>.89**</td>
<td>.67**</td>
<td>.65**</td>
<td>.24</td>
</tr>
<tr>
<td></td>
<td>(.02)</td>
<td>(.05)</td>
<td>(.05)</td>
<td>(.17)</td>
</tr>
<tr>
<td>Random Ortho choice¹</td>
<td>.03**</td>
<td>.03**</td>
<td>.03**</td>
<td>.03**</td>
</tr>
<tr>
<td></td>
<td>(.007)</td>
<td>(.007)</td>
<td>(.007)</td>
<td>(.007)</td>
</tr>
</tbody>
</table>

-2log likelihood (df)  2931.161 (7)  2379.707 (12)  2354.822 (16)  2343.278 (17)
AIC²                    2945.161  2403.707  2354.822  2377.278
Explained var.³ within pupils .62  .67  .86
Explained var.³ between pupils .70  .74  .93

Note. ¹Ortho = Orthographic; ²AIC=Akaike’s Information Criterion; ³var. =variance.
Model 1: predicted by time; Model 2: predicted by time and main effects; Model 3: predicted by time, main effects, and interaction effects; Model 4: predicted by time, main effects, interaction effects, and random effect.
* p < .05, ** p < .01, † p = .055.
2.4.3 Spelling ability

Parameter estimates for the spelling ability model are given in Table 2.4. The longitudinal covariance structure of spelling ability, just as for pseudoword reading fluency, was best described by a heterogeneous first-order autoregressive structure with an autocorrelation of .61-.72. The variances appeared to be larger further in time (i.e., at a later age).

In Model 1, significant effects for Time 2 (7.54) and Time 3 (18.38) showed improvement in spelling ability. In Model 2, orthographic choice, rapid serial naming, phoneme awareness (both deletion and word reversal), and word reading fluency contributed significantly to the explanation of spelling ability. Both flashed (pseudo)word production and Grade 2 vocabulary had no single effect on predicting spelling ability. Grade 2 vocabulary did not even predict spelling ability with no other predictors entered. Therefore these predictors were not added to the final model.

Model 3 showed that the effect of sound deletion changed over time. The effect was significantly larger in Time 3 (Grade 4) than in Time 1 (Grade 2). The effect of the other predictors remained the same throughout the grades. In the final model (Model 4 in Table 2.4) a random effect of sound deletion was added. It improved the model fit significantly ($\chi^2 = 6.43, df = 1, p = 0.011$), indicating that the effect of sound deletion on spelling ability varied across children. It should be noted that rapid serial naming had a suppression effect in predicting spelling ability (see Discussion).

When the predictors were added (Model 2) in comparison with the model with only the three measurement occasions of spelling ability (Model 1), 73% of the variance between the children was explained. By including interaction effects between Time and sound deletion 2% was added, and an additional 12% was explained by including a random effect of sound deletion, making the total variance explained by the final model (Model 4) 87%.
Table 2.4
Parameter estimates (regression coefficients and standard errors) for multilevel models of spelling ability

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>119.06** (70)</td>
<td>94.39** (74)</td>
<td>95.58** (2.89)</td>
<td>95.66** (2.79)</td>
</tr>
<tr>
<td>T2</td>
<td>7.54** (52)</td>
<td>.44 (87)</td>
<td>-.18 (2.01)</td>
<td>.38 (1.96)</td>
</tr>
<tr>
<td>T3</td>
<td>18.38** (79)</td>
<td>7.70** (1.13)</td>
<td>-4.23 (2.88)</td>
<td>-3.27 (2.70)</td>
</tr>
<tr>
<td>Deletion</td>
<td>.34** (0.6)</td>
<td>.21** (0.9)</td>
<td>.22** (0.9)</td>
<td></td>
</tr>
<tr>
<td>Word reversal</td>
<td>.15* (0.6)</td>
<td>.13** (0.6)</td>
<td>.13* (0.6)</td>
<td></td>
</tr>
<tr>
<td>RAN</td>
<td>.13* (0.7)</td>
<td>.15* (0.7)</td>
<td>.15* (0.6)</td>
<td></td>
</tr>
<tr>
<td>Orthographic choice</td>
<td>.21** (0.4)</td>
<td>.23** (0.4)</td>
<td>.22** (0.4)</td>
<td></td>
</tr>
<tr>
<td>Word reading</td>
<td>.12** (0.3)</td>
<td>.12** (0.2)</td>
<td>.11** (0.2)</td>
<td></td>
</tr>
<tr>
<td>fluency (DMT3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>.05 (11)</td>
<td>.04 (11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time2*deletion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td></td>
<td>.62** (14)</td>
<td>.59** (14)</td>
<td></td>
</tr>
<tr>
<td>Time3*deletion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance T1</td>
<td>62.17** (55)</td>
<td>32.54** (4.9)</td>
<td>32.30** (4.05)</td>
<td>25.90** (3.84)</td>
</tr>
<tr>
<td>Variance T2</td>
<td>51.86** (6.62)</td>
<td>19.10** (2.46)</td>
<td>18.80** (2.40)</td>
<td>11.86** (2.69)</td>
</tr>
<tr>
<td>Variance T3</td>
<td>88.30** (11.25)</td>
<td>40.80** (5.43)</td>
<td>34.63** (4.51)</td>
<td>26.38** (4.25)</td>
</tr>
<tr>
<td>Autoregression</td>
<td>.71** (0.4)</td>
<td>.25** (0.7)</td>
<td>.23** (0.7)</td>
<td>-.05 (1.2)</td>
</tr>
<tr>
<td>coefficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random Deletion</td>
<td></td>
<td></td>
<td></td>
<td>.02** (0.06)</td>
</tr>
<tr>
<td>-2log likelihood (df)</td>
<td>2458.628 (7)</td>
<td>2309.565 (12)</td>
<td>2289.366 (14)</td>
<td>2279.928 (15)</td>
</tr>
<tr>
<td>AIC</td>
<td>2472.628</td>
<td>2333.565</td>
<td>2317.366</td>
<td>2309.928</td>
</tr>
<tr>
<td>Explained variance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>within pupils</td>
<td>.54</td>
<td>.58</td>
<td>.68</td>
<td></td>
</tr>
<tr>
<td>Explained variance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>between pupils</td>
<td>.73</td>
<td>.75</td>
<td>.87</td>
<td></td>
</tr>
</tbody>
</table>

*Note. AIC= Akaike’s Information Criterion.
Model 1: predicted by time; Model 2: predicted by time and main effects; Model 3: predicted by time, main effects, interaction effects; Model 4: predicted by time, main effects, interaction effects, and random effect.
* p < .05, ** p < .01, † p = .056.

2.5 Discussion

To confirm the correct operationalization of the theoretical concepts, the principal component analysis demonstrated that both word-specific orthographic knowledge and fast identification of larger orthographic units in a brief exposure task with words and pseudowords loaded on the same factor and was a stable orthographic processing factor over the three years.
The same was true for the phoneme awareness factor (sound deletion and word reversal). However, it should be noted that in all grades sound deletion had a higher factor loading. Rapid serial naming over the three years and vocabulary were two additional separate factors.

Orthographic processing, as measured with word-specific orthographic knowledge and fast identification of larger orthographic units, is an important predictor of Dutch polysyllabic word reading fluency, in addition to phoneme awareness, rapid serial naming, and initial level of vocabulary. Furthermore, from the high autocorrelations it appeared that reading ability in Grade 2 is strongly related to later reading skills. The results showed that, contrary to the predictions based on the results of other studies, the role of phoneme awareness did not diminish over grades. The effect over the years remained the same. In accordance with the predictions, the role of rapid serial naming became stronger during the years. Moreover, there was individual variability in word-specific orthographic knowledge, meaning that there are substantial differences between children.

Orthographic processing is also an important predictor of pseudoword reading fluency, in addition to phoneme awareness and rapid serial naming. As expected, vocabulary had no influence in predicting pseudoword reading fluency. Again, high autocorrelations indicated that pseudoword reading ability in Grade 2 is strongly related to later pseudoword reading skills. Furthermore, comparable to word reading fluency, the role of rapid serial naming became stronger over the years. Phoneme awareness was also important, but the effect remained the same over the years. There was a trend to significance that the influence of word-specific orthographic knowledge on pseudoword reading fluency became stronger, which gives some support to the view that word-specific orthographic knowledge may be used to identify unfamiliar words (see also the neighbourhood effect, e.g., Andrews, 1997; Marinus & de Jong, 2010). As in word reading fluency, there was individual variability in word-specific orthographic knowledge between the children.

To predict spelling ability, only word-specific orthographic knowledge played a significant role, whereas fast identification of larger orthographic
units had no additive role. Apparently, fast (sub)lexical orthographic processing, measured with a brief exposure task, is not crucial for spelling ability. However, word reading fluency was essential. As predicted, phoneme awareness contributed to the prediction and rapid serial naming did not. The effect of phoneme awareness (sound deletion) became stronger during the years, and there was individual variability in sound deletion between the children.

The central issue in the present study was the role of orthographic processing. When controlled for phoneme awareness, rapid serial naming and initial level of vocabulary, orthographic processing predicted word and pseudoword reading fluency. This suggests that orthographic processing is especially important in the phase when the precise and redundant connections between orthographic and phonemic representations of polysyllabic words are learned and automatized (Booth et al., 1999; Verhoeven & van Leeuwe, 2009). Moreover, the individual variability in word-specific orthographic knowledge that was found among older dyslexics (Bekebrede et al., 2009; 2010) seemed already to be present in younger persons across the entire reading ability range, adding to the prediction of word and pseudoword reading fluency.

With regard to the individual variability, an additional exploratory analysis was carried out to investigate whether poor young readers would also show larger individual variability in orthographic processing than in phonological processing. This was found in young adolescents and adults (the phonological-core variable-orthographic differences model; van der Leij & Morfidi, 2006; Bekebrede et al., 2009). Confirming the model, poor readers defined as the lowest 25% in Grade 4 on word reading fluency with better orthographic processing in Grade 4 – with equal orthographic processing compared to average readers in Grade 4 –, performed the same on phoneme awareness, rapid serial naming, and reading comprehension (in Grade 4 as well as in Grade 2 and 3) as the poor readers with worse orthographic processing. However, they were better on polysyllabic word reading in Grade 4 and showed a trend to do better on spelling. Important to note, that it did not matter for these results if orthographic processing was
seen as a composite of word-specific orthographic knowledge and fast identification of larger orthographic units, or was seen as solely word-specific knowledge. The compensatory mechanism of gathering orthographic knowledge already seems to be present at this age and is starting to give an advantage, as was the case in young adolescents. Therefore, due to the variability in word-specific orthographic knowledge, there are children who, at least from Grade 4 upwards, could escape from the constraints of phonological recoding and exchange more serial processing (fast grapheme to phoneme conversion) for parallel processing using larger orthographic units.

The present study also showed that, in accordance with other studies, rapid serial naming was essential to predict reading fluency and it became more important during the years (e.g., de Jong & van der Leij, 2003; Kirby et al., 2003; Landerl & Wimmer, 2008; Vaessen & Blomert, 2010; Wimmer & Mayringer, 2002). When children understand the basic phonological principles in combination with reading experience, the relationship between the lexical access and retrieval of names of well known symbols (e.g., digits) and reading fluency grows stronger (van den Bos et al., 2002; van den Broeck et al., 2010). However, it is important to note that the additional role of orthographic processing in predicting word reading fluency supports the view that the retrieval of orthographic knowledge is different from the retrieval of symbol knowledge, in accordance with Moll et al. (2009).

Most longitudinal studies in a relative transparent orthography have indicated that phoneme awareness is only a strong predictor in the early phases of reading acquisition. In later grades it has not an additional effect on top of earlier reading skills (Kirby et al., 2003; Landerl & Wimmer, 2008), although it remained an important concurrent predictor (Lervåg et al., 2009). In the present study phoneme awareness remained important in predicting both word and pseudoword reading fluency, similar to the findings of Cardoso-Martins and Pennington (2004) and Roman, Kirby, Parrila, Wade-Woolley, and Deacon (2009). The differences between the studies may be that phoneme awareness tasks are not sensitive enough to have a large predictive role when administered very early in the reading.
acquisition process (i.e., kindergarten). In this phase it is about initial phoneme awareness: awareness of sounds without mapping them to graphemes. During reading development letter knowledge and reading skills influence phoneme awareness (Snowling, 2000). Therefore, when phoneme awareness is administered in the fluency period with tasks of appropriate difficulty, it might be more sensitive to predict reading fluency. In this phase it is about more advanced phoneme awareness, the tasks that are administrated are more complex. For example, whereas blending and rhyming – initial phoneme awareness – do not differentiate children, sound deletion does (Bosse, Tainturier, & Valdois, 2007; de Jong & van der Leij, 2003; Hulme et al., 2002; Wesseling & Reitsma, 2000). Moreover, the present study used polysyllabic words as a dependent variable. It may be argued that phoneme processing at the segmental level is important in reading polysyllabic words, which are more complex to identify than monosyllabic words.

The role of initial level of vocabulary differed in the prediction of word and pseudowords reading fluency, in agreement with the predictions. When familiar (existing) words are used, vocabulary has an influence, whereas vocabulary does not play a role in the prediction of non-familiar (non-existing) words (de Jong & van der Leij, 2002; Wood, 2009).

The present study also addressed the prediction of spelling ability. In this phase of spelling acquisition phoneme awareness has an increasing influence on spelling proficiency (Treiman & Bourassa, 2000). Besides, there existed individual variability in phoneme awareness. The spelling ability was dependent of the individual performance of phoneme awareness. Both word-specific orthographic knowledge and reading polysyllabic words had an additive value in predicting spelling ability. Reading polysyllabic words stresses the need to process larger orthographic units, such as morphemes. It is well-known that morpheme knowledge is important in spelling ability (Treiman & Bourassa, 2000). The contribution of word-specific orthographic knowledge supports the view that lexical representations are important for accurate spelling (Perfetti, 1992). However, fast identification of larger orthographic units, measured with a
brief exposure task, did not contribute significantly to the prediction of spelling ability. Apparently, rapid identification of orthographic units does not play a role in spelling, which is dictated by the relatively slow and elaborate process of phonology to orthography mapping.

With regard to the present study, there are three methodological issues that needed to be discussed. Firstly, although the principal component analysis demonstrated that both phoneme awareness measures loaded on a single factor with higher loadings for sound deletion, representing a relatively stable phoneme awareness factor over the three years, sound deletion added a significant contribution to the final model of predicting word reading fluency, but the other measure of phoneme awareness, word reversal, did not. In contrast, in predicting pseudoword reading fluency and spelling ability sound deletion and word reversal contributed both to the prediction. There is a possibility that sound deletion is a better measure for segmental phonology than word reversal. Moreover, in pseudoword reading fluency and spelling ability the role of phoneme awareness is more stressed (Treiman & Bourassa, 2000) whereby both measures had a contribution.

Secondly, the principal component analysis also indicated that the brief exposure task and the orthographic choice task loaded on a single factor, representing a relatively stable orthographic processing factor over the three years. Although it has been suggested in an earlier section that the absence of a contribution of the brief exposure task to the prediction of spelling may be related to the relatively slow spelling mechanisms, it should be noted that for practical reasons not all children performed this brief exposure orthographic processing task in the last year (Grade 4). Therefore the additional gaining or predictive value may have been restricted. However, \(t\)-tests showed no systematic relationship between missingness among average readers on this brief exposure task in Grade 4 and this brief exposure task a year earlier (Grade 3) \(t(70.6) = -0.9, p = .39\). Thirdly, in predicting spelling ability, rapid serial naming had a negative effect. It seems that rapid serial naming suppressed the relation between word reading fluency and spelling. Apparently, there is irrelevant variance on rapid serial naming, which is not related to spelling ability. Both rapid serial naming
and word reading fluency involve speed, which is not common for spelling ability. It could be that this relation affects the predictive power of rapid serial naming to spelling ability, and therefore a negative effect arose and the influence of word reading fluency was enhanced. When rapid serial naming was excluded from the prediction, the effect of reading fluency was smaller (although still significant), suggesting that in predicting spelling ability speed is not crucial in Grade 2 to 4.

In sum, the most important contribution of the present study to the available evidence is that orthographic processing, operationalized as word-specific orthographic knowledge and fast identification of larger orthographic units, is an important predictor for word and pseudoword reading fluency and spelling ability in a relatively transparent language, in addition to phoneme awareness and rapid serial naming (and vocabulary in the case of word reading fluency). Orthographic processing is a stable and distinct factor from phoneme awareness and rapid serial naming over the three years. Therefore, orthographic processing should be incorporated in future longitudinal research in investigating gaining fluency.
Abstract

The phonological-core variable-orthographic differences (PCVOD) model (van der Leij & Morfidi, 2006) has been proposed as an explanation for the heterogeneity among dyslexic readers in their profiles of reading-related subskills. The predictions of this model were investigated in a sample of 72 Dutch secondary school students (dyslexics and controls). First, the PCVOD assumption was confirmed that phonological processing and orthographic competence are independent contributors to the prediction of reading fluency and spelling. Among the phonological processing tasks, phonological recoding explained substantial unique variance, but not phonemic awareness or rapid serial naming. Next, the dyslexic readers were divided into two subgroups based on high (ORTH+) and low levels (ORTH-) of orthographic competence. Both subgroups performed below controls on all measures tapping phonological processing, reading and spelling but the ORTH+ group performed as well as non-disabled controls on Dutch and English orthographic choice. As predicted by the model, there were no differences between the subgroups on the tasks that depend on phonological processing, with or without reading. There were differences on Dutch word reading fluency and spelling. Furthermore, the ORTH+ subgroup outperformed ORTH- on tasks demanding speeded word processing such as “flashed” presentation. This finding was independent of lexicality (words or pseudowords), language (Dutch or English) or response mode (lexical decision or typing), but restricted to silent reading. This supports the view that the ORTH+ subgroup is better at identifying larger orthographic units. There was no indication of differences between the subgroups in reading experience. Our data, therefore, support the PCVOD model.

3.1 Introduction

Over the last few decades there has been a great deal of research investigating the causes of developmental dyslexia (see for recent reviews, Beaton, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Because reading acquisition is a complex process generating large individual differences (Share & Stanovich, 1995), the population of dyslexic children is not homogenous with respect to all reading-related subskills. Whereas there is consensus among researchers that the core problem in dyslexia lays in phonological processing deficits (Bailey, Manis, Pedersen, & Seidenberg, 2004; Vellutino et al., 2004), there is no consensus as regards the heterogeneity in subskills that are less reliant on phonological processing (Bailey et al., 2004; Bosse, Tainturier, & Valdois, 2007; Castles & Coltheart, 1993; Wolf & Bowers, 1999). The present study investigates one of these possible sources of the heterogeneity in cognitive functioning of dyslexics: orthographic competence.

First, it will be argued that phonological processing is a universal subskill of reading an alphabetic language, independent of orthographic complexity. Evidence supporting the phonological deficit as a theory of dyslexia will be briefly reviewed. We then outline arguments supporting the claim that orthographic competence is an independent predictor of reading development and, furthermore, may be the source of variable differences within the group of dyslexics.

3.1.1 Universality of phonological processing

It is well established that phonological processing is crucial in learning to read. Although the term phonological processing is normally used to refer to a variety of tasks tapping perception, learning, and memory for speech-based (phonological) information (see e.g., Shankweiler & Fowler, 2004; Share, 1995; Wagner & Torgesen, 1987), phonemic awareness represents the most comprehensively investigated constituent of the phonological
processing constellation. Phonemic awareness, the understanding that a spoken word consists of a sequence of sounds and the ability to manipulate those sounds, has been shown to be one of the most potent predictors of early reading (Bowey, 2005; Ehri, Nunes, Stahl, & Willows, 2001). Underlining the universality of phonemic awareness, cross-linguistic transfer has been found in bilingual studies with Spanish and English speaking children (Durgunoğlu, Nagy, & Hancin-Bhatt, 1993; Lindsey, Manis, & Bailey, 2003), in French/English speaking children (Comeau, Cormier, Grandmaison, & Lacroix, 1999), Hebrew/English (Geva & Siegel, 2000) and Russian/Hebrew children (Schwartz, Leikin, & Share, 2005). There is cross-linguistic transfer even in children who do not learn an alphabetic orthography. Gottardo, Yan, Siegel, and Wade-Woolley (2001) found that Chinese rhyme detection skills predict English reading skills in Chinese children learning English as a second language.

Another phonological processing variable, rapid serial naming, involves the quick retrieval of symbolic information from long-term memory (Jorm & Share, 1983; Wagner & Torgesen, 1987). Rapid serial naming, especially of digits and letters, plays a significant role in predicting reading. Cardoso-Martins and Pennington (2004) found that rapid naming of letters and digits in kindergarten predicted fluent reading and spelling in English, but was a weaker predictor of word and pseudoword reading accuracy. Phonemic awareness was found to be a more robust predictor, whereas rapid serial naming played only a modest role. However, in a study of young Dutch adolescents learning English as a second language, rapid serial naming was the strongest predictor of reading in both languages (Morfidi, van der Leij, de Jong, Scheltinga, & Bekebrede, 2007). It appears that in languages with more consistent one-to-one grapheme-phoneme mappings, rapid serial naming is a strong predictor of reading fluency at every age, whereas phonemic awareness only plays a major role in predicting reading among beginning readers. Once children have mastered the spelling-sound code (after grade one in transparent orthographies) it is harder to detect the independent contribution of phonemic awareness to reading performance because individual differences in a relatively consistent
orthography mainly concern speed of reading and not accuracy (e.g.,
German: Wimmer, Mayringer, & Landerl, 2000; Dutch: de Jong & van der
Leij, 1999). However, as is argued by Caravolas, Volín, and Hulme (2005),
psychometric qualities of the phonemic awareness measures may be
decisive in explaining the contrasting results (see also Morfidi et al., 2007).

Phonological processing is also implicated in phonological recoding,
given that phonological recoding is the ability to use grapheme-phoneme
translation and phoneme blending strategies to identify unfamiliar words.
As a consequence, it implies phonemic awareness and letter knowledge.
Because many words are unfamiliar to the young reader at the sight-word
level, they can be expected to be read by phonological recoding, using the
grapheme-phoneme correspondence rules. However, the more experienced
reader may also use phonological recoding when he has to read a word that
he has not seen before. To ensure unfamiliarity and trigger phonological
recoding, tasks with pseudowords have been used frequently in research.
Phonological recoding is the key mechanism in reading acquisition.
According to Share (1995), phonological recoding forms the basis for direct
word recognition because repeated (successful) recoding of unfamiliar
words acts as a self-teaching mechanism enabling the acquisition of word-
specific orthographic knowledge. This process of self-teaching mechanism
appears to be a universal means of bootstrapping the process of orthographic
learning not only in pointed Hebrew, which is a very shallow orthography
(Share, 1999; 2004), but also in moderately shallow Dutch (de Jong &
Share, 2007) and in English - the deepest of alphabetic orthographies
(Bowey & Miller, 2007; Bowey & Muller, 2005; Cunningham, 2006; Kyte

3.1.2 Orthographic competence as an additional independent
predictor

Phonological processing is not the only predictor of reading development.
Orthographic competence, often measured by lexical decision tasks,
contributes unique variance to word recognition even after controlling for phonological processing (i.e., phonological recoding and phonemic awareness) (Cunningham, Perry, & Stanovich, 2001). In addition, orthographic competence contributes unique variance after controlling for print exposure, in children as well as in adults (Cunningham, Perry, Stanovich, & Share, 2002; Cunningham & Stanovich, 1990; Stanovich & West, 1989). The contribution of orthographic competence has also been found to increase with age (Badian, 2001). Although orthographic competence as a contributor to reading development has received less attention than phonological processing in a cross-linguistic perspective, there are indications that it is an independent predictor in other languages and orthographies than English (e.g., in Chinese: Ho, Chan, Lee, Tsang, & Luan, 2004; Dutch: Morfidi et al., 2007).

It should be noted that there has been considerable debate about the role of orthographic processing skill with regard to word identification in reading and orthographic learning (see for reviews, Burt, 2006; Castles & Nation, 2006). Two main concerns have been voiced. One is that most studies do not involve measures of on-line orthographic processing as distinct from phonological recoding which is, by definition, process-oriented. Most tasks measure the outcome of the learning process, i.e., word-specific knowledge (lexical decision). As a consequence, most, if not all, studies do not contribute to the understanding of orthographic processing skill as a distinct component of word identification and reading acquisition. The second concern is that, to assess the contribution of orthographic processing skill to differences in reading development, the influence of factors such as phonological processing, reading experience and verbal competence should be taken into account first. Because the present study has relatively experienced readers as participants - on average, 15.5 years of age - it was not designed as a study of early orthographic learning and on-line orthographic processing, and cannot shed light on the first issue. By controlling the factors mentioned in the second issue (comparable to the studies of Cunningham et al., 2001; 2002), our study aimed to contribute to the understanding of individual differences, in particular the use of
orthographic knowledge. It therefore extends the existing literature in two ways. First, individual differences are studied in students who have learned to read and spell in their native Dutch, which has a relatively shallow orthography, and learn English as a second language. This is important because findings from English-language investigations should be verified in more transparent orthographies. Second, both reading and spelling are taken as variables to be predicted. To underscore the fact that orthographic processing is not measured in a direct way, the term orthographic competence will be used throughout this paper.

3.1.3 Universality of the phonological deficit

Cross-linguistically, it is well established that dyslexia is strongly related to deficits in phonological processing. There has been some debate about the specific role of phonemic awareness in relative consistent orthographies (see for example, Landerl & Wimmer, 2000; Caravolas et al., 2005). However, as is argued by de Jong and van der Leij (2003), it may be assumed that although the correlation between phonemic awareness and reading performance tends to decrease during primary school when the native language has a relatively shallow orthography, phonemic processing of dyslexic readers is still deficient at a later age, provided that the measures are sufficiently sensitive. With respect to rapid serial naming, there is strong evidence across languages that dyslexics are uniformly slower than controls (e.g., de Jong & van der Leij, 2003; Denckla & Rudel, 1974; Gallagher, Laxon, Armstrong, & Frith, 1996; Ho & Lai, 1999; Wimmer et al., 2000; Wolf, Bally, & Morris, 1986). Furthermore, a major characteristic of dyslexics is that they have problems in phonological recoding irrespective of the transparency of the orthography. The well-known finding that dyslexics have poor phonological recoding skills in English (Rack, Snowling, & Olson, 1992) can be generalized to languages with a more transparent orthography (e.g., Swedish: Miller-Guron & Lundberg, 2000; German: Landerl & Wimmer, 2000; Dutch: van der Leij & van Daal, 1999)
as well as in cross-linguistic studies (e.g., van der Leij & Morfidi, 2006). One of the most powerful paradigms for revealing the defective phonological recoding mechanism of dyslexics is by brief presentation of the stimulus word. Yap and van der Leij (1993a) were able to demonstrate that when dyslexics are required to read briefly presented words and pseudowords ("flashed" for 200 ms), they were more profoundly impaired on pseudowords compared to words, a result that the authors have interpreted as evidence of an “automatic decoding deficit”.

3.1.4 Variability in orthographic competence

Although most studies find differences in orthographic competence between groups of normal achieving students and dyslexics, there is evidence suggesting larger variability in orthographic competence within the group of dyslexics than in phonological processing, in particular, phonological recoding. The larger variability has been investigated in two studies. In a study with Swedish college students, Miller-Guron and Lundberg (2000) found a subgroup of dyslexic readers who read better in English than in their native Swedish, although Swedish has a transparent orthography. In contrast, another subgroup did not perform better in English than in Swedish. In a transparent script, words can be read using a grapheme-phoneme decoding strategy, whereas in English the abundant irregularity of grapheme-phoneme correspondences is likely to deter readers from using a similar strategy (Seymour, Aro, & Erskine, 2003; Ziegler & Goswami, 2005). Instead, it may be assumed that the greater orthographic irregularity of English is more favorable to a sight-word or a larger orthographic unit approach (e.g., orthographic neighbours) than to a grapheme-phoneme decoding strategy, in contrast to Swedish, where decoding would be favored. Apparently, some of the dyslexics in the study of Miller-Guron and Lundberg (2000) had the ability to use such orthographic skills in English whereas others did not.
In a similar study, van der Leij and Morfidi (2006) investigated Dutch dyslexic adolescents who began to learn English in secondary school. They also found a subgroup of dyslexic students who performed better in English than was expected based on their Dutch reading skills. This subgroup had superior orthographic knowledge in both Dutch and English compared to another subgroup of dyslexics who were comparable in phonological processing and Dutch reading but performed more poorly in orthographic knowledge in both languages and in English word reading.

The findings that within the group of dyslexics the phonological core deficit may be accompanied by variability in a processing domain that is less dependent on phonological processing may be conceptualized within the framework that Stanovich proposed for all poor readers - both dyslexic and non-dyslexic (Stanovich, 1988; see also, Stanovich & Siegel, 1994). His phonological-core variable-difference model states there is a core phonological deficit in children with dyslexia. Independent of this core deficit the performance in task related skills might vary considerably, most notably in general intelligence. Thus dyslexics, with performance in general intelligence in the normal range, share the same phonological deficit with poor readers who have subnormal intelligence, the garden-variety poor readers. The latter group, however, is characterized by additional non-phonological deficits that vary depending on IQ. In the same vain but restricted to the dyslexic group and the reading domain, van der Leij and Morfidi (2006) developed their phonological-core variable-orthographic differences model (PCVOD). The authors suggested that the differences between the two dyslexic subgroups in English could well be explained by the variable way the dyslexics performed in orthographic competence. The students with better orthographic competence may have favored reading strategies other than grapheme-phoneme decoding, and showed a “large orthographic unit preference” (van der Leij & van Daal, 1999; see also, Miller-Guron & Lundberg, 2000; Ziegler & Goswami, 2005). Because the subgroups were comparable in defective phonological processing in both languages, the findings support a model that postulates a universal phonological deficit in all dyslexics and a variable difference in
orthographic competence. The PCVOD model is the focus of the present study.

3.1.5 Orthographic competence in spelling

Thus far, orthographic competence has only been discussed with regard to reading. In reading, orthographic knowledge is the basis for recognizing words or large sublexical parts of words. In spelling, this same knowledge is important in a somewhat different way. The mapping of phonology to orthography, which is used for spelling however, is more variable than from orthography to phonology as required in reading (Fletcher-Flinn, Shankweiler, & Frost, 2004), thus making spelling more difficult to acquire than reading. Even in most transparent orthographies, there are discrepancies in regularity for reading and spelling (see Joshi & Aaron, 2005). Regularity usually refers to the grapheme-to-phoneme correspondences relevant to reading (so-called “forward” regularity), but there often are more irregularities in the phoneme-to-grapheme correspondences relevant to spelling (“backward” regularity). Because of these irregularities in phoneme-to-grapheme correspondences there are often more ways to spell a pronounced word than to read/pronounce a written word, even in relatively transparent orthographies such as Dutch and German (Bosman & van Orden, 1997; Wimmer & Mayringer, 2002). For example, the words *sleep* and *cheap* are both pronounced with the same vowel, but are spelled differently. Even knowing how to read these two words, a child required to spell a new unseen word containing the same vowel (e.g., *leap*), has no way of choosing between the two ways of spelling the vowel. Moreover, spelling is more difficult because it relies completely on representations in memory than reading that relies on identification and recognition processes (Fletcher-Flinn et al., 2004). It may be assumed that orthographic knowledge at all phonological levels - corresponding with single phonemes, speech sound clusters, and whole words - is a critical element in spelling (Ziegler, Stone, & Jacobs, 1997). There is evidence that
dyslexic readers have less orthographic knowledge than age controls at sixth grade as indicated by their poorer spelling performance (e.g., de Jong & van der Leij, 2003). Because spelling relies heavily on orthographic competence, the PCVOD model, if supported with regard to reading, also predicts substantial variability in spelling within the group of dyslexics.

3.2 Research questions

The preceding discussion suggests that both phonology and orthography are important in reading and spelling. Over and above phonological processing, therefore, orthographic competence might be a fruitful avenue for understanding the heterogeneity among dyslexics.

The first purpose of our study was to test the ‘phonological-core variable-orthographic differences’ (PCVOD) model within the context of a study designed to replicate and extend the work of van der Leij and Morfidi (2006). This model postulates a core phonological deficit common to all dyslexics, with co-existing differences in orthographic competence. Therefore our study made three major predictions:

(a) phonological processing and orthographic competence contribute independently to the explanation of variance in reading and spelling;
(b) all dyslexics suffer from a phonological core deficit;
(c) within the group of dyslexics there exists larger variability in orthographic competence than in phonological processing. Some dyslexics demonstrate relatively “normal” orthographic competence and outperform dyslexics with poorer orthographic competence in tasks that rely on orthographic competence.

3.3 Study design

Following Cunningham et al. (2001, p. 564), our first aim was to confirm that individual differences in orthographic competence are not parasitic on
phonological processing. Thus, orthographic competence should contribute to the prediction of word reading fluency after the variance accounted for by vocabulary and phonological processing had been partialed out. Accordingly, composites were constructed for phonological processing and orthographic competence. To control for phonological processing, phonological recoding (grapheme-phoneme translation) and a non-reading phonological composite were entered first in a regression analysis. In the last step, orthographic competence was entered to investigate whether it accounted for variance after phonological processing was partialed out.

After establishing the independent contribution of orthographic competence, variability in orthographic competence was further investigated by comparing two subgroups of poor readers. Both subgroups were equally poor in reading their native language (Dutch), but one subgroup performed significantly better in tests of orthographic competence. Similar to the study of van der Leij and Morfidi (2006), we focused on students in secondary education who were in the process of learning English as a second language. We used the orthographic composite as a selection criterion for the subgroups of dyslexic students. There were, however, important differences between the present study and the earlier study.

First, the students in the present investigation were on average a year older. Their greater experience with L2 English gave us the opportunity to determine whether the predictions of the PCVOD model are independent of reading experience. Second, in addition to replicating the phonological core deficit findings, the main focus of the present study was on tasks that involve orthographic competence. In addition to lexical decision tasks to tap orthographic knowledge, we included a flashed word identification task to measure orthographic competence skill. We reasoned that flashed presentation prevents the reader from using a grapheme-phoneme decoding strategy, forcing him or her to read larger (orthographic) units. As noted in an earlier section, according to the “automatic decoding deficit” hypothesis of Yap and van der Leij (1993a), dyslexics perform poorly in this respect, in general. Possibly, some of them are helped when their better orthographic competence skill is triggered by the need to process larger orthographic
units. Third, a larger sample was used in order to increase statistical power. In addition, the range in age and in class and school level was smaller, resulting in a more homogeneous sample. Fourth, spelling was included.

By selecting students whose general learning ability is within the normal range, we controlled for the influence of general intellectual differences. In addition, differences in reading ability were established by using strict criteria for normal versus poor reading. Thus, according to traditional conventions (see for example, Stanovich, 1988) our poor readers can be labeled dyslexics. We also controlled for reading experience with a questionnaire assessing the personal reading habits of the participants.

### 3.4 Method

#### 3.4.1 Participants

The native language of the participants, Dutch (L1), is characterized by a relatively high syllabic complexity (determined by the abundance of closed syllables and consonant clusters) - comparable to English, German and the Scandinavian languages - and a relatively low orthographic complexity (determined by the degree of inconsistency in grapheme-phoneme correspondence) (Seymour et al., 2003). Consequently, the main difference between Dutch and English pertains to orthography (with English a deep ‘outlier’, and Dutch as relatively transparent) and not to syllabic complexity.

In this sample, students learn their second language English (L2) when they enter secondary school at the age of twelve. The participants of our study had received about two lessons of 50 minutes a week in English from grade seven upwards. At the time of testing they were attending Grade 10.

Ninety-four secondary school students from four high schools participated in this study. School counsellors nominated a total of 47 dyslexics and a group of 47 normal readers matched on age, gender, and type of school. Since children with an IQ below 85 do not attend the schools participating in this study, we saw no need to test IQ. There were no
children involved with other learning disabilities or neuropsychological deficits.

In order to verify the counsellors’ classification, we used the Dutch One Minute Test (Brus & Voeten, 1973), a test of word reading fluency, which is scored in words read correctly in one minute. The norms of Kuijpers et al. (2003) were used to verify the designation of the control and dyslexic students. We excluded students in the dyslexic group who scored above the 25th percentile and also students in the control group who scored below the 25th percentile. This left 72 participants; 37 dyslexic and 35 normal readers. There were 20 boys in each group, 17 girls in the dyslexic group and 15 girls in the control group. There was no relationship between the participants’ reading status (dyslexic/control) and gender, $\chi^2(1, N = 72) = .07, p = .79$. The mean age of the dyslexics was 187.2 months ($SD = 9.54$) compared to 187.9 months ($SD = 8.97$) for the controls. Furthermore the two groups did not differ on verbal ability ($F < 1$) and receptive vocabulary in either Dutch or English ($F < 1$). The characteristics of the dyslexics and the control group of normal readers are presented in Table 3.1.

**Table 3.1**
*Characteristics of the participants on background and selection variables*

<table>
<thead>
<tr>
<th>Variables (max)</th>
<th>Controls</th>
<th>Dyslexics</th>
<th>Manova $F(1, 69)$</th>
<th>Effect size $\eta^2_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>35</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>15</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean age in months</td>
<td>187.90</td>
<td>187.16</td>
<td>9.54</td>
<td>164.11$^{ns}$</td>
</tr>
<tr>
<td>Word reading fluency L1 (116)</td>
<td>98.17</td>
<td>68.81</td>
<td>10.58</td>
<td>164.13$^{**}$</td>
</tr>
<tr>
<td>Verbal competence (26)</td>
<td>13.77</td>
<td>14.05</td>
<td>4.88</td>
<td>164.07$^{ns}$</td>
</tr>
<tr>
<td>Receptive vocabulary Dutch (20)</td>
<td>13.29</td>
<td>12.78</td>
<td>3.12</td>
<td>164.57$^{ns}$</td>
</tr>
<tr>
<td>Receptive vocabulary English (20)</td>
<td>16.31</td>
<td>16.43</td>
<td>2.02</td>
<td>164.05$^{ns}$</td>
</tr>
<tr>
<td>Start learning English (range 1 - 5)</td>
<td>2.09</td>
<td>1.92</td>
<td>.83</td>
<td>164.93$^{ns}$</td>
</tr>
</tbody>
</table>

*Note.* $^{**} p < .01$, $^{ns}$ = not significant.
3.4.2 Selection variable

*Word reading fluency L1, Dutch.* The Een Minuut Test [One Minute Test] (Brus & Voeten, 1973) was used to identify poor readers in L1, Dutch. The test consists of 116 words of increasing difficulty. The participant is asked to read aloud as many words as possible in one minute. The test score is the number of words read correctly in 60 seconds. Parallel test and test-retest reliabilities are over .80 (Brus & Voeten, 1973; van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994).

3.4.3 Control measures

*Verbal ability.* Verbal competence was measured with the Similarities subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1955, Dutch adaptation, 1970). The participants are asked in what way two words are similar. Each of the 13 questions is awarded 2, 1, or 0 points. After four consecutive 0-point answers, the test is discontinued. Split-half reliability of .81 is reported.

*Receptive vocabulary L1 and L2.* Following van der Leij and Morfidi (2006), we constructed two short versions of the Peabody Picture Vocabulary Test (Manschot & Bonnema, 1978) to assess oral language competence. The English version of the van der Leij and Morfidi test consists of 60 items. From each series of 10 consecutive items, we chose two items to construct a 20-item test. The same procedure was used to obtain the 20 Dutch items. In each item, four pictures with different meanings are presented and the participant is required to point to the picture corresponding to the given word. For the original versions, split-half reliability was reported to be .88 and .72 for Dutch and English respectively (van der Leij & Morfidi, 2006). The reliability (Cronbach’s α) of this shortened Dutch and English version was lower, .56 and .44 respectively, probably due to test length.
Literacy (reading habits) questionnaire. A questionnaire assessing background information regarding exposure to print and perceived skill in reading and writing in Dutch and English, and in understanding and speaking (English), both at school and in leisure time, was developed. The questionnaire also included items about the experience of the participants with the use of computers. The questionnaire consisted of 28 multiple-choice questions. A translation of the Dutch questionnaire is given in Appendix A.

3.4.4 Phonological processing

Phonemic awareness. To measure phonemic awareness a computerized word reversal task was developed as part of the Interactive Dyslexia Test (IDT; Bekebrede, van der Leij, Plakas, & Schijf, 2006). This subtest was originally developed by Buis (n.d.). Participants hear two pseudowords (e.g., *git* – *tig*) then press a true or false button on the computer keyboard to indicate whether the second word is the reverse of the first. The test consists of 10 examples and 60 test items - all monosyllabic words with one or two consonants at the beginning or end of the word. The internal consistency (Cronbach’s $\alpha$) was found to be .78.

Phonemic awareness (spoonerisms). A second way to measure phonemic awareness is by using a spoonerisms task. Van der Leij and Morfidi (2006) adapted the original German version of Landerl, Wimmer, and Frith’s spoonerisms task (1997). The students are required to transpose the onsets of two words. It consists of 15 pairs of two words. The first five items have a single initial consonant. In the following five items one word of the pair has a single initial consonant and the other word is a consonant cluster. In the last five items both words have a consonant cluster. To reduce the verbal short-term memory load, pictures of the items were shown during each word pair. The internal consistency (Cronbach’s $\alpha$) was found to be .78 (van der Leij & Morfidi, 2006).
Rapid serial naming. The participants are required to read aloud a series of 50 digits (8, 1, 3, 6, 5 in random order) as quickly and accurately as possible, while the time is recorded (Denckla & Rudel, 1974). Test-retest reliability of .74 has been reported (van der Leij & Morfidi, 2006).

3.4.5 Orthographic competence

Orthographic choice L1, Dutch. To measure orthographic knowledge in the participants’ native tongue, Dutch, van der Leij and Morfidi (2006) developed an adaptation of the Olson, Forsberg, Wise, and Rack (1994) orthographic choice task in English. This was based on Assink and Kattenberg’s (1994) six categories of spelling difficulty in Dutch (analogy, congruence, etymology, double vowels or consonants, pronunciation options and spelling of loan words). Forty pairs of homophonic words (e.g., ‘blauw – blouw’ [blue]) are presented on an A4-format page. The participants are asked to choose the correctly spelled word, and time was also recorded. The internal consistency (Cronbach’s α) was found to be .64.

Orthographic choice L2, English. This test (Olson et al., 1994) was used to evaluate orthographic knowledge in L2, English, and to identify dyslexics with differing degrees of orthographic knowledge. Forty pairs of words (e.g., wurd-word) are presented on an A4-format page. The participants are required to choose the correctly spelled word. Both accuracy and time are recorded. Internal consistency (Cronbach’s α) was found to be .78.

Flashed word identification. In this test, a word appears on a computer screen for 200 ms and is then masked (IDT; Bekebrede et al., 2006). The participants are required to press a true or false button on the computer keyboard to indicate whether the word is correctly spelled or not. The test consists of three examples and four blocks of 10 items, with one, two and three syllables and loan words. Loan words are words from other languages that do not adhere to Dutch grapheme-phoneme correspondence conventions.
rules (e.g., ‘milieu’ [milieu], ‘cyclus’ [cycle]). In each block there are five correctly spelled words. When more than eight errors are committed in a single block, the test is discontinued. The reliability (Cronbach’s $\alpha$) was found to be .66.

3.4.6 Reading and spelling measures in Dutch

**Flashed word production, Dutch.** This task requires silent reading and spelling of real words and depends on both speed and accuracy. A word is flashed on a computer screen for 200 ms and then masked (IDT; Bekebrede et al., 2006). The participant is asked to type the flashed word. There are three examples followed by four blocks of 10 items with one, two and three syllables and loan words. The test is discontinued after eight incorrect responses in a single block. The internal consistency (Cronbach’s $\alpha$) was found to be .88.

**Flashed pseudoword production.** In this silent pseudoword reading and spelling task a pseudoword is flashed on a computer screen for 200 ms and then masked (IDT; Bekebrede et al., 2006). The participant is required to type the flashed pseudoword. The pseudowords were constructed by changing the vowels of a flashed word production test. The test consists of three examples followed by three blocks of 10 items containing one, two and three syllables. When the participant makes more than eight errors in a single block, the test is discontinued. The internal consistency (Cronbach’s $\alpha$) was found to be .86.

**Pseudoword reading fluency.** The Klepel (van den Bos et al., 1994) is a speeded reading test requiring phonological recoding. The test was constructed by changing consonants or vowels in the words in the Dutch One Minute Test without violating the pronunciation rules of Dutch. The Klepel consists of 116 pseudowords of increasing difficulty. The test score
is the number of pseudowords correctly read in two minutes. Parallel test reliabilities are reported to be over .89 (van den Bos et al., 1994).

**Spelling to dictation (PI-dictee, [PI-dictation]), Dutch.** To test the spelling ability of the participants we used a shortened version of the Dutch PI-dictee test (Geelhoed, Bos, & Kappers, 1994). This dictation test is a standardized spelling test containing nine blocks of items of increasing difficulty. We used the last block of this test, which has 15 polysyllabic words and added the Dutch word ‘onmiddellijk’ [immediately]. The words are read aloud and the participant is asked to write down the word correctly. The reliability (Cronbach’s α) of this shortened version was found to be .78.

### 3.4.7 Reading and spelling measures in English

**Word reading fluency L2, English (One Minute Test, OMT).** The English One Minute Test (Fawcett & Nicolson, 1996) demands speed and accuracy in reading English words. The test consists of 120 words of increasing difficulty. The test score is the number of words read correctly in one minute. Fawcett and Nicolson reported test-retest reliability of .99.

**Flashed English word production.** In this silent reading and spelling task an English word is flashed on a computer screen for 200 ms and then masked (IDT; Bekebrede et al., 2006). The participants are asked to type the English word. Block one consists of 20 monosyllabic words, based on a wordlist developed by McDougall, Borowsky, MacKinnon, and Hymel (2005). Block 2 consists of 10 two-syllable words, Block 3 consists of 10 three-syllable words, and Block 4 consists of 10 final ‘e’ words with one to three syllables. The test is discontinued after more than eight errors in a single block. Internal consistency (Cronbach’s α) was found to be .93.

**Pseudoword reading accuracy L2, English.** The English words of the computerized test of van der Leij and Morfidi (2006) were used to construct
a list of English pseudowords by changing the vowels of the words. The pseudoword-list consisted of 40 pseudowords with CVCC, CVCV, CVCVC and CVCCVC structures. The participants are required to read aloud the pseudowords as accurately as possible. The internal consistency (Cronbach’s α) of this test was found to be .83.

3.4.8 Procedure

All tasks were individually administered in two sessions of up to 45 minutes. One session included all the paper and pencil tests and the other the computerized tests. The paper and pencil tests were divided into separate Dutch and English subsets. Within each subset the order of the tests was randomized. For practical reasons, all participants received the same fixed order of the computerized tests; word reversal, flashed word identification, flashed word, pseudoword, and English word production.

3.4.9 Analyses

Composite scores for phonological processing and orthographic competence were first created by summing the standardized scores for individual measures. Next, a regression analysis was conducted to investigate whether orthographic competence predicted variance in word recognition after variance accounted for by vocabulary and phonological processing is partialled out.

To test the predictions of the PCVOD model, the dyslexic group was divided in two, a group with low and a group with high orthographic competence. The scores were submitted to a multivariate analysis of variance (MANOVA) with the different groups of measurements as dependent variables and group (control, ORTH+, and ORTH-) as the between-subjects factor. Three planned contrasts examined differences between each group. If the multivariate statistics indicated significant
Chapter 3

overall differences ($F$ values are presented in the tables), the statistics for the three pairwise contrasts were considered.

3.5 Results

3.5.1 Descriptive statistics

Table 3.2 presents the correlations of the phonological, orthographic and reading variables among all students ($N = 72$). Two out of three phonological variables revealed moderate correlations with word reading fluency (.62 - .70). Only spoonerisms was an exception (.28). All orthographic variables showed moderate to higher correlations with word reading fluency (.63 -.75).

Table 3.2

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fluency word reading</td>
<td>1.00</td>
<td>0.86</td>
<td>-0.63</td>
<td>0.62</td>
<td>0.28</td>
<td>0.75</td>
<td>0.63</td>
<td>0.52</td>
<td>0.70</td>
<td>0.79</td>
<td>0.74</td>
</tr>
<tr>
<td>2. Fluency pseudoword reading</td>
<td>1.00</td>
<td>-0.63</td>
<td>0.70</td>
<td>0.29</td>
<td>0.60</td>
<td>0.44</td>
<td>0.45</td>
<td>0.56</td>
<td>0.69</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>3. Rapid serial naming</td>
<td>1.00</td>
<td>-0.53</td>
<td>-0.21</td>
<td>-0.43</td>
<td>-0.30</td>
<td>-0.21</td>
<td>-0.33</td>
<td>-0.48</td>
<td>-0.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Word reversal</td>
<td>1.00</td>
<td>0.41</td>
<td>0.46</td>
<td>0.37</td>
<td>0.50</td>
<td>0.46</td>
<td>0.56</td>
<td>0.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Spoonerisms</td>
<td>1.00</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.27</td>
<td>0.30</td>
<td>0.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Spelling</td>
<td>1.00</td>
<td>0.68</td>
<td>0.53</td>
<td>0.55</td>
<td>0.70</td>
<td>0.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Orthographic choice L1</td>
<td>1.00</td>
<td>0.63</td>
<td>0.45</td>
<td>0.57</td>
<td>0.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Orthographic choice L2</td>
<td>1.00</td>
<td>0.54</td>
<td>0.68</td>
<td>0.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Flashed word identification</td>
<td>1.00</td>
<td>0.69</td>
<td>0.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Flashed word production</td>
<td>1.00</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Flashed pseudoword production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

Note. Correlations greater than 0.24 are significant at the 0.05 level.

To investigate the relationships among the orthographic variables and phonological variables separately two principal component analyses were performed (see Table 3.3 and 3.4 for the component loadings). Both analyses revealed only one component with an eigenvalue greater than one,
respectively an orthographic and phonological component. Spoonerisms had the lowest loading of the phonological variables.

### Table 3.3
Principal component loadings for all three orthographic variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashed word identification</td>
<td>-.80</td>
</tr>
<tr>
<td>Orthographic choice L1</td>
<td>-.83</td>
</tr>
<tr>
<td>Orthographic choice L2</td>
<td>-.80</td>
</tr>
</tbody>
</table>

*Note. Accounted for 64% of the variance.*

### Table 3.4
Principal component loadings for all three phonological variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word reversal</td>
<td>-.87</td>
</tr>
<tr>
<td>Rapid serial naming</td>
<td>-.77</td>
</tr>
<tr>
<td>Spoonerisms</td>
<td>-.66</td>
</tr>
</tbody>
</table>

*Note. Accounted for 59.5% of the variance.*

Because spoonerisms had a low correlation with both the other two phonological measures and with reading, as well as a low factor loading and a possible ceiling effect, it was not included in the phonological composite. Therefore, the phonological composite consisted of two measures, word reversal and rapid serial naming. Following Cunningham et al. (2001), pseudoword reading fluency (phonological recoding) is treated as a separate measure because it involves grapheme-phoneme decoding. Based on the correlations and factor loadings the orthographic composite consisted of three measures, Dutch and English orthographic choice, and flashed word identification.

### 3.5.2 Hierarchical regression analyses

Hierarchical regression analyses were employed to investigate whether orthography plays a significant role in predicting L1 word reading fluency. In these analyses vocabulary was entered first at Step 1 to control for vocabulary as a cognitive aspect in predicting word fluency. Followed by
pseudoword reading fluency and the phonological composite at Step 2 and 3 to partial out the phonological processing variance. To determine whether orthographic competence made an independent contribution, the orthographic composite was entered at the last step. The overall model was significant, $F(4, 66) = 76.25, p < .01$ (see Table 3.5). Pseudoword reading explained 69% of the variance. After pseudoword reading was partialed out, the phonological composite did not predict word reading, but the orthographic composite accounted for an additional 8% of the variance.

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>$R$</th>
<th>$R^2$ change</th>
<th>$F$ change</th>
<th>$\beta$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vocabulary L1</td>
<td>.222</td>
<td>5%</td>
<td>3.54**</td>
<td>-.04</td>
<td>-.62ns</td>
</tr>
<tr>
<td>2</td>
<td>Pseudoword reading fluency</td>
<td>.857</td>
<td>69%</td>
<td>173.23**</td>
<td>.58</td>
<td>6.89**</td>
</tr>
<tr>
<td>3</td>
<td>Phonological composite$^1$</td>
<td>.862</td>
<td>0.8%</td>
<td>2.05ns</td>
<td>.10</td>
<td>1.26ns</td>
</tr>
<tr>
<td>4</td>
<td>Orthographic composite$^2$</td>
<td>.908</td>
<td>8%</td>
<td>30.145**</td>
<td>.37</td>
<td>5.49**</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>83%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. $^1$Phonological composite = word reversal and rapid serial naming; $^2$Orthographic composite = orthographic choice L1, L2, and flashed word identification. ** $p < .01$, ns = not significant.

When separate hierarchical regression analyses were employed for the normal students and dyslexic students to check whether orthography and phonology played different roles in the two groups, some differences were seen. For the normal readers the overall model explained a significant 50% of the total variance, $F(4, 29) = 7.21, p < .01$, with vocabulary accounting for 15% of the variance, pseudoword reading for 21%, phonology for 8% and orthography for 6%. For the dyslexic students the model explained 59% of the total variance, $F(4, 31) = 13.65, p < .01$, with vocabulary accounting for 3% of the variance, pseudoword reading for 38%, phonology for 2.5% and orthography for 20%. In explaining L1 word reading fluency the role of phonological recoding was greater among dyslexics ($\beta = .44, t = 3.30, p < .01$) than among normal readers ($\beta = .19, t = 1.07, ns$). The role of orthographic competence was also somewhat greater among dyslexics ($\beta = .48, t = 4.17, p < .01$) compared to control students ($\beta = .31, t = 1.89, p = .069$).
Hierarchical regression analyses were also employed to investigate whether orthography plays a significant role in predicting L1 spelling ability. In these analyses the same predictors were entered as in the prediction of word reading fluency. Vocabulary was entered first at Step 1, followed by pseudoword reading fluency at Step 2 and phonological and orthographic composites at Steps 3 and 4. A significant model again emerged, \( F(4, 66) = 24.64, p < .01 \), explaining 60% of the variance (see Table 3.6). Pseudoword reading fluency explained 36% of the variance. After pseudoword reading was partialed out phonological processing did not predict variance in spelling ability, whereas orthographic competence accounted for 23% of the variance. The influence of the orthographic composite (\( \beta = .62, t = 6.13, p < .01 \)) was larger than phonological recoding (\( \beta = .24, t = 1.94, p = .057 \)).

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>( R )</th>
<th>( R^2 ) change</th>
<th>( F ) change</th>
<th>( \beta )</th>
<th>( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vocabulary L1</td>
<td>.050</td>
<td>0.2%</td>
<td>.17( ^{ns} )</td>
<td>-.22</td>
<td>-2.65</td>
</tr>
<tr>
<td>2</td>
<td>Pseudoword reading fluency</td>
<td>.606</td>
<td>36%</td>
<td>38.57( ** )</td>
<td>.24</td>
<td>1.94( ^{†} )</td>
</tr>
<tr>
<td>3</td>
<td>Phonological composite(^1)</td>
<td>.611</td>
<td>0.6%</td>
<td>.65( ^{ns} )</td>
<td>.06</td>
<td>.50( ^{ns} )</td>
</tr>
<tr>
<td>4</td>
<td>Orthographic composite(^2)</td>
<td>.776</td>
<td>23%</td>
<td>37.53( ** )</td>
<td>.62</td>
<td>6.13( ** )</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60%</td>
</tr>
</tbody>
</table>

Note. \(^1\)Phonological composite = word reversal and rapid serial naming; \(^2\)Orthographic composite = orthographic choice L1, L2, and flashed word identification.
\( ^* p < .05, \; ^{**} p < .01, \; ^{†} p = .057, \; ^{ns} \) = not significant.

Overall it appears that in addition to phonological recoding, orthography plays an independent role in predicting L1 word reading fluency and spelling. At this age non-reading phonological processing does not contribute.

### 3.5.3 Individual differences

In this section the variability of orthographic competence among the dyslexic readers is investigated. To examine individual differences, the
dyslexic sample was subdivided into two subgroups with low and superior orthographic competence by using the median of the orthographic composite as a cut-off point. The dyslexics with a score below the median \((n = 18)\) formed the group with low orthographic competence \((\text{ORTH}^-)\). The dyslexic readers with a score above the median \((n = 19)\) formed the group with superior orthographic competence \((\text{ORTH}^+)\). To verify this classification, the orthography measures were considered across the three groups. The means, standard deviations, and main effects of group are presented in Table 3.7.

**Table 3.7**

*Mean scores \((M)\), standard deviations \((SD)\), and main effects of group for the control students and two dyslexic subgroups, \((\text{ORTH}^+ = \text{superior orthographic competence}, \text{ORTH}^- = \text{inferior orthographic competence})\) on orthographic competence*

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control M, SD</th>
<th>ORTH(^+) M, SD</th>
<th>ORTH(^-) M, SD</th>
<th>MANOVA F(2, 67)</th>
<th>Effect size (\eta^2_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthographic choice L1 (40)</td>
<td>37.15, 2.05</td>
<td>36.11, 1.94</td>
<td>32.28, 2.89</td>
<td>27.75(a, c)</td>
<td>.45</td>
</tr>
<tr>
<td>Orthographic choice L2 (40)</td>
<td>37.74, 2.42</td>
<td>37.28, 1.74</td>
<td>32.28, 4.44</td>
<td>21.76(a, c)</td>
<td>.39</td>
</tr>
<tr>
<td>Flashed word identification (40)</td>
<td>29.74, 3.84</td>
<td>26.72, 3.06</td>
<td>23.11, 3.83</td>
<td>19.57(a, b, c)</td>
<td>.37</td>
</tr>
<tr>
<td>Orthographic composite(^1) (z-score)</td>
<td>1.47, 1.77</td>
<td>.34, .84</td>
<td>-3.08, 2.10</td>
<td>43.30(a, b, c)</td>
<td>.56</td>
</tr>
</tbody>
</table>

*Note. \(^{1}\)Orthographic composite = orthographic choice L1, L2, and flashed word identification.*

Significant between-group differences are indicated by subscripts: \(a\) Controls - ORTH\(^-\); \(b\) Controls - ORTH\(^+\); \(c\) ORTH\(^+\) - ORTH\(^-\).*

\(**\) \(p < .01\).

The contrast between the ORTH\(^-\) and control students showed a significant difference on the orthographic composite, \(F(1, 67) = 85.68, p < .01, \eta^2_p = .56\). The planned contrast revealed significant differences. The ORTH\(^-\) subgroup performed worse on orthographic choice in English, \(F(1, 67) = 40.37, p < .01, \eta^2_p = .38\), and in Dutch, \(F(1, 67) = 54.40, p < .01, \eta^2_p = .45\). They were also inferior on flashed word identification, \(F(1, 67) = 38.62, p < .01, \eta^2_p = .37\).

The ORTH\(^+\) performed worse on the orthographic composite than the control students, \(F(1, 67) = 5.29, p < .05, \eta^2_p = .07\). However, the ORTH\(^+\)
Dutch dyslexic adolescents

group performed significantly worse than the control students on only one out of three orthographic measures that made up the orthographic composite. The ORTH+ performed similarly to the control students on orthographic choice in English ($F < 1$) and on orthographic choice in Dutch, $F(1, 67) = 2.46, ns$. However, they performed worse in flashed word identification, $F(1, 67) = 7.99, p < .01, \eta^2_p = .11$.

Because the selection of the two subgroups was based on the orthographic composite, it follows that there was a significant difference on the orthographic composite between ORTH+ and ORTH, $F(1, 67) = 37.01, p < .01, \eta^2_p = .36$. In addition, on each of the three tasks there were differences in English orthographic choice, $F(1, 67) = 25.91, p < .01, \eta^2_p = .28$; Dutch orthographic choice, $F(1, 67) = 25.78, p < .01, \eta^2_p = .28$; and on flashed word identification, $F(1, 67) = 8.78, p < .01, \eta^2_p = .12$.

The PCVOD model also predicts that the three groups should not differ on the control measures. The main effects of group confirmed that this was the case. The control students and the two dyslexic groups did not differ on verbal competence (WAIS Similarities, $F(2, 69) = 1.29, ns$; receptive vocabulary in Dutch, $F(2, 69) = 2.12, ns$; and English, $F < 1$).

3.5.4 Phonological processing

To test the assumption of a common phonological core among dyslexics, performance of the three groups on the phonological tasks is presented in Table 3.8.

The contrast between the ORTH− and control students showed a significant difference on the phonological composite, $F(1, 69) = 20.32, p < .01, \eta^2_p = .23$. The contrast between the ORTH− and control students showed significant differences on both phonological tasks (word reversal, $F(1, 69) = 16.64, p < .01, \eta^2_p = .19$; rapid serial naming, $F(1, 69) = 13.77, p < .01, \eta^2_p = .17$). The ORTH+ also performed more poorly on the phonological composite than the control students, $F(1, 69) = 20.20, p < .01, \eta^2_p = .23$. The planned contrast between ORTH+ and the control students
Chapter 3

revealed the same pattern of outcomes as those obtained in ORTH− (word reversal, $F(1, 69) = 10.19, p < .01, \eta^2_p = .13$; rapid serial naming, $F(1, 69) = 21.23, p < .01, \eta^2_p = .24$).

Table 3.8
Mean scores (M), standard deviations (SD), and main effects of group for the control students and two dyslexic subgroups, (ORTH+ = superior orthographic competence, ORTH− = inferior orthographic competence) on phonological processing

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control</th>
<th>ORTH+</th>
<th>ORTH−</th>
<th>MANOVA</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>F(2, 69)</td>
</tr>
<tr>
<td>Word reversal (60)</td>
<td>50.31</td>
<td>5.32</td>
<td>44.95</td>
<td>6.48</td>
<td>43.33</td>
</tr>
<tr>
<td>Rapid serial naming (sec)</td>
<td>16.83</td>
<td>2.85</td>
<td>21.58</td>
<td>4.44</td>
<td>20.72</td>
</tr>
<tr>
<td>Phonological composite\textsuperscript{(z-score)}</td>
<td>.97</td>
<td>1.22</td>
<td>.93</td>
<td>1.77</td>
<td>-.97</td>
</tr>
</tbody>
</table>

Note. 1Phonological composite = word reversal and rapid serial naming. Significant between-group differences are indicated by subscripts: a Controls - ORTH−; b Controls - ORTH+. \textsuperscript{**}p < .01.

The contrast between the ORTH− and control students showed a significant difference on the phonological composite, $F(1, 69) = 20.32, p < .01, \eta^2_p = .23$. The contrast between the ORTH− and control students showed significant differences on both phonological tasks (word reversal, $F(1, 69) = 16.64, p < .01, \eta^2_p = .19$; rapid serial naming, $F(1, 69) = 13.77, p < .01, \eta^2_p = .17$). The ORTH+ also performed more poorly on the phonological composite than the control students, $F(1, 69) = 20.20, p < .01, \eta^2_p = .23$. The planned contrast between ORTH+ and the control students revealed the same pattern of outcomes as those obtained in ORTH− (word reversal, $F(1, 69) = 10.19, p < .01, \eta^2_p = .13$; rapid serial naming, $F(1, 69) = 21.23, p < .01, \eta^2_p = .24$).

There was no significant difference between the two dyslexic subgroups on the phonological composite ($F < 1$). Supporting the predictions of the PCVOD model, the planned contrast comparing the two dyslexic subgroups indicated no significant differences on phonemic awareness and rapid serial naming ($F < 1$) between the two dyslexic subgroups.
Reading and spelling ability in Dutch and English were compared across the three groups. The means, standard deviations and main effects for group are presented in Table 3.9. Note that Dutch word reading fluency is the selection variable.

**Table 3.9**

Mean scores (M), standard deviations (SD), and main effects of group for the control students and two dyslexic subgroups (ORTH\textsuperscript{+} = superior orthographic competence, ORTH\textsuperscript{-} = inferior orthographic competence) on the Dutch and English reading and spelling measures

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control</th>
<th>ORTH\textsuperscript{+}</th>
<th>ORTH\textsuperscript{-}</th>
<th>MANOVA</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>F(2, 67)</td>
</tr>
<tr>
<td><strong>Dutch</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading fluency L1</td>
<td>98.17</td>
<td>8.72</td>
<td>72.80</td>
<td>7.83</td>
<td>12.09</td>
</tr>
<tr>
<td>(116)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pseudoword reading fluency</td>
<td>96.00</td>
<td>11.99</td>
<td>62.83</td>
<td>18.23</td>
<td>57.41</td>
</tr>
<tr>
<td>L1 (116)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Flashed word production</td>
<td>37.24</td>
<td>2.66</td>
<td>33.39</td>
<td>4.88</td>
<td>25.00</td>
</tr>
<tr>
<td>(40)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Flashed pseudoword</td>
<td>18.09</td>
<td>4.29</td>
<td>14.50</td>
<td>3.45</td>
<td>9.12</td>
</tr>
<tr>
<td>production (30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spelling ability (16)</td>
<td>12.62</td>
<td>2.31</td>
<td>10.00</td>
<td>1.75</td>
<td>7.29</td>
</tr>
<tr>
<td><strong>English</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Word reading fluency L2</td>
<td>74.32</td>
<td>14.98</td>
<td>51.39</td>
<td>12.74</td>
<td>45.29</td>
</tr>
<tr>
<td>(120)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pseudoword reading</td>
<td>36.85</td>
<td>3.29</td>
<td>34.11</td>
<td>4.86</td>
<td>32.88</td>
</tr>
<tr>
<td>accuracy L2 (40)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flashed word production</td>
<td>44.09</td>
<td>4.39</td>
<td>36.28</td>
<td>6.30</td>
<td>26.18</td>
</tr>
<tr>
<td>(50)</td>
<td></td>
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</table>

**Note.** Significant between-group differences are indicated by subscripts: \(^a\) Controls - ORTH\textsuperscript{-}; \(^b\) Controls - ORTH\textsuperscript{+}; \(^c\) ORTH\textsuperscript{+} - ORTH\textsuperscript{-}.

\(^{**}\) \(p < .01\).

Compared to the control students, the ORTH\textsuperscript{+} subgroup performed significantly worse on all the Dutch reading and spelling tasks, word reading fluency, \(F(1, 67) = 148.20, p < .01, \eta^2_p = .69\); pseudoword reading fluency, \(F(1, 67) = 75.95, p < .01, \eta^2_p = .54\); flashed word production, \(F(1, 67) = 79.51, p < .01, \eta^2_p = .55\); flashed pseudoword production, \(F(1, 67) = 60.50, p < .01, \eta^2_p = .48\); and spelling ability, \(F(1, 67) = 46.36,\)
Furthermore, the ORTH⁻ group attained lower scores than controls on the English reading and spelling measures: word reading fluency, $F(1, 67) = 50.47, p < .01, \eta^2_p = .43$; flashed English word production, $F(1, 67) = 87.88, p < .01, \eta^2_p = .57$; and English pseudoword accuracy, $F(1, 67) = 10.88, p < .01, \eta^2_p = .14$.

The ORTH⁺ subgroup also scored significantly below the control students on Dutch word and pseudoword reading (word reading fluency, $F(1, 67) = 84.56, p < .01, \eta^2_p = .56$; pseudoword reading fluency, $F(1, 67) = 58.28, p < .01, \eta^2_p = .47$), as well as on Dutch silent reading and spelling of words (flashed word production, $F(1, 67) = 8.16, p < .01, \eta^2_p = .11$) and pseudowords (flashed pseudoword production, $F(1, 67) = 10.05, p < .01, \eta^2_p = .13$), and spelling $F(1, 67) = 11.63, p < .01, \eta^2_p = .15$. On English word reading fluency, $F(1, 67) = 32.71, p < .01, \eta^2_p = .33$ they performed more poorly than the control readers, also at silent English reading and spelling (flashed English word production, $F(1, 67) = 17.35, p < .01, \eta^2_p = .21$) and English pseudoword accuracy, $F(1, 67) = 5.39, p < .05, \eta^2_p = .08$.

The ORTH⁺ subgroup, however, performed significantly better than the ORTH⁻ subgroup in Dutch word reading fluency, $F(1, 67) = 7.65, p < .01, \eta^2_p = .10$. Both subgroups did not differ at pseudoword reading fluency, $F(1, 67) = 1.16, ns$. The ORTH⁺ group were also better in flashed word production, $F(1, 67) = 28.83, p < .01, \eta^2_p = .30$; in flashed pseudoword production, $F(1, 67) = 16.80, p < .01, \eta^2_p = .20$; and in spelling ability, $F(1, 67) = 9.23, p < .01, \eta^2_p = .12$. With regard to English, the ORTH⁺ were superior in flashed word production, $F(1, 67) = 21.56, p < .01, \eta^2_p = .25$ but not in word reading fluency ($F < 1$), and English pseudoword accuracy ($F < 1$).
3.5.6 Questionnaire

Questions relating to print exposure, the amount of time spent reading and writing in English, watching English television revealed no significant group effects. The only questionnaire item that revealed a significant group effect concerned the amount of time spent learning English in school, $F(2, 68) = 6.01, p < .01$, $\eta^2_p = .15$; the normal group reported spending less time learning English, and there was a significant difference between the two dyslexic subgroups, $F(1,68) = 5.27, p < .05$, $\eta^2_p = .07$ in which the ORTH− group reported spending more time in learning English than the ORTH+ group. To control for print exposure in Dutch, we asked the participants about the amount of time they spent on reading and writing Dutch. These questions revealed no significant group differences.

Four questions relating to how the students perceived their skill in reading and learning English and Dutch revealed significant group effects in which the control students had the least difficulties in comparison with the two dyslexic subgroups. These questions were: “How easy do you find it to read English?”, $F(2, 69) = 3.80, p < .05$, $\eta^2_p = .10$; “How difficult do you find it to learn English?”, $F(2, 69) = 7.24, p < .01$, $\eta^2_p = .17$; “How many problems do you have with Dutch reading?”, $F(2, 69) = 28.37, p < .001$, $\eta^2_p = .45$; and “How many problems do you have with Dutch spelling?”, $F(2, 69) = 35.58, p < .001$, $\eta^2_p = .49$. In the comparison of the two dyslexic subgroups the only significant difference emerging was on the question about problems with Dutch spelling, $F(1, 69) = 4.61, p < .05$, $\eta^2_p = .06$, where the ORTH− group had more problems than the ORTH+ group.

With regard to the number of times students felt they had to read an unknown English and Dutch word before attaining immediate recognition, significant group effects were found for English, $F(2, 69) = 7.29, p < .01$, $\eta^2_p = .18$, and Dutch, $F(2, 69) = 4.99, p < .01$, $\eta^2_p = .13$. The control group recognized an unknown word quicker than both subgroups. The two subgroups were not significantly different ($F < 1$) on this measure either.

From the results of the questionnaire it appears that it is unlikely that the differences between ORTH+ and ORTH− may be explained by
differences in exposure to Dutch or English. This conclusion is supported by the fact that entering a composite of the questions regarding time spent on reading and writing in English and Dutch (Questions 17, 18, 22, and 24, respectively, of the questionnaire, see Appendix A) in the regression analysis did not change the overall picture. In predicting Dutch word reading fluency the overall model explained a significant 83% of the total variance, $F(5, 61) = 57.73, p < .01$, with vocabulary accounting for 6% of the variance, composite exposure to Dutch and English accounting for 5% ($ns$), pseudoword reading for 62%, phonology for 0.6% ($ns$), and orthography for 9% of the variance. In predicting spelling ability the overall model explained a significant 60% of the total variance, with vocabulary accounting for 0.5% of the variance ($ns$), composite exposure to Dutch and English accounting for 2.5% ($ns$), pseudoword reading for 33%, phonology for 0.5% ($ns$), and orthography for 24% of the variance.

In addition, to investigate whether the finding that the ORTH group reported spending more time on learning English than the other groups caused any different outcomes, this question was controlled for as a covariate. There appeared to be no different results in any of the English tasks.

### 3.6 Discussion

In the present study, three major predictions of the PCVOD model of van der Leij and Morfidi (2006) were investigated: a) phonological processing and orthographic competence contribute independently to the explanation of variance in reading and spelling; b) all dyslexics suffer from a phonological core deficit; c) within the group of dyslexics there exists larger variability in orthographic competence than in phonological processing.

The first prediction was supported by the findings of the present study. However, only phonological recoding - essentially a reading task - played an important role in the prediction, in contrast to phonemic awareness and rapid serial naming. In addition, the findings revealed that orthographic
competence is an independent predictor of word reading fluency, and plays an even more important role in predicting spelling. The findings also supported the second and third predictions. The dyslexic readers were weak in all tasks measuring phonological processing but showed larger variation in orthographic competence and on reading and spelling measures that rely more on orthographic competence.

The results of the present study support the view that phonological recoding is the key process in reading and spelling performance (Share, 1995). At this age (on average, 15.5 years), phonemic awareness does not play a role in the predictions. This finding is not surprising because, as mentioned in the introduction, in relatively transparent orthographies the role of phonemic awareness is confined to the initial phase of learning to read (de Jong & van der Leij, 1999; Wimmer et al., 2000). The finding that rapid serial naming does not contribute, in contrast to a related study (Morfidi et al., 2007), is related to the predictive power of the task for pseudoword reading fluency that was not used as a predictor in the study of Morfidi et al.. An important finding is that orthographic competence contributes to the prediction. Because the native language under study was Dutch with its relatively shallow orthography, this finding may be considered as an indication that the role of orthographic competence in reading development should be taken seriously (as is recommended by Castles & Nation, 2006), independent of orthographic complexity of the language under study.

This recommendation is also supported by the results with regard to the other predictions. Two subgroups of dyslexic readers were selected who possessed good (ORTH\(^+\)) or poor orthographic competence (ORTH\(^-\)). The claim of the PCVOD model, that a universal core phonological deficit is the main feature of dyslexia, was confirmed by the equally poor performance of both subgroups on tasks that rely on phonological processing (i.e., phonemic awareness, rapid serial naming and phonological recoding in Dutch and English). (Below, we discuss the exception to this rule: flashed pseudoword production).
The second claim of the model, the variable orthographic differences, was supported by the fact that the ORTH\(^+\) subgroup performed at the level of age-matched normal readers in L1 and L2 orthographic knowledge (both parts of the selection composite), confirming the findings of van der Leij and Morfidi (2006) and Miller-Guron and Lundberg (2000). The validity of the differentiation based on orthographic competence is strengthened by the fact that ORTH\(^+\) outperformed ORTH\(^-\) when the tasks demanded speeded (pseudo)word processing and therefore involved some kind of processing of larger orthographic units. This finding was independent of word type (words or pseudowords), language (Dutch or English) or response mode (lexical decision or typing). Moreover, the advantage in orthographic knowledge in English and in Dutch could not be attributed to factors such as exposure to English or Dutch, phonological processing, verbal competence or vocabulary, indicating that it is a specific, individual characteristic.

Three aspects of the findings require comment: 1) the characteristics of the selected participants, in particular the subgroups; 2) the relevance of the findings to reading theory in a cross-linguistic perspective; and 3) the interpretation of the differences on speeded tasks between atypical readers in terms of early reading processes. In addition, some practical implications will be suggested. First, there is no reason to doubt whether all selected participants were dyslexic. Both subgroups performed at a normal level on non-reading tasks (Dutch verbal competence, and vocabulary in Dutch and English), but more poorly than the control group on all tasks that related to reading and spelling, with the exception of the ORTH\(^+\) subgroup who were at normal levels in orthographic knowledge (L1 and L2). Although the ORTH\(^+\) subgroup was better than the ORTH\(^-\) subgroup on measures that relate to orthographic competence, it is a subgroup with subnormal reading and spelling performance. It is therefore unlikely that the ORTH\(^+\) subgroup may consist of relatively better readers with more reading experience, as is often found in subtype studies (Stanovich, Siegel, & Gottardo, 1997). The subgroups were comparable in a variety of oral reading tasks: pseudoword reading fluency in L1, pseudoword accuracy in L2, and word reading fluency in L2. In addition, the subgroups did not differ on tasks that involve
non-print phonological processing, indicating their comparability with regard to the phonological core deficit. So, the ORTH⁺ subgroup was only better on a subset of tasks measuring reading and reading subskills. Furthermore, differences in experience between the subgroups were only found in time spent in learning English (ORTH⁻ spend more time) and in problems with Dutch spelling (ORTH⁻ had more problems). Because there were no differences with regard to reading, we suggest that these differences reflect the consequences of the differences in orthographic competence but not the cause. However, it should be mentioned that the questionnaire was a self-report multiple-choice questionnaire. Future research should consider including more direct measures of reading experience. In addition, instead of the shortened versions of the vocabulary tasks that had only moderate reliability coefficients, the original longer and more reliable versions should be used in future research.

Second, with regard to reading theory in a cross-linguistic perspective, as mentioned before, the role of orthographic competence in a relatively shallow orthography should not be underestimated. It has been suggested by Seymour and Duncan (2004) in their unitary/dual foundation model that in a shallow orthography, only a phonological route of simple recoding ability (small units) is used (the alphabetic process). In contrast, in a deep orthography two options are available: the logographic process, which is direct whole-word recognition, and the alphabetic process. However, our findings support the conclusion that even in a more transparent orthography than English there exists evidence for a logographic process. Orthographic competence (which presumably is closely related to processing at the level of whole words and large orthographic units) was found to be an independent predictor of reading and spelling, together with phonological recoding that relies more on the translation of grapheme-phoneme correspondences. The independent contribution to the prediction should, however, not be taken as evidence in support for a model with separate routes in a relatively transparent orthography such as Dutch. The correlation between word and pseudoword reading is very high, both in fluency tasks (.86) and in flashed production tasks (.75). As a consequence, the subgroups
should not be regarded as different subtypes based on two independent core deficits related to a defective route, but should be interpreted as evidence that the basic (phonological) core deficit can be combined with a gradual difference in orthographic competence.

Third, on all the L1 and L2 speeded (pseudo)word processing tasks that involve identification or production (typing) as a response, the group with better orthographic competence outperformed the group with inferior orthographic competence. Whereas the flashed word identification and production results may be interpreted as a sign of better orthographic knowledge at the lexical level, the most striking result is the difference in the fast identification and production of pseudowords. This task involves the rapid processing (presented only 200 ms and masked afterwards), and producing by typing of pseudowords that, by definition, do not have a representation in memory.

In an earlier study, the large difference between dyslexics and various control groups on a similar flashed pseudoword task was interpreted by Yap and van der Leij (1993a) as evidence for an “automatic decoding deficit”. Why does the ORTH+ subgroup of the present study escape from that deficit? To interpret that finding, it should be mentioned that the flashed (and masked) presentation of words aims to measure the early and automatic components of word recognition, the key indication of orthographic learning, independently of other, slower and more strategic influences on

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1 Following an interesting suggestion of an anonymous reviewer we divided the dyslexic subgroups in two extreme groups, by dividing the dyslexics into three equal groups based on the orthographic composite, and leaving the ‘middle’ group out. The same results were obtained as in using all the dyslexics, except there was no longer a difference between the ORTH++ and the control students on flashed word identification and on the overall orthographic composite. And on the flashed word production task the ORTH++ also performed similarly to the control students. When defined as a more extreme group the ORTH++ is even more similar to the controls on orthography and benefits from it in flashed word production.

2 In answer to a query by an anonymous reviewer, it should be noted that differences in short-term memory are not a likely explanation. On a visual attention span task (comparable to the task of Bosse et al., 2007; results not described in this paper) that requested the participants to memorize and reproduce in the right order series of flashed capital letters, the two subgroups both differed from the controls, but not from each other.
Dutch dyslexic adolescents

reading (Castles & Nation, 2006, referring to Booth, Perfetti, & MacWinney, 1999). It seems to be that the ORTH\(^+\) subgroup has a better memory for word-traces at the level of larger orthographic units when encouraged to use it by flashed presentation (and masking) and silent reading. They appear to apply this word-trace memory not only to familiar words but also spontaneously in reading pseudowords. Although mapping from sound to print puts a strong demand on phonological processing, they seem to be able to adapt their identification strategy by grasping larger orthographic units. However, this higher-order recognition skill is only triggered in conditions involving silent reading and when identifying pseudowords in speeded processing conditions. In these conditions there is a less than maximal load on phonological processing, possibly because there is no oral output. When oral reading in unspeeded conditions is involved, as is the case in pseudoword reading fluency in L1 and accuracy of pseudoword reading in L2, the subgroups do not differ. Because the orthographic measures (orthographic knowledge in L1 and L2, and flashed word identification) also do not implicate oral responding, the picture emerging is that the dyslexic subgroups differ in the ability to perceive large orthographic units at the word and sublexical level, but only when conditions do not place a burden on phonological processing as in oral reading. The influence of stimulus and task conditions on the variability in (pseudo)word-trace memory is an interesting topic for further study.

As a final remark, our findings have implications for practice in classrooms and other instructional settings. Speeded word and pseudoword processing may not only be a useful way to differentiate individual reading profiles within the dyslexic population from a diagnostic point of view but also as a way to stimulate orthographic processing at the (sub)lexical level in instruction and remediation (see for example, Das-Smaal, Klapwijk, & van der Leij, 1996; van den Bosch, van Bon, & Schreuder, 1995). Therefore it seems of importance to include silent reading measures and tasks that rely on higher-order word-recognition skills in instruction and remediation in classrooms and future studies. Also it is important in future research to investigate the role of reading comprehension with regard to orthographic
competence. Does better orthographic competence contribute to better comprehension when reading?

In conclusion, the PCVOD model is supported by the findings of the present study. The dyslexics in this study appear to share core phonological deficits; yet can be differentiated on the basis of orthographic competence. These characteristics may transcend orthographies, and thus appear to be universal. Dyslexics with greater orthographic competence tend to be better at perceiving larger orthographic units irrespective of lexicality and language, provided conditions favor such processing. Future research should attempt to understand how this model applies to other samples of dyslexic children, of varying ages and languages.
Chapter 4  Dutch dyslexia in adulthood: Core features and variety*

Abstract

This study tested the phonological core deficit hypothesis among Dutch dyslexic adults and also evaluated the pattern of individual differences among dyslexics predicted by the phonological-core variable-orthographic differences (PCVOD) model (van der Leij & Morfidi, 2006) in a sample of 57 control adults and 56 dyslexic adults. It was confirmed that Dutch adult dyslexics share a phonological core deficit. As predicted, there was significantly larger variability among dyslexics in orthographic coding relative to phonological coding. Orthographic coding also explained additional variance in word reading fluency after phonological coding was partialed out. Consistent with the PCVOD model, when two subgroups were selected which differed in levels of orthographic coding, the high-scoring subgroup outperformed the low-scoring subgroup on almost all reading and reading-related tasks. As anticipated, the high-scoring subgroup had near-normal levels of orthographic abilities. These advantages were not attributable to differences in general cognitive competence, print exposure, or educational attainment.

In the present study, the core features of a Dutch adult dyslexic sample are investigated, in particular the persistence of problems with phoneme awareness, rapid serial naming and phonological recoding. We also evaluate the phonological-core variable-orthographic differences model (PCVOD) proposed by van der Leij and Morfidi (2006) to explain the heterogeneity within the dyslexic group. According to the PCVOD approach, a common core phonological deficit is accompanied by greater variability in tasks that rely on orthographic coding.

4.1 Phonological core deficits across orthographies and age

It is well established that phonological coding, the ability to use speech codes to represent information in the form of words and parts of words including phonemes, is strongly implicated in reading acquisition. According to Vellutino, Fletcher, Snowling, and Scanlon (2004), phonological coding deficits qualify as the universal and stable core characteristic of dyslexia across languages with alphabetic writing systems. Subskills of reading that rely on phonological coding are phoneme awareness and rapid serial naming, and there is also a strong relationship with phonological recoding because grapheme-phoneme correspondences are required to retrieve the pronunciation of unknown words (e.g., Stanovich & Siegel, 1994).

Phoneme awareness has been found to be one of the strongest predictors of reading acquisition (e.g., Cardoso-Martins & Pennington, 2004; Share, Jorm, Maclean, & Matthews, 1984). This applies to all languages with alphabetic scripts studied to date (e.g., Caravolas, Volín, & Hulme, 2005; Holopainen, Ahonen, & Lyytinen, 2001; Ziegler & Goswami, 2005). Although the period of time during which phoneme awareness affects typical reading development may be relatively brief in more consistent orthographies (de Jong & van der Leij, 1999; Landerl & Wimmer, 2000), dyslexic readers show impairments in phoneme awareness when task demands are adapted to their developmental level, independent of
orthographic depth and age (Bruck, 1992; Caravolas et al., 2005; de Jong & van der Leij, 2003; Elbro, Nielsen, & Petersen, 1994; Lyytinen, Leinonen, Nikula, Aro, & Leiwo, 1995; Miller-Guron & Lundberg, 2000; Miller-Shaul, 2005; Morfidi, van der Leij, de Jong, Scheltinga, & Bekebrede, 2007; Pennington, van Orden, Smith, Green, & Haith, 1990; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Wilson & Lesaux, 2001).

Rapid serial naming appears to be the most important predictor of fluency of word reading and dyslexia at a younger age in alphabetic scripts (e.g., Caravolas et al., 2005; de Jong & van der Leij, 2003; Denckla & Rudel, 1974; Vaessen, Gerretsen, & Blomert, 2009; van den Bos, Zijlstra, & lutje Spelberg, 2002; Wimmer, Mayringer, & Landerl, 2000). Moreover, it is clear that difficulties in rapid serial naming persist into adolescence (Morfidi et al., 2007) and adulthood (Miller et al., 2006; Reid, Szcerbinski, Iskierka-Kasperek, & Hansen, 2007; Vukovic, Wilson, & Nash, 2004).

Poor phonological recoding skill has also been shown to be a universal characteristic of young dyslexics, for example in English (Herrmann, Matyas, & Pratt, 2006; Rack, Snowling, & Olson, 1992; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003), German (Landerl & Wimmer, 2000), and Dutch (van der Leij & van Daal, 1999; Yap & van der Leij, 1993a). At a later age, severe difficulty with phonological recoding continues to be the most striking characteristic of dyslexics across languages and orthographies (Bruck, 1998; Elbro et al., 1994; Lyytinen et al., 1995; Miller-Guron & Lundberg, 2000; Miller-Shaul, 2005; Snowling et al., 1997). One of the aims of the present study was to investigate whether phonological core deficits extend to Dutch dyslexic adults who, as yet, have not been studied.

4.2 Variability in orthographic coding

Although the prevailing causal model of dyslexia focuses on the unitary phonological deficit model (Vellutino et al., 2004), it has been argued that these deficits may be accompanied by large individual differences in other
domains of cognitive processing. In 1988, Stanovich developed the phonological-core variable-difference (PCVD) model, which postulates that all poor readers suffer from comparable core deficits in phonological processing, but may differ in general cognitive skills. The PCVD model was proposed as a framework for conceptualizing the differences between IQ-discrepant dyslexics and IQ-nondiscrepant poor readers on tasks outside the phonological core. In a subsequent study, Stanovich and Siegel (1994) suggested that relative to non-discrepant poor readers, dyslexic readers are relatively less disadvantaged in tasks that tap orthographic coding\(^3\), compared with their phonological deficits, and might even display a processing (“compensatory”) superiority (see also Siegel, Share, & Geva, 1995).

Extending the PCVD model to individual variation within the dyslexic population, van der Leij and Morfidi (2006) suggested that a phonological-core variable-orthographic differences model (PCVOD) was a better description of their empirical evidence. The PCVOD model assumes that, although dyslexics may on average show less severely impaired orthographic skills (relative to their phonological deficits), there are large individual differences within the group. Some dyslexics’ phonological deficits may be partly offset by relatively good performance on tasks that involve orthographic processing of larger orthographic units. In contrast, other dyslexics may have deficits in both phonological and orthographic coding and possess less compensatory potential in orthographic coding than is suggested by Stanovich and Siegel (1994).

The PCVOD approach to the issue of heterogeneity within the dyslexic population differs markedly from the influential surface/phonological approach to dyslexia sub-typing (e.g., Castles & Coltheart, 1993) in which, following the dual-route model of word reading (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), the lexical and non-lexical (i.e., orthographic

\(^3\) Orthographic coding, “the ability to represent a printed word in memory and then to access the whole word pattern, a single letter, or letter cluster in that representation” (Berninger et al., 1992, p. 260), relies less on phonological coding than phonological recoding does.
and phonological) dimensions of word recognition are considered two equally important sources of potential breakdown in word recognition among developmental dyslexics. The dual-route view implies that, in addition to dyslexics with both phonological and orthographic deficits, surface dyslexia (selective orthographic deficits) and phonological dyslexia (selective phonological deficits) will be equally prevalent. However, English-language findings (see e.g., Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Stanovich, Siegel, & Gottardo, 1997) have shown that developmental surface dyslexia is both less severe and less common than phonological dyslexia. Furthermore, these disproportionate prevalence rates are consistent with many studies showing that within the dyslexic population as a whole, orthographic coding is less severely impaired than phonological processing (see for a review, Share & Stanovich, 1995). More generally, it is well established that phonological processing correlates more strongly with reading ability than orthographic coding in the general population (Share, 1995). Finally, there is evidence that orthographic coding is partly but not entirely parasitic on phonological processing (Cunningham, Perry, & Stanovich, 2001). Collectively, these findings contradict what might be termed the "equivalence assumption" regarding orthographic and phonological causes of dyslexia. Instead, the data favor an approach to dyslexic heterogeneity characterized by greater heterogeneity in orthographic coding coupled with relative homogeneity as regards phonological deficits as exemplified in the phonological-core variable-orthographic difference model.

Bekebrede, van der Leij, and Share (2009) tested the PCVOD model in a study of Dutch adolescents. Supporting the universality of the phonological core hypothesis, all dyslexics performed poorly on phonological coding and phonological recoding (pseudoword reading fluency). However, Bekebrede et al. found a dyslexic subgroup with better orthographic skills who excelled at silent speeded word processing and tasks relying on some kind of large-unit processing that extended across word type (words or pseudowords), language (Dutch or English), and response mode (lexical decision or typing). These differences could not be attributed
to differences in print exposure, phonological coding, verbal competence or vocabulary, reading experience, or general intelligence.

4.3 The present study

The present study set out to examine the PCVOD predictions in a sample of Dutch dyslexic adults for several reasons. First, because the model is supported by data from adolescents, it may be even more applicable in adults for whom reading is in its developmental end-state and individual differences have stabilized.

Second, because orthographic coding is partly but not entirely parasitic on phonological processing (Share & Stanovich, 1995), orthographic coding should account for unique variance in word recognition even after controlling for phonological variables such as phoneme awareness and phonological recoding (Cunningham et al., 2001). The variance explained by orthographic coding is only partly explained by experience (i.e., print exposure) among children and adults (Cunningham & Stanovich, 1990; see for a Dutch replication, Bekebrede et al., 2009), suggesting that orthographic coding is, at least in part, an individual or "within-child" ability.

Third, Dutch adults learn to read English as a second language. In comparison to their first language with its relatively shallow script, the study of L2 English reading is informative for the PCVOD model because of the greater demands in English on processing larger orthographic units (Seymour, Aro, & Erskine, 2003; Ziegler & Goswami, 2005). For example, Miller-Guron and Lundberg (2000) identified a subgroup of adult Swedish dyslexics who had, as they termed it, a “preference for English reading” but showed similar impairments in phonological coding in comparison to a subgroup without a preference for English. In a similar study with Dutch dyslexic adolescents, a subgroup of dyslexic students was found with superior orthographic knowledge in Dutch and English, and who also were better in English reading compared to other dyslexics. Phonological coding
and Dutch reading, however, were comparable in the two groups (van der Leij & Morfidi, 2006).

Fourth, the model challenges the prevailing view expressed by Vellutino et al. (2004, p. 7) that: “There is abundant evidence that the child who has limited phonological awareness and limited alphabetic mapping skills also has limited orthographic awareness and limited orthographic knowledge … . These limitations have been observed in both dyslexic children and adults”. In contrast, the PCVOD model predicts that the limitations in orthographic skills are less constrained among dyslexics than their limitations in phonological awareness.

### 4.4 Research questions

The present study was designed to test the PCVOD model in a sample of Dutch dyslexic adults. The first prediction was that they would show a phonological core deficit. In particular we predicted poorer performance on standard tasks relying on phonological coding (i.e., phoneme awareness, rapid serial naming and phonological recoding) relative to both control age and reading age controls. Other predictions addressed the issue of heterogeneity within the dyslexic group. The foundation assumptions of the PCVOD model were tested using the methodology of Bekebrede et al. (2009). Given that orthographic coding is considered to be only partly parasitic on phonological skills, orthographic coding was expected to account for significant additional variance in fluency of word reading after phonological coding was partialed out. Next, the PCVOD model predicts that among dyslexics, the variability in orthographic coding will be significantly greater than the variability in phonological coding. Thus, some dyslexics (we term ORTH⁺) will have relatively “normal” orthographic skills, whereas other dyslexics (termed ORTH⁻) have very poor orthographic skills in spite of a common phonological deficit. We also sought evidence for external validity for the model by testing the hypothesis that differences between dyslexic subgroups in orthographic coding are accompanied by
differences in performance on tasks that depend on the processing of larger orthographic units, either due to word characteristics (chiefly spelling-sound complexity) or stimulus presentation condition.

With regard to word characteristics we exploited that fact that the most important second language in the Netherlands is English. English reading is known to be more dependent on larger orthographic units because a letter-by-letter reading strategy is often insufficient to identify many words owing to the extreme irregularity of English spelling (Share, 2008a; Ziegler & Goswami, 2005).

Additional external validity was adduced using a stimulus presentation condition that necessitates the processing of larger orthographic units, namely, brief or "flashed" presentation of words, (see e.g., Bekebrede et al., 2009). Presenting words for 200 ms followed by masking deters the use of an exhaustive grapheme-phoneme decoding strategy, and increases reliance on larger (orthographic) units. Brain imaging studies have confirmed that in the first 250 ms of word recognition, the visual word form area is activated (e.g., Bolger, Perfetti, & Schneider, 2005; Maurer, Brem, Bucher, & Brandeis, 2005). Furthermore, ERP studies indicate that there is an orthographic/lexicality peak around N170, followed by a phonological peak around N300 (Dien, 2009; see also Simon, Bernard, Lalonde, & Rebaï, 2006). Together, these results support the assumption that recognition of larger orthographic units takes place within the first 200 ms (for a review, see Wolf, 2007). In particular, the processing of pseudo words flashed for only 200 ms may reveal whether multi-letter units are processed because unfamiliarity at the word level makes "direct" word recognition impossible but, at the same time, also curtails processing at the single grapheme level (Yap & van der Leij, 1993a).

Finally, a stringent test of the PCVOD model requires that several mediating factors be excluded. The subgroup with superior orthographic coding (ORTH⁺) should not simply have had more exposure or experience with written Dutch or English reading, or differ in educational attainment or general ability. Furthermore, the PCVOD model predicts that, despite comparable print exposure, the subgroup with superior orthographic coding
should be better readers than the subgroup with inferior orthographic coding because they are able to rely to a larger degree on superior representations of spelling patterns of printed words and of sublexical letter clusters (Berninger et al., 1992).

4.5 Method

4.5.1 Participants

The parents of the children who participated in the longitudinal study of the Dutch Dyslexia Program (DDP) (van der Leij, Lyytinen, & Zwarts, 2001) were invited to participate in the present study. The van der Leij et al. study comprised a group of infants with a genetic risk for dyslexia and a matched control group without this genetic risk. The at-risk infants had at least one dyslexic parent and another first or second grade relative who reported lifelong reading and/or spelling difficulties and who performed poorly on a word and pseudoword reading fluency test administered to all parents at the start of the project. Additionally, a questionnaire was administered to gain information about additional learning disabilities or neuropsychological deficits. Five fathers reported hyperactivity or attention problems; three were in the at-risk group and two in the control group. Because no formal diagnoses were available and there were no overall group-wise differences, these parents were kept in the sample. Five years later, 113 parents consented to participate in the present study. There were 57 parents in the control group (27 males and 30 females) and 56 in the dyslexic group (25 males and 31 females). There was no relationship between gender and reading status (dyslexic/control) $\chi^2(1, N = 113) = .08$, ns.

The typical educational attainment of these adults was middle to higher vocational education. As anticipated, there was a significant effect of educational attainment on the participants’ reading status, $U = 1230$, $Z = -2.24$, $p < .05$, with the dyslexic group's educational attainment lower than the non-dyslexic group. The average age among the adults was 37
years and 3 months ($SD = 4$ months), with a range of 28 to 48 years. There were no differences between the groups in age.

The adult dyslexics were also compared to 23 normal readers from Grades 8 and 9 (mean age 14;10 years) selected from the dataset of Morfidi et al., (2007) and used as a reading-age control group. These two groups were matched on Dutch word reading fluency (dyslexic adults $M = 78.5$ words per minute, $SD = 17.05$, reading age controls $M = 83.5$ words per minute, $SD = 12.45$), $F(1, 78) = 1.59$, $ns$). A variety of reading and phonological data were available from the reading-age control group.

### 4.5.2 Phonological coding

**Phoneme awareness.** To measure phoneme awareness a computerized word reversal task was developed as part of the Interactive Dyslexia Test (IDT; Bekebrede, van der Leij, Plakas, & Schijf, 2006). This subtest was originally developed by Buis (n.d.). Participants hear two pseudowords (e.g., ket – tek) and are asked to press a true or false button to indicate whether the second word is the reverse of the first. The test consists of 10 examples and 60 test items - all monosyllabic words with either one or two consonants at the beginning or end of the word. The internal consistency (Cronbach’s $\alpha$) was found to be .84.

**Rapid serial naming of digits** (Denckla & Rudel, 1974). The participants are required to read aloud a series of 50 digits (8, 1, 3, 6, 5, in random order) as quickly and accurately as possible, while time is recorded. Van der Leij and Morfidi (2006) reported test-retest reliability of .74.

### 4.5.3 Orthographic coding

**Orthographic choice L1.** To measure orthographic knowledge in native Dutch, van der Leij and Morfidi (2006) developed an adaptation of Olson,
Forsberg, Wise, and Rack's (1994) English orthographic choice task. Forty pairs of homophonic words (e.g., ‘hoet – hoed’ [hat]) are presented on a printed page. The participants are asked to choose the correctly spelled word. Both accuracy and time are recorded. The internal consistency (Cronbach’s $\alpha$) was found to be .68.

**Orthographic choice L2.** This test (Olson et al., 1994) was used to evaluate orthographic knowledge in L2 English. Forty pairs of printed words (e.g., *wurd* – *word*) are presented and the participants are required to choose the correctly spelled word. Both accuracy and time are recorded. Internal consistency (Cronbach’s $\alpha$) was found to be .81.

### 4.5.4 Reading measures in Dutch

**Word reading fluency L1.** The Een Minuut Test (EMT) [One Minute Test] (Brus & Voeten, 1973) was used to identify poor readers in L1 Dutch. The test consists of 116 words of increasing difficulty. The participant is asked to read aloud as many words as possible in one minute. Both accuracy and speed are emphasized. The test score is the number of words read correctly in 60 seconds. Parallel test and test-retest reliabilities are over .80 (van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994).

**Pseudoword reading fluency.** The Klepel (van den Bos et al., 1994) is a speeded reading test consisting of 116 pseudowords of increasing difficulty. The test was constructed by changing consonants or vowels in the words of the Dutch One Minute Test without violating the pronunciation rules of Dutch. The test score is the number of pseudowords correctly read in two minutes. Parallel test reliabilities are reported to be over .89 (van den Bos et al., 1994).

**Flashed word identification.** In this test (IDT; Bekebrede et al., 2006) a word appears on a computer screen for 200 ms and then masked. The
participants are required to press a true or false button to indicate whether the word is correctly spelled or not. The test consists of three examples and 40 items containing one, two, and three syllables. In each block of ten items there are five correctly spelled words. The internal consistency (Cronbach’s $\alpha$) was found to be .74.

*Flashed word production.* This task (IDT; Bekebrede et al., 2006) requires silent reading and production of real words and depends on both speed and accuracy. A word is flashed on a computer screen for 200 ms and then masked. The participant is asked to type the flashed word. Again, there are three examples followed by 40 items with one, two, and three syllables. The test is discontinued after eight incorrect responses in a set of 10 items. The internal consistency (Cronbach’s $\alpha$) was found to be .91.

*Flashed pseudoword production.* In this silent pseudoword reading and production task a pseudoword is flashed on a computer screen for 200 ms and then masked (IDT; Bekebrede et al., 2006). The participant is required to type the flashed pseudoword. The pseudowords were constructed by changing the vowels of another flashed word production test not administered to these adults. The test consists of three examples followed by three blocks of 10 items containing one, two, and three syllables. When the participant commits more than eight errors in a single block, the test is discontinued. The internal consistency (Cronbach’s $\alpha$) was found to be .90.

4.5.5 *Reading measures in L2 English*

*Word reading fluency L2.* The English One Minute Test (OMT) (Fawcett & Nicolson, 1996) demands speed and accuracy in reading English words. The test consists of 120 words of increasing difficulty. The test score is the number of words read correctly in one minute. Fawcett and Nicolson reported test-retest reliability of .99.
Flashed word production L2. In this silent reading and production task, an English word is presented on a computer screen for 200 ms and then masked (IDT; Bekebrede et al., 2006). The participants are asked to type the English word. Block 1 consists of 20 monosyllabic words, Block 2 consists of 10 two-syllable words, Block 3 consists of 10 three-syllable words, and Block 4 consists of 10 final ‘e’ words with one to three syllables. The test is discontinued after more than eight errors in a single block. Internal consistency (Cronbach’s α) was found to be .96.

4.5.6 Control measures

Non-verbal (spatial) ability. To measure general non-verbal ability, a spatial subtest of the GAT-B, General Aptitude Test-Battery (van der Flier & Boomsma-Suerink, 1994), was administered. The participants are required to solve as many questions as possible in six minutes with a maximum of 40. The participants see an unfolded figure and must choose among four options which figure is correctly folded. The complete General Aptitude Test-Battery has good reliability and sufficient construct validity according to the national assessment of psychometric qualities of tests.

General verbal ability. When the parents were selected to participate in the longitudinal study, verbal ability was measured with the Similarities subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1955, Dutch adaptation, 1970). This task does not involve reading. The participants are asked in what way two words are similar. Responses to each of the 13 items are awarded 2, 1, or 0 points. After four consecutive 0-point answers, the test is discontinued. Split-half reliability of .81 is reported.

Literacy questionnaire. A questionnaire assessing background information regarding reading habits was developed. The questionnaire consisted of 5 “themes" with a total of 22 multiple-choice questions: perceived easiness of the English language (consisted of 4 questions with a reliability of α .86);
preference for Dutch (consisting of 6 questions with a reliability of $\alpha .75$); exposure to English (4 questions with a reliability of $\alpha .85$); exposure to Dutch (4 questions, reliability .73), and 5 additional questions about computer use. A translation of this questionnaire is given in Appendix B.

4.5.7 Procedure

All tasks were individually administered in two sessions of up to 45 minutes in a quiet room at home or in a laboratory setting. One session included all the paper and pencil tests in the same fixed order (orthographic choice L1 and L2; rapid serial naming; word reading fluency L1 and L2; pseudoword reading fluency; and GAT-B spatial ability); the other session included the computerized tests in the same fixed order for practical reasons (word reversal; flashed word identification; flashed word, pseudoword, and English word production).

4.6 Results

4.6.1 Comparisons between dyslexic adults and normal adult readers

In Table 4.1 the control adults are compared with the dyslexic adults in a multivariate analysis of variance (MANOVA). As predicted by the phonological core hypothesis, the dyslexics' performance was well below the control adults on both phonological coding measures, word reversal and rapid serial naming. In addition, the dyslexic adults were inferior on the four orthographic measures, despite a ceiling effect on English orthographic choice with the control adults, as well as on all the reading fluency measures (Dutch and English words and pseudowords) and flashed identification and production tasks. On spatial ability and verbal competence there were no significant differences between the two groups.
Table 4.1
Mean scores (M), standard deviations (SD), and main group effects for control adults and dyslexic adults on phonological, orthographic, reading, and control measures

<table>
<thead>
<tr>
<th>Variables (max)</th>
<th>Controls (57)</th>
<th>Dyslexics (56)</th>
<th>MANOVA</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Word reversal (60)</td>
<td>55.29</td>
<td>3.37</td>
<td>46.87</td>
<td>6.24</td>
</tr>
<tr>
<td>Rapid serial naming (sec)</td>
<td>17.23</td>
<td>4.04</td>
<td>22.44</td>
<td>6.01</td>
</tr>
<tr>
<td>Orthographic choice L1 (40)</td>
<td>38.61</td>
<td>1.25</td>
<td>36.43</td>
<td>2.41</td>
</tr>
<tr>
<td>Time orthographic choice L1 (sec)</td>
<td>62.51</td>
<td>18.19</td>
<td>100.93</td>
<td>39.16</td>
</tr>
<tr>
<td>Orthographic choice L2 (40)</td>
<td>39.51</td>
<td>0.78</td>
<td>36.63</td>
<td>3.45</td>
</tr>
<tr>
<td>Time orthographic choice L2 (sec)</td>
<td>53.65</td>
<td>17.02</td>
<td>96.80</td>
<td>61.48</td>
</tr>
<tr>
<td>Word reading fluency L1 (116)</td>
<td>106.14</td>
<td>9.65</td>
<td>78.45</td>
<td>17.05</td>
</tr>
<tr>
<td>Pseudoword reading fluency (116)</td>
<td>102.19</td>
<td>12.89</td>
<td>59.22</td>
<td>19.51</td>
</tr>
<tr>
<td>Word reading fluency L2 (120)</td>
<td>97.88</td>
<td>18.12</td>
<td>63.80</td>
<td>19.66</td>
</tr>
<tr>
<td>Flashed word identification (40)</td>
<td>35.04</td>
<td>2.61</td>
<td>28.70</td>
<td>3.10</td>
</tr>
<tr>
<td>Flashed word production (40)</td>
<td>38.81</td>
<td>1.64</td>
<td>33.89</td>
<td>6.30</td>
</tr>
<tr>
<td>Flashed pseudoword production (30)</td>
<td>21.02</td>
<td>2.89</td>
<td>12.55</td>
<td>4.10</td>
</tr>
<tr>
<td>Flashed English word production (50)</td>
<td>48.51</td>
<td>2.35</td>
<td>37.82</td>
<td>11.06</td>
</tr>
<tr>
<td>Spatial ability (GATB) (40)</td>
<td>25.70</td>
<td>6.09</td>
<td>25.55</td>
<td>5.34</td>
</tr>
<tr>
<td>Verbal ability (26)</td>
<td>16.79</td>
<td>2.91</td>
<td>16.47</td>
<td>3.73</td>
</tr>
</tbody>
</table>

Note. **p < .01, ns = not significant.

4.6.2 Comparisons between dyslexic adults and younger reading-age controls

The findings indicated that the dyslexic adults performed worse than the reading age controls on pseudoword reading fluency (dyslexic adults $M = 59.22, SD = 19.51$; reading age controls $M = 79.43, SD = 17.69$), $F(1, 78) = 18.37, p < .01, η²_p = .20$) and were slower on rapid serial naming (dyslexic adults $M = 22.44, SD = 6.01$; reading age controls $M = 18.24, SD = 2.26$), $F(1, 78) = 8.90, p < .01, η²_p = .10$). On a spoonerisms task (participants had to transpose the onsets of two words, see van der Leij & Morfidi, 2006), the dyslexic adults ($M(z$-score) = -.37, $SD = 1.18$) also performed worse than the reading age controls ($M(z$-score) = 3.04, $SD = .75$), $F(1, 78) = 5.60, p < .05, η²_p = .07$). However, on word reading fluency in English the adults performed better than the younger reading age controls (dyslexic adults $M = 63.80, SD = 19.66$; reading age controls $M = 51.04$,
SD = 16.20), F(1, 78) = 7.49, p < .01, $\eta^2_p = .09$). On orthographic choice accuracy the groups did not differ (dyslexic adults $M = 36.43$, SD = 2.41; reading age controls $M = 35.61$, SD = 2.17), F(1, 78) = 1.97, ns). These data not only confirm the severity of the phonological deficit among adult dyslexics in Dutch, but also support a central claim of the PCVOD model that phonological and orthographic deficits are not equally important sources of reading difficulty as assumed in the influential surface/phonological typology.

### 4.6.3 Hierarchical regression analysis

Following Cunningham et al. (2001), we combined all four orthographic measures (Dutch and English orthographic choice accuracy and time) into a single composite measure. (A principal components analysis revealed a one-factor solution with an eigenvalue of 3.1 that explained 77.7% of the variance emerged; all the factor loadings exceeded .83). The four measures were combined by averaging standardized scores. The two phonological coding tasks, however, rapid serial naming and word reversal, were not treated as a composite because the correlation was only moderate ($r = -.36$).

Hierarchical regression analysis was employed to determine whether orthographic coding played a significant role in predicting Dutch word reading fluency after the influence of phonological variables was ruled out. In this analysis (see Table 4.2), verbal ability was entered at Step 1 to control for general cognitive abilities and accounted for 4.1% of the variance, followed by the phonological measures, word reversal and rapid serial naming at Steps 2 and 3, accounted for 31.7% and 27.5%, respectively. After these measures were partialed out, the orthographic composite explained a significant portion of additional variance (9.8%) in word reading fluency.
Table 4.2

Variance ($R^2$ change) in predicting Dutch (L1) fluency of word reading explained by phonological and orthographic variables

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>$R$</th>
<th>$R^2$ change</th>
<th>$F$ change</th>
<th>$\beta$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Verbal ability</td>
<td>.203</td>
<td>4.1%</td>
<td>4.55*</td>
<td>-.02</td>
<td>-.39ns</td>
</tr>
<tr>
<td>2</td>
<td>Word reversal</td>
<td>.598</td>
<td>31.7%</td>
<td>51.84**</td>
<td>.23</td>
<td>3.41**</td>
</tr>
<tr>
<td>3</td>
<td>Rapid serial naming</td>
<td>.796</td>
<td>27.5%</td>
<td>78.12**</td>
<td>-.46</td>
<td>-8.09**</td>
</tr>
<tr>
<td>4</td>
<td>Orthographic composite¹</td>
<td>.855</td>
<td>9.8%</td>
<td>37.40**</td>
<td>.39</td>
<td>6.12**</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>73.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. ¹Orthographic composite = orthographic choice accuracy and time L1 and L2.  
* $p < .05$, ** $p < .01$, ns = not significant.

4.6.4 Individual differences

The PCVOD model predicts that there will be greater variability among dyslexics in orthographic coding compared to phonological abilities. Figure 4.1 shows the mean and variance (±1 standard deviation scores) for phonological and orthographic coding among the dyslexic and control adults. To facilitate comparison, phonological coding is indicated by a phonological composite (for this purpose only) consisting of word reversal and rapid serial naming, and orthographic coding is indicated by the same four-measure composite as above. Figure 4.1 confirms that there exists more variability amongst dyslexics in orthographic coding than in phonological coding. In addition, the variability amongst dyslexics in orthographic coding is larger than amongst controls. To formally test this, we used multilevel analysis by organizing our data with test scores nested in subjects. Subsequently, we used a multivariate analysis enabling a comparison between groups as well as tests.
Consistent with this key prediction of the PCVOD model, the dyslexics were found to have more variation on orthography than on phonology compared to control adults \( (p < .01) \).4

**Figure 4.1**
Variability among dyslexic and control adults on phonology and orthography

To further investigate the orthographic variability, the dyslexics were subdivided into subgroups with high and low orthographic coding. The dyslexic adults were divided into three almost equal groups based on the orthographic composite. The dyslexics who scored in the top third of the composite \( (n = 19) \) formed the ORTH+ subgroup with high orthographic coding.

4 To use multivariate analyses we specified three different contrasts: 1) the variances of orthographic scores of the control adults are equal to the variances of the orthographic scores of the dyslexics \( (\chi^2 = 815.20) \); 2) the variances of the phonological scores of the control adults are equal to the variances of the phonological scores of the dyslexics \( (\chi^2 = 769.50) \), and 3) the variances of the orthographic scores of the dyslexics are equal to the phonological scores of the dyslexics \( (\chi^2 = 783.75) \). These three models were contrasted with a model with no restrictions to the variances \( (\chi^2 = 759.39) \). All the restricted models were significantly worse, therefore the conclusion is that in comparison with the control adults, the dyslexics have more variance on orthographic coding than on phonological coding.
coding, whereas the dyslexic adults who scored in the lowest third of the orthographic composite \((n = 19)\) formed the ORTH\textsuperscript{−} subgroup with low orthographic coding. (The intermediate group \((n = 18)\) was discarded).

To validate this subdivision, performance on the separate orthography measures was compared across the three groups. The means, standard deviations and main effects of group are presented in Table 4.3. The three planned contrasts to examine differences between the groups are reported in the text if the multivariate statistics indicated significant overall differences.

The contrast between the ORTH\textsuperscript{−} subgroup and the controls showed a significant difference on the orthographic composite, \(F(1, 92) = 132.83, p < .01, \eta^2_p = .59\), and on the four variables separately, accuracy of orthographic choice in Dutch, \(F(1, 92) = 69.63, p < .01, \eta^2_p = .43\), and in English, \(F(1, 92) = 140.44, p < .01, \eta^2_p = .61\), and speed of orthographic choice: Dutch, \(F(1, 92) = 76.81, p < .01, \eta^2_p = .46\), and English, \(F(1, 92) = 77.54, p < .01, \eta^2_p = .46\).

The contrast between the ORTH\textsuperscript{+} subgroup and the control adults did not reveal a significant difference on the orthographic composite, \(F(1, 92) = 3.36, p = .07\). The ORTH\textsuperscript{+} subgroup scored below normal readers on the time of the Dutch orthographic choice task, \(F(1, 92) = 4.29, p < .05, \eta^2_p = .05\), but performed as well as the control adults on accuracy on orthographic choice in Dutch and on accuracy and speed of the orthographic choice in English (accuracy L1, \(F(1, 92) = 3.69, p = .058\); accuracy L2 \((F < 1)\), and speed L2, \(F(1, 92) = 1.41, ns\)). These data indicate that the ORTH\textsuperscript{+} subgroup of dyslexics perform within the normal to low-normal range in orthographic skills.

The two dyslexic subgroups differed in the defining measure of overall orthographic coding, \(F(1, 92) = 63.94, p < .01, \eta^2_p = .41\), and ORTH\textsuperscript{+} also outperformed ORTH\textsuperscript{−} on the four constituent variables: orthographic choice in Dutch, \(F(1, 92) = 84.00, p < .01, \eta^2_p = .24\), and in English, \(F(1, 92) = 82.35, p < .01, \eta^2_p = .48\), and the time to complete these orthographic choice tasks, Dutch \(F(1, 92) = 30.64, p < .01, \eta^2_p = .25\), and English, \(F(1, 92) = 39.45, p < .01, \eta^2_p = .30\).
Table 4.3
Mean scores (M), standard deviations (SD), and main group effects for the control adults and two dyslexic subgroups, (ORTH\(^+\) = superior orthographic coding, ORTH\(^-\) = inferior orthographic coding) on orthographic and phonological coding

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control (57)</th>
<th>ORTH(^+) (19)</th>
<th>ORTH(^-) (19)</th>
<th>MANOVA (56)</th>
<th>Effect size (\eta^2_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortho choice L1 (40)(^1)</td>
<td>38.61</td>
<td>1.25</td>
<td>37.74</td>
<td>1.15</td>
<td>34.72 (a, c)</td>
</tr>
<tr>
<td>Time ortho choice L1(^1)</td>
<td>62.51</td>
<td>18.19</td>
<td>77.53</td>
<td>13.57</td>
<td>127.33 (a, b, c)</td>
</tr>
<tr>
<td>Ortho choice L2 (40)(^2)</td>
<td>39.51</td>
<td>0.78</td>
<td>39.11</td>
<td>1.10</td>
<td>33.61 (a, c)</td>
</tr>
<tr>
<td>Time ortho choice L2(^2)</td>
<td>53.65</td>
<td>17.02</td>
<td>66.00</td>
<td>12.96</td>
<td>147.06 (a, c)</td>
</tr>
<tr>
<td>Orthographic composite(^3)</td>
<td>1.94</td>
<td>1.23</td>
<td>0.83</td>
<td>0.72</td>
<td>5-5.16 (a, c)</td>
</tr>
</tbody>
</table>

\(\eta^2_p\) \(F(2, 92)\)

Word reversal (60)      55.29  3.37  50.29  4.59  44.58  5.91  47.48 \(a, b, c\) \(F(2, 89)\) .52
Rapid serial naming (sec) 17.23  4.04  22.24  5.36  24.63  5.82  20.68 \(a, b\) .32

Note. \(^1\)Ortho= orthographic choice; \(^2\) Orthographic composite = orthographic choice accuracy and time in seconds L1 and L2.

Significant between-group differences are indicated by subscripts: \(^a\) Controls - ORTH\(^-\); \(^b\) Controls - ORTH\(^+\); \(^c\) ORTH\(^+\) - ORTH\(^-\).

\(**p < .01.\)

4.6.5 Phonological coding

To test the assumption of a common phonological core among dyslexics, performance of the three groups on the phonological tasks is presented in Table 4.3. The planned contrast between the ORTH\(^+\) subgroup and the control adults revealed that ORTH\(^-\) performed worse on word reversal, \(F(1, 89) = 90.94, p < .01, \eta^2_p = .51\), and rapid serial naming, \(F(1, 89) = 35.21, p < .01, \eta^2_p = .28\). ORTH\(^+\) were also significantly below control adults on both word reversal, \(F(1, 89) = 18.17, p < .01, \eta^2_p = .17\), and rapid serial naming, \(F(1, 89) = 14.80, p < .01, \eta^2_p = .14\).

There was no significant difference between the two subgroups on rapid serial naming, \(F(1, 89) = 2.34, ns\). However, ORTH\(^+\) outperformed ORTH\(^-\) on word reversal, \(F(1, 89) = 16.39, p < .01, \eta^2_p = .16\). We return to this finding below.
4.6.6  Reading in Dutch and English

Reading ability in Dutch and English were compared across the three groups (see Table 4.4).

Table 4.4
Mean scores (M), standard deviations (SD), and main group effects for the control adults and two dyslexic subgroups (ORTH+ = superior orthographic coding, ORTH- = inferior orthographic coding) on the Dutch and English reading measurements

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control (57)</th>
<th>ORTH+ (19)</th>
<th>ORTH- (18)</th>
<th>MANOVA F(2, 91)</th>
<th>Effect size</th>
<th>η²_p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Dutch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Word reading fluency L1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(116)</td>
<td>106.14</td>
<td>9.65</td>
<td>85.68</td>
<td>14.61</td>
<td>69.89</td>
<td>17.04</td>
</tr>
<tr>
<td>Pseudoword reading fluency L1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(116)</td>
<td>102.19</td>
<td>12.89</td>
<td>68.68</td>
<td>21.60</td>
<td>49.33</td>
<td>15.99</td>
</tr>
<tr>
<td>Flashed word identification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(40)</td>
<td>35.04</td>
<td>2.61</td>
<td>30.63</td>
<td>2.11</td>
<td>26.89</td>
<td>2.49</td>
</tr>
<tr>
<td>Flashed word production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(40)</td>
<td>38.81</td>
<td>1.64</td>
<td>37.63</td>
<td>1.83</td>
<td>29.61</td>
<td>6.87</td>
</tr>
<tr>
<td>Flashed pseudoword production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(30)</td>
<td>21.02</td>
<td>2.89</td>
<td>14.79</td>
<td>3.75</td>
<td>10.22</td>
<td>3.92</td>
</tr>
<tr>
<td>English</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Word reading fluency L2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(120)</td>
<td>97.88</td>
<td>18.12</td>
<td>74.21</td>
<td>16.16</td>
<td>49.65</td>
<td>14.71</td>
</tr>
<tr>
<td>Flashed word production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(50)</td>
<td>48.51</td>
<td>2.35</td>
<td>45.11</td>
<td>3.57</td>
<td>30.65</td>
<td>9.79</td>
</tr>
</tbody>
</table>

Note. Significant between-group differences are indicated by subscripts: a Controls - ORTH-; b Controls - ORTH+; c ORTH+ - ORTH.
** p < .01.

The ORTH+ subgroup performed more poorly than the controls on all the Dutch reading tasks: word reading fluency, $F(1, 91) = 116.90, p < .01, \eta^2_p = .56$; pseudoword reading fluency, $F(1, 91) = 157.77, p < .01, \eta^2_p = .63$; flashed word identification, $F(1, 91) = 145.41, p < .01, \eta^2_p = .62$; flashed word production, $F(1, 91) = 103.86, p < .01, \eta^2_p = .53$; and flashed pseudoword production, $F(1, 91) = 147.55, p < .01, \eta^2_p = .62$. In addition, on the two English reading tasks ORTH+ performed more poorly, English word reading fluency, $F(1, 90) = 103.26, p < .01, \eta^2_p = .53$ and flashed English word production, $F(1, 90) = 181.30, p < .01, \eta^2_p = .67$. 

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The ORTH\textsuperscript{+} subgroup was also inferior to the control adults on all the Dutch reading tasks except flashed word production, $F(1, 91) = 1.77, \text{ns.}$ Word reading fluency, $F(1, 91) = 38.77, p < .01, \eta^2_p = .30$; pseudoword reading fluency, $F(1, 91) = 66.04, p < .01, \eta^2_p = .42$; flashed word identification, $F(1, 91) = 44.26, p < .01, \eta^2_p = .33$; and flashed pseudoword production, $F(1, 91) = 51.16, p < .01, \eta^2_p = .36$. There was also a significant difference on the English word reading tasks, English word reading fluency, $F(1, 90) = 27.06, p < .01, \eta^2_p = .23$, and flashed English word production, $F(1, 90) = 7.16, p < .01, \eta^2_p = .07$.

As predicted, when the two dyslexic subgroups were compared, ORTH\textsuperscript{+} outperformed ORTH\textsuperscript{-} on Dutch word reading (fluency, $F(1, 91) = 15.00, p < .01, \eta^2_p = .14$; flashed word production, $F(1, 91) = 53.38, p < .01, \eta^2_p = .37$; and flashed word identification, $F(1, 91) = 20.74, p < .01, \eta^2_p = .19$); and also on English word reading, (fluency $F(1, 90) = 18.35, p < .01, \eta^2_p = .17$, and flashed English word production, $F(1, 90) = 81.39, p < .01, \eta^2_p = .48$). In addition, ORTH\textsuperscript{+} was better on pseudoword reading fluency, $F(1, 91) = 14.29, p < .01, \eta^2_p = .14$, as well as flashed pseudoword production, $F(1, 91) = 17.85, p < .01, \eta^2_p = .16$.

To control for differences in phoneme awareness as an explanation of the differences in the reading measures as opposed to orthographic coding differences, the word reversal task was used as a covariate in the analysis of reading outcomes: five of the seven differences remained significant. The differences between the ORTH\textsuperscript{+} and ORTH\textsuperscript{-} subgroup remained significant for flashed word identification, $F(1, 33) = 11.56, p < .01, \eta^2_p = .26$; flashed word production, $F(1, 33) = 9.09, p < .01, \eta^2_p = .22$; flashed pseudoword production, $F(1, 33) = 4.11, p = .05, \eta^2_p = .11$; English flashed word production, $F(1, 33) = 14.88, p < .01, \eta^2_p = .31$; and English word reading fluency, $F(1, 33) = 11.12, p < .01, \eta^2_p = .26$. However, the difference in Dutch word reading fluency and in (Dutch) pseudoword reading fluency disappeared after partialing out word reversal (word reading fluency, $F(1, 33) = 2.73, \text{ns}$; pseudoword reading fluency, $F(1, 33) = 1.91, \text{ns}$).
4.6.7 Cross-script comparisons

In order to test the prediction that ORTH\(^+\) will have an advantage reading English words that are more dependent on larger-unit orthographic processing, we examined the interaction between ORTH\(^+\) and ORTH\(^-\) and flashed word production in Dutch and English. Consistent with PCVOD predictions, there is a greater difference between the groups in English: the ORTH\(^+\)'s advantage is even greater in English than in Dutch: Greenhouse-Geisser, $F(1, 36) = 19.53, p < .01, \eta^2_p = .35$. It turns out that ORTH\(^+\) benefit from English in the flashed condition, where there are greater demands on orthographic coding. Even in (non-flashed) reading fluency an interaction was found: Greenhouse-Geisser, $F(1, 34) = 5.27, p = .028, \eta^2_p = .13$. The ORTH\(^+\) are better overall (summing across languages) and Dutch is easier overall (summing across groups), but, as predicted, the ORTH\(^+\) had a greater advantage in English.

4.6.8 Ruling out alternative accounts for ORTH\(^+\)'s advantages

The PCVOD model predicts that the differences between the subgroups on orthographic coding are not due to differences in general intelligence, age, gender, or educational attainment (see Table 4.5).

There were no differences between any of the groups on spatial ability or age. There was also no relationship between gender and group (control/ORTH\(^+\)/ORTH\(^-\)), $\chi^2(2, N = 95) = 1.52, ns$. Neither did the ORTH\(^-\) subgroup differ significantly from the control adults on verbal competence, $F(1, 92) = 2.86, p = .09, \eta^2_p = .03$. The ORTH\(^-\) subgroup, however, did have lower educational attainment than the control adults, $U = 216, Z = -4.17, p < .01$. The ORTH\(^+\) subgroup outperformed the control adults on verbal competence, $F(1, 92) = 4.83, p < .05, \eta^2_p = .05$. There were no differences on educational attainment, $U = 538, Z = -.05, ns$. The ORTH\(^+\) subgroup performed better on verbal competence, $F(1, 92) = 9.89, p < .01, \eta^2_p = .10$. 
than ORTH\textsuperscript{−} subgroup, and there was a significant difference between the two subgroups on educational attainment, $U = 71$, $Z = -3.35$, $p < .01$.

Table 4.5

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Control (57)</th>
<th>ORTH\textsuperscript{+} (19)</th>
<th>ORTH\textsuperscript{−} (19)</th>
<th>MANOVA</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Spatial ability (GATB) (40)</td>
<td>25.70</td>
<td>6.09</td>
<td>27.16</td>
<td>3.92</td>
<td>23.65</td>
</tr>
<tr>
<td>Verbal ability (Screening) (26)</td>
<td>16.79</td>
<td>2.91</td>
<td>18.58</td>
<td>2.85</td>
<td>15.35</td>
</tr>
<tr>
<td>Age (48)</td>
<td>37.72</td>
<td>4.49</td>
<td>38.11</td>
<td>3.30</td>
<td>36.35</td>
</tr>
<tr>
<td>Educational attainment (7)\textsuperscript{1,2}</td>
<td>5.88</td>
<td>1.14</td>
<td>5.89</td>
<td>1.15</td>
<td>4.29</td>
</tr>
</tbody>
</table>

\textit{Note.} Significant between-group differences are indicated by subscripts: a Controls - ORTH\textsuperscript{−}; b Controls - ORTH\textsuperscript{+}; c ORTH\textsuperscript{+} - ORTH\textsuperscript{−}.

\textsuperscript{1}Educational attainment is highest completed educational level; 1 primary school; 2 lower secondary vocational education; 3 lower general secondary education; 4 upper general secondary education; 5 pre-university education; 6 higher professional/vocational education; 7 university.

\textsuperscript{2}Mann-Whitney statistics are reported in the text.

\textsuperscript{*}p < .05, \textsuperscript{ns} = not significant.

To control for the differences in verbal ability as an explanation of the differences in the reading measures instead of orthographic abilities, the similarities task was used as a covariate in the analysis of reading measures. All significant differences between ORTH\textsuperscript{+} and ORTH\textsuperscript{−} remained significant for all the reading measures. When educational attainment was used as a covariate, only the difference between ORTH\textsuperscript{+} and ORTH\textsuperscript{−} on word reading fluency disappeared, $F(1, 38) = 3.06$, $p = .09$, $\eta^2 = .08$. Once again, it appears that orthographic coding per se, rather than other alternative factors are responsible for the advantages of ORTH\textsuperscript{+}.

### 4.6.9 Questionnaire findings

With regard to English, ORTH\textsuperscript{−} reported that they found it more difficult to read, $F(1, 87) = 51.61$, $p < .01$, $\eta^2 = .37$; to speak, $F(1, 87) = 14.43$, $p < .01$, $\eta^2 = .14$; to understand, $F(1, 87) = 13.29$, $p < .01$, $\eta^2 = .13$; and that they
needed more opportunities to recognize an unfamiliar word, \( F(1, 87) = 25.50, p < .01, \eta^2_p = .23 \), than the controls. ORTH\(^+\) also reported more difficulties with reading, \( F(1, 87) = 4.18, p < .05, \eta^2_p = .05 \), than the control adults and more time required to recognize an unfamiliar word, \( F(1, 87) = 10.49, p < .01, \eta^2_p = .11 \). There were no differences in understanding, \( F(1, 87) = 1.12, ns \), and in speaking \( (F < 1) \). ORTH\(^-\) did differ from ORTH\(^+\) on two questions about perceived easiness of English: ORTH\(^-\) reported more difficulties with reading, \( F(1, 87) = 14.88, p < .01, \eta^2_p = .15 \), and speaking, \( F(1, 87) = 4.99, p < .05, \eta^2_p = .05 \).

With regard to Dutch, ORTH\(^-\) reported that they had more problems with reading, \( F(1, 86) = 113.45, p < .01, \eta^2_p = .58 \); spelling, \( F(1, 86) = 120.62, p < .01, \eta^2_p = .59 \); and reading subtitles, \( F(1, 86) = 14.01, p < .01, \eta^2_p = .14 \), than the controls. They also needed more encounters in order to recognize an unfamiliar word, \( F(1, 86) = 40.91, p < .01, \eta^2_p = .33 \). ORTH\(^+\) reported more difficulties with reading, \( F(1, 86) = 29.96, p < .01, \eta^2_p = .26 \), and spelling, \( F(1, 86) = 41.26, p < .01, \eta^2_p = .33 \), than the control adults. They also needed more time to recognize an unfamiliar word \( F(1, 86) = 21.33, p < .01, \eta^2_p = .20 \). There were no reported differences in reading subtitles, \( F(1, 86) = 1.30, ns \). ORTH\(^+\) reported less difficulties than ORTH\(^-\) with reading, \( F(1, 86) = 10.88, p < .01, \eta^2_p = .12 \), and spelling, \( F(1, 86) = 7.52, p < .01, \eta^2_p = .08 \). The subgroups reported equal difficulties with the subtitles, \( F(1, 86) = 3.32, ns \), and they did not differ in the time they needed to recognize an unfamiliar word \( (F < 1) \). There were no significant differences between the groups in preferring Dutch or English in reading or spelling \( (F < 1) \).

On all questions regarding exposure to English and Dutch (reading and writing for work and for leisure L1 and L2), there were no group differences. There were also no differences on the questions involving computer use.
4.7 Discussion

The first prediction of this study was that Dutch dyslexic adults suffer from a phonological core deficit in their relatively transparent native orthography. The findings confirmed that adult dyslexics have deficient performance on tasks of phoneme awareness, rapid serial naming, and phonological recoding (pseudoword reading fluency). The dyslexics also had severe difficulties in word reading fluency and on all the (computerized) reading tasks. Supporting the universality of their difficulties, the dyslexic adults also had severe reading problems in English. These differences did not appear to be due to a problem in general learning ability, because there were no differences on tasks tapping spatial ability and verbal competence. Therefore these findings support the view of dyslexia as a specific learning disorder (e.g., Stanovich, 1988). The fact that these dyslexics also performed below the much younger reading-age control group on tasks tapping phoneme awareness, rapid serial naming, and phonological recoding, provides strong evidence of a phonological core deficit. The finding that the adult dyslexics outperformed the reading age controls on English word fluency reflects the fact that they had much more experience with the English language. The reading age control group had not as yet received much formal teaching in English.

Our study also aimed to determine whether the phonological-core variable-orthographic differences model (PCVOD) of dyslexic heterogeneity can be extended to adult dyslexics. The prediction that orthographic coding contributes to the prediction of word reading fluency was confirmed, because it explained additional variance after phoneme awareness and rapid serial naming were partialed out. This is consistent with the view (see Share, 1995) that orthographic coding is partly but not entirely parasitic on phonological processing. Our data also confirmed the prediction that dyslexics have significantly greater variability in orthographic coding than in phonological coding compared to control adults (Figure 4.1). These findings collectively confirm that orthographic abilities are an important source of heterogeneity within the dyslexic subpopulation.
Two findings jointly confirmed the central assumption of the PCVOD model that phonological and orthographic deficits are not equally important sources of reading difficulty. First, the combined dyslexic group's phonological skills fell below both chronological age and reading age controls, whereas their orthographic skills surpassed reading-age controls. Second, the subgroup with superior orthographic abilities (ORTH$^+$) were comparable to normal (age-matched) readers in orthographic coding, but performed poorly on phonological coding tasks whereas the subgroup with inferior orthographic abilities was poor in both. These outcomes contrast sharply with the assumption of equivalence inherent in the surface/phonological typology founded on the dual route model (Castles & Coltheart, 1993; Coltheart et al., 2001).

Another prediction concerned differences in tasks that are commonly assumed to rely on the processing of larger orthographic units. As anticipated, the ORTH$^+$ subgroup had less problems reading English words, which tend not to adhere to the (relatively regular) Dutch grapheme-phoneme correspondence rules. In addition, the ORTH$^+$ subgroup was better on tasks tapping speeded word processing (flashed (pseudo)word identification and production in Dutch and English), which are also assumed to rely heavily on rapid processing of larger orthographic units. The ORTH$^+$ subgroup showed a larger effect of language and were better in the English (relative to Dutch) flashed word production task.

It might be argued that the ORTH$^+$ subgroup were better readers, not because of their orthographic superiority, but owing to more exposure and reading experience than the ORTH$^-$ subgroup (as suggested by Stanovich et al., 1997). However, self-report data indicated that there were no differences in exposure to either Dutch or English between the two subgroups. In particular, data about English exposure may be considered a good test-case for the development of individual differences in reading acquisition because not only is English a compulsory second language in the Netherlands at the secondary and tertiary level of schooling, but it also plays an important role in everyday life. The findings suggest that similar exposure had different effects on L2 learning in the two subgroups, in accordance with the
predictions of the PCVOD model. There were, however, some minor experience-related differences. The ORTH\textsuperscript{+} subgroup indicated that they encountered fewer difficulties with Dutch reading and spelling than the ORTH\textsuperscript{-} subgroup, and that they considered English reading and spelling easier. These results, however, were in accordance with the finding that the ORTH\textsuperscript{+} subgroup were better readers. When these variables were covaried, all the group differences remained, with the sole exception of pseudoword reading fluency which just lost its significance. It may be argued that pseudoword reading fluency (phonological recoding of unknown words) is relatively close to the phonological core in comparison to the other reading tasks. The other tasks either permit the use of lexical knowledge (e.g., word reading fluency in Dutch and English) or oblige the reader to use larger orthographic units owing to the brief presentation time. However, owing to the fallibility of self-report data, our data cannot conclusively dismiss the possibility of more experience and exposure as an alternative explanation, but it seems fair to say that there is little support for this alternative.

A potentially more damaging alternative explanation is that ORTH\textsuperscript{+} had less severe phonological deficits. The ORTH\textsuperscript{+} subgroup did indeed perform better on phoneme awareness and the reading task that depends heavily on phonological coding (pseudoword reading fluency). To investigate whether the reading differences between ORTH\textsuperscript{+} and ORTH\textsuperscript{-} might simply be the product of the phoneme awareness advantage of the ORTH\textsuperscript{+} subgroup, we partialed out this factor. Five of the seven differences between the two subgroups on the reading tasks remained significant (the exceptions being Dutch word and pseudoword reading fluency). Moreover, the reliable differences that remained were, as anticipated, on those measures that appear to have a strong orthographic processing component (the English-language tasks and the flashed tasks in both languages). The fact that there were no differences between the subgroups in rapid serial naming is consistent with a number of studies finding that RAN is not reliably linked to orthographic processing (Bowey & Miller, 2007; Cunningham, 2006; Moll, Fussenegger, Willburger, & Landerl, 2009).
A third alternative explanation is that the ORTH\(^+\) subgroup had superior cognitive abilities. However, these adults did not differ on spatial ability, and although the ORTH\(^+\) subgroup outperformed both the control adults and ORTH\(^-\) subgroup in verbal ability, when verbal ability was used as a covariate, all the reading differences remained. These findings, therefore, do not support a general cognitive abilities explanation for the differences in reading performance between the two dyslexic subgroups.

One appealing interpretation of the findings is offered by the three components of the connectionist model: phonology, orthography, and semantics (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996). Within this framework, ORTH\(^+\) is mainly hampered when processing depends heavily on phonology. When orthography is predominant they perform at comparable levels to control adults. In semantics they may even have an advantage. These two strengths may enable them to compensate for their reading deficit to a certain extent particularly in circumstances that place a premium on orthographic processes (Snowling, 2000). It might be speculated that this explains the difference in educational attainment with ORTH\(^-\). ORTH\(^-\) are far worse than ORTH\(^+\) in semantics and orthography but less so in phonology. Similar profiles were obtained in our earlier study of young Dutch adolescents (Bekebrede et al., 2009). A subgroup of dyslexics with better orthographic coding was less impaired in tasks tapping orthographic and semantic competence than in tasks tapping phonology, whereas ORTH\(^-\) was hampered in all three.

In sum, while Dutch-speaking adult dyslexics share a core phonological deficit, there exists substantial variability in their orthographic coding as specified by the PCVOD model. Moreover, the dyslexic subgroup with greater orthographic coding was superior on all tasks that are conventionally assumed to involve the processing of larger orthographic units. These differences were not found to be attributable to non-orthographic factors such as phoneme awareness, general cognitive abilities or print exposure, or educational attainment. Above all, both subgroups can be classified as dyslexics by virtue of the fact that they fall far below typical readers on the majority (ORTH\(^+\)) or all (ORTH\(^-\)) of the reading and reading related tasks.
Chapter 5  Cognitive profiles of poor readers compared to typical readers in middle childhood, early and late adolescence, and adulthood*

Abstract

Cognitive profiles of poor readers were compared to typical readers across four different ages, mid-primary school (Grade 4), beginning (Grade 7) and end of secondary school (Grade 10), and adulthood. The four groups of participants were tested with equivalent tasks tapping Dutch and English (pseudo)word reading fluency and the reading-related processes of rapid serial naming, speeded parallel symbol processing and phoneme awareness. At all tasks, differences between typical and poor readers were large. Whereas typical readers showed better performance with age on all word reading fluency tasks, the poor readers did only between Grade 4 and 7, indicating a widening gap. In rapid serial naming, speeded parallel symbol processing, and phoneme awareness, the results of the poor readers showed the same pattern of early leveling off. The multiple case study approach, used to investigate the heterogeneity of the cognitive profiles, confirmed a large individual variety of persistent problems in all reading-related processes at all ages. However, deficits in rapid serial naming and speeded parallel symbol processing were more prevalent in the higher age-groups. In addition to the word fluency results, these findings support the view of persistent speed limitations in script processing resulting in an end state of poor readers at the typical average level of Grade 4.

* Bekebrede, J. I., van der Leij, A., Schijf, G. M., & Share, D. L.
5.1 Introduction

The present study aims to investigate differences between poor and normal readers on reading fluency and reading-related processes across four different ages. These ages represent four important stadia of reading development: mid-primary school, beginning and end of secondary school, and adulthood. The general expectations are that, assuming that the measures and samples are equivalent across these ages, differences in reading fluency will be larger with age, and there will be a large individual variety of persistent problems in all reading-related processes in all age-groups.

With regard to reading, longitudinal studies have shown that reading difficulties persist during primary school (de Jong & van der Leij, 2003), and into (young) adolescence (Landerl & Wimmer, 2008; Shaywitz et al., 1999; Snowling, Muter, & Carroll, 2007), young adulthood (Undheim, 2009) and middle adulthood (Maughan et al., 2009), and are characterized by a large gap with reading achievement in the normal range (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996).

This persistent gap is mainly determined by a slow rate of word identification. Differences in rate of cognitive processing tend to be very stable over time which makes them very suitable for cross-age comparisons (Aarnoutse, van Leeuwe, Voeten, & Oud, 2001; Landerl & Wimmer, 2008). In particular in relatively transparent orthographies (like Dutch, the language of the present study), rate is the strongest indicator of within-age differences, because accuracy levels tend to be high from the very start (Seymour, Aro, & Erskine, 2003) and progress in word reading fluency mainly implies increased speed (Bergmann & Wimmer, 2008; Verhoeven & van Leeuwe, 2009). With regard to differences in reading development, de Jong and van der Leij (2003) have confirmed that reading speed differentiates dyslexic, weak and normal readers far better than reading accuracy in the period from Grade 1 to 6. It is important to note that speed limitations in word identification as a characteristic of poor reading is independent of word frequency, because it appears in both unfamiliar and
Cognitive profiles of poor readers compared to typical readers

familiar words (e.g., Landerl & Wimmer, 2008; Leinonen et al., 2001; van der Leij & van Daal, 1999). Lack of reading speed as a persistent characteristic of poor reading is also supported by studies conducted in less transparent orthographies, like English and French (e.g., Bruck, 1998; Sprenger-Charolles, Colé, & Serniclaes, 2006; Torgesen et al., 2001). Torgesen et al. (2001, p. 33) conclude after an extensive training study of poor readers: “Although the children’s average scores on reading accuracy and comprehension were in the average range at the end of the follow-up period, measures of reading rate showed continued severe impairment for most of the children”.

For the present study it is important to note that in Dutch, although the growth rate tends to decline after Grade 3 (Verhoeven & van Leeuwe, 2009), word reading fluency of typical readers keeps increasing well into adulthood (van den Bos, Zijlstra, & lutje Spelberg, 2002; van den Broeck, Geudens, & van den Bos, 2010). As a consequence of their persistent speed limitations in word identification, it may be hypothesized that the gap between atypical readers and typical readers increases with age, not only between Grade 1 and 6 (de Jong & van der Leij, 2003), but also in the decades to follow (van den Broeck, et al., 2010). At the outcome level of word reading skill, confirmation of this hypothesis would support the Matthew-effect as described by Stanovich (1986): the poor-get-poorer whereas the rich-get-richer. Although the strongest test of this developmental hypothesis would be a life-span longitudinal study, cross-sectional data may shed some light on the question whether this effect correlates to larger deficiencies and a more generalized deficit in related cognitive and academic domains.

5.1.1 Reading-related processes and reading development

Reading-related processes qualify as important cognitive correlates of reading development. It is evident that differences between poor and normal readers have been found, not only across ages, but also across languages in
rate of alphanumeric symbol processing and phoneme awareness. Rate of alphanumeric symbol processing, such as the identification and coding of letters and digits, is slow. Especially when there is a need for fast parallel processing because of short presentation times ("flashed" items), these deficits were revealed, both at the level of words (Bouma & Legein, 1980), single symbols (digits) and pseudowords (Yap & van der Leij, 1993a; 1993b). Problems with parallel symbol processing are also apparent when dyslexic readers have to name a string of flashed capital letters. For example in a visual span task, both French and English dyslexics make more mistakes than control readers (Bosse, Tainturier, & Valdois, 2007). Moreover, they were able to distinguish a visual attention span deficit subtype from the well-known phonological deficit subtype in both languages. Comparing simultaneous and serial visual processing skills for flashed capital letters, Lassus-Sangosse, N’guyen-Morel, and Valdois (2008) conclude that the majority of dyslexics, irrespective of subtype, suffer from a simultaneous visual processing deficit but showed preserved serial processing skills. Rate of alphanumeric symbol processing is also involved in rapid serial naming. Slowness in rapid serial naming of letters and digits is a universal and persistent characteristic of poor readers (e.g., de Jong & van der Leij, 2003; Denckla & Rudel, 1974; Gallagher, Laxon, Armstrong, & Frith, 1996; Korhonen, 1995; Landerl & Wimmer, 2008; Miller et al., 2006; Morfidi, van der Leij, de Jong, Scheltinga, & Bekebrede, 2007; Swanson & Hsieh, 2009; Vaessen, Gerretsen, & Blomert, 2009; Vukovic, Wilson, & Nash, 2004; Wimmer, Mayringer, & Landerl, 2000).

Another well-known characteristic of poor readers is that they have a problem with phoneme awareness, the ability to identify and to manipulate sounds in spoken words. This deficit has been found across ages and languages and has been called a core deficit of dyslexia (e.g., Bekebrede, van der Leij, Plakas, Share, & Morfidi, 2010; Bruck 1992; Caravolas, Volín, & Hulme, 2005; de Jong & van der Leij, 2003; Elbro, Nielsen, & Petersen, 1994; Landerl & Wimmer, 2000; Miller-Shaul, 2005; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Swanson & Hsieh, 2009; Vellutino, Fletcher, Snowling, & Scanlon, 2004).
Although deficits in rapid serial naming, parallel symbol processing, and phoneme awareness are well-established cognitive correlates ("markers") of poor reading, the question whether such processes are underlying causes of poor reading or, in broader sense, necessary conditions for reading acquisition is still debated. For example, the role of phoneme awareness in learning to read has been questioned by Castles and Coltheart (2004) who suggest that existing literacy skills have not been controlled in all available studies. In their comment, Hulme, Snowling, Caravolas, and Carroll (2005) argue that the balance of evidence favor a causal link. However, they also consider the role of phoneme awareness in learning to read as part of a multicausal context.

The use of the concept of visual attention to label a dyslexia-specific deficit (Bosse et al., 2007) has also been criticized, in particular by Hawelka and Wimmer (2008) who conclude that when there is no connection needed to a verbal code in a purely visual attention task, poor readers do not show any deficits. The authors suggest that the poor readers do not have a problem with "pure" visual attention but suffer from a problem in establishing a letter string representation which includes both position and name codes. In agreement with this view, we will consider this task (that is used in our study) as a parallel symbol processing task which clearly involves verbal coding.

The role of rapid serial naming has also been questioned by Vellutino et al. (2004), who claim that there may be no specific relation between rapid serial naming speed deficits and reading disability. The study of van der Sluis, de Jong, and van der Leij (2007) confirmed that rapid serial naming does not only explain variance in word reading fluency but also in arithmetic fluency and is, therefore, not restricted to reading. For the purpose of the present study, the question of causal relations is not relevant because our cross-sectional datasets do not permit causal inferences. However, cognitive markers are well-suited to indicate individual variation. The interesting question is whether patterns of weaknesses are present at the various ages of our study, and whether patterns change with age (see Present study section for predictions).
With regard to patterns of weaknesses, it has been suggested that probabilistic and multifactorial models provide a better explanation for the variety in cognitive profiles that is evident in reading disorders than deterministic models, which most often focus on a single cause (Pennington, 2006). The study of Ziegler et al. (2008) supports this suggestion, stating that their data showed no single cause of dyslexia, but rather a complex pattern of phonological, phonemic, and letter processing deficits. Many dyslexics showed deficits in more than one domain. Therefore, dyslexia should be investigated at the level of individuals rather than as a unitary disorder. To accomplish that, reading-related processes have been studied in multiple case studies focused on the combination of related problems. Phonological deficits, tapped by tasks triggering rapid serial naming and phoneme awareness, are the most prevalent characteristics of clinically diagnosed cases of dyslexia, not only in early adulthood (Ramus et al., 2003), but also at the age of primary school (White et al., 2006; see for a French example, Sprenger-Charolles, Colé, Kipffer-Piquard, Pinton, & Billard, 2009). At the primary school, multiple case studies indicated that there are also clinically diagnosed dyslexics who do not exhibit a deficit in reading-related processes (phonological deficit) (Sprenger-Charolles et al., 2009; White et al., 2006). However, with regard to the relative transparent orthography of Dutch, there have not been studies published yet about multiple case studies. In the present study, a multiple case study approach is used for the four different samples to investigate the extent to which cognitive profiles vary across age.

5.2 The present study

To our knowledge, no studies have been published about any language comparing poor readers to typical readers at four relevant age-levels using the same selection test (Een-Minuut-Test, EMT, the Dutch one minute test measuring oral reading of a continuous list of words of increasing syllabic length, Brus & Voeten, 1973, see below) and selection criteria, followed by
the same measures of reading-related processes. In order to avoid possible effects of clinical diagnosis (e.g., subjectivity of applied criteria, inclusion of comorbid cases), our selection method was based on psychometric criteria using available data-sets. Because data from different studies were used, some of our sample sizes of poor readers were relatively large, for example, in comparison to the multiple case studies mentioned above. The control groups which were used for comparisons consisted of a representative sample of typical readers and were not one-to-one matched to the poor readers. On the selection variable, the selected atypical groups (the lowest 25%) were distinct from the unselected higher scoring 75% of the participants who were considered to be typical readers.

In the present study, four cross sectional age-groups were used representing important stages of reading. The youngest group consisted of children in the middle of primary school (Grade 4). At this age, individual differences of reading fluency tend to stabilize and growth rate has dropped from large (Grade 1) to medium (Grade 2 and 3) to small (but still significant) (Verhoeven & van Leeuwe, 2009). As measured by the EMT, average readers have reached a mastery level of about 70 words per minute. The second and third group were secondary school students, at the beginning (Grade 7) and end (Grade 10) of secondary school. In the Netherlands, Grade 7 is the first class in secondary school and reflects the transition from primary to secondary school, in which many new subjects are taught. On average, word reading fluency is about 80 words per minute on the EMT (Schijf, 2009). An important feature for the present study is the beginning of formal instruction in English as L2, allowing for assessment of learning to read in a second language. Grade 10 represents the end of secondary school when sufficient mastery levels have been adopted to go to vocational education or occupation, or continue to sequential education. Average readers read about 90 to 100 words per minute on the EMT (Bekebrede, van der Leij, & Share, 2009). The fourth group consisted of adults, for whom reading is at end-mature level. This group has gained a high degree of reading efficiency and normally has a lot of Dutch and
English reading and language experience. On average more than 100 words per minute are read on the EMT (Bekebrede et al., 2010).

The main expectation in the present study is that, assuming that typical readers perform better at higher ages, the gap between poor and typical readers will widen with age. With regard to word reading fluency, the assumption that typical readers better perform at higher ages is supported by the studies of van den Bos et al. (2002) and van den Broeck et al. (2010). The present study extends these findings to fluency of pseudoword reading and English word reading. Because word and pseudoword reading fluency trigger the same reading mechanisms and vary only with respect to familiarity at the word level (Share, 2008a), age-related progress is also expected for pseudoword reading fluency. In addition, facilitated by the cross-linguistic transfer of reading and reading-related processes between L1 and L2 (Morfidi et al., 2007), the same applies to L2 English word reading fluency, once English is instructed as an obligatory second language in secondary school in the Netherlands. In contrast to typical readers, poor readers who differ significantly in word reading fluency at the youngest age are not expected to show better performance with age. There are indications that their ultimate performance level is equal to a reading age of Grade 4 (about 70 words per minute on the EMT; see van den Broeck et al., 2010). This means that we expect larger differences at a higher age for all measures of word reading fluency independent of frequency (real words or pseudowords) and language (Dutch or English), indicating the persistent influence of speed limitations in poor readers’ processes (Bergmann & Wimmer, 2008; van der Leij & van Daal, 1999).

With regard to the three reading-related processes, the available evidence is still inconclusive. In typical readers, we expected, age-related differences in rapid serial naming between the younger groups (from Grade 4 to 7 and from Grade 7 to 10), possibly followed by a leveling off after Grade 10 (see van den Bos et al., 2002). With regard to speeded parallel symbol processing measured by the visual span task adopted from Bosse et al. (2007) we expected a difference between primary school (Grade 4) and secondary school (Grade 7) because their findings indicate that Grade 5
students outperform Grade 3 students (Bosse & Valdois, 2009). However, whether there is still an increasing gap after Grade 7 has not been investigated yet. Finally, regarding phoneme awareness it is not yet investigated with the same measures whether there is a leveling off in mastery levels of typical readers or whether it continues to increase into adulthood just as speed and fluency measures. It should be noted, however, that we did not include speed of processing in our measure for phoneme awareness, so the analogy may not be justified. If typical readers of older age outperform their counterparts at younger ages, it makes sense to expect that the gap between poor and typical readers also increases with age because of the persistent influence of their deficits.

In addition, assuming that the underlying deficits of poor reading are multifactorial (Pennington, 2006; Ziegler et al., 2008), we expected the poor readers’ cognitive profiles of the reading-related processes to show considerable individual variety and complexity across the four ages. However, if the gap with typical readers is larger at higher ages, it may be expected that older poor readers show more deficits than younger poor readers. This may in particular apply to tasks that involve symbol processing speed such as rapid serial naming and, possibly, speeded parallel symbol processing, which correlate with development of word reading fluency (e.g., de Jong & van der Leij, 1999; Landerl & Wimmer, 2008; van den Bos et al., 2002) and seem to be affected by comparable speed limitations as word reading fluency.

5.3 Method

5.3.1 Participants

To ensure that our samples are representative for the typical intellectual range, in the studies at secondary school the differentiation of the educational system was preserved in the participant selection. Three educational levels were included, namely preparatory secondary vocational
education-theoretical pathway, higher general secondary education, and pre-
university education. In the remaining samples, no such selection method
was necessary because in primary school the educational system in the
Netherlands is not differentiated for the typical range and the adults have
left school. However, the same three educational levels can be applied to the
adult sample to control the representativeness. Furthermore, to exclude
outliers, students with neuropsychological deficits or low intellectual
abilities did not attend in the present study. Poor primary school readers
with low intellectual abilities (including comorbid cases with other
developmental disorders such as ADHD, autism, etc.) were automatically
excluded, as these children go to special educational schools. In secondary
school these students attend the lowest educational levels, which we did not
select. All participants had normal levels of verbal ability. Finally, to select
poor readers, the lowest 25% of Dutch word reading fluency per age-group
was used as a cut-off criterion. It should be noted that the sample sizes
differed, because the participants in the present study were selected from
other studies.

*Grade 4.* The first group of participants consisted of 137 Grade 4 children,
63 male and 74 female, with a mean age of 9 years and 10 months ($SD = 6$
months, range 8;11 - 11;3) (see for the original study, Bekebrede, van der
Leij, Oort, & Share, in preparation). Because complete classrooms
participated, the whole range of the reading distribution was included.
Distinctions in reading level were based on word reading fluency
(EMT < 56 words per minute). There were 35 poor readers and 102 typical
readers. The 25% norm based on our sample fell within standard score 8
(range 1 - 19) of the January-norms of 4th grade (53 - 57 words per minute;
vander Bos, lutje Spelberg, Scheepstra, & de Vries, 1994).

*Grade 7.* The second group of participants consisted of 452 Grade 7 students,
221 male and 231 female, with a mean age of 12 years and 7 months
($SD = 5.5$ months, range 11;3 - 14;11) (see for the original study, Schijf,
2009). The educational levels were evenly spread, respectively 33%
preparatory secondary vocational education-theoretical pathway, 34% higher general secondary education, and 33% pre-university education. Distinctions in reading level were based on word reading fluency (EMT < 73 words per minute), resulting in 120 poor readers and 332 typical readers. The 25% norm based on our sample fell within standard score 8 (range 1 - 19) of the January-norms of 7th grade (70 - 74 words per minute; van den Bos et al., 1994). There was a significant effect of educational level on the Grade 7 participants’ reading status, $U = 15744, Z = -3.56, p < .01$; the poor readers had a lower educational level.

**Grade 10.** The third group of participants were 79 young adolescents from Grade 10, 42 male and 37 female, with a mean age of 15 years and 8 months ($SD = 9$ months, range 14;3 - 17;6) (see for the original study, Bekebrede et al., 2009). The students were spread across the three educational levels respectively 38% preparatory secondary vocational education-theoretical pathway, 34% higher general secondary education, and 28% pre-university education. Distinctions in reading level were based on word reading fluency (EMT < 71 words per minute) resulting in 21 poor readers and 58 typical readers. The 25% norm based on our sample fell below the 25th percentile of the norms of 10th grade (< 79 words per minute; Kuijpers et al., 2003). There was a trend to a significant effect of educational level on the Grade 10 participants’ reading status, $U = 453, Z = -1.84, p = .066$.

**Adults.** The last group of participants existed of 86 adults, 41 male and 45 female, with a mean age of 37 years and 6 months ($SD = 4$ years, range 28 - 48 years) (see for the original study, Bekebrede et al., 2010). The adults were parents of the children who participate in the longitudinal study of the Dutch Dyslexia Program (DDP) (e.g., van Herten et al., 2008) and applied voluntarily for participation. In the screening for participating in the DDP the dyslexic parents were tested and selected according to fairly wide criteria (e.g., word and pseudoword reading scores below 20%). Typical parents were matched on age, neighbourhood, and background. The average educational level of these adults was higher vocational education. When the
educational levels of the adults were translated to the secondary school differentiations, 29% had an education subsequent to preparatory secondary vocational education-theoretical pathway, 46% subsequent to higher general secondary education, and 25% subsequent to pre-university education. Distinctions in reading level were based on word reading fluency (EMT < 74 words per minute), resulting in 21 poor readers and 65 typical readers. The 25% norm based on our sample fell below the 25th percentile of the norms of 10th grade (Kuijpers et al., 2003). There was a significant effect of educational level on the adults’ reading status, $U = 372, Z = -3.33, p < .01$; the poor readers had a lower educational level.

5.3.2 Measures

**Word reading fluency.** The Dutch Een-Minuut-Test (EMT) (Brus & Voeten, 1973) was used to identify poor readers in all age-groups. Participants who scored below the 25th percentile per age-group were identified as poor readers. The participants have to read aloud as many words as quickly and accurately as possible in one minute from a list containing 116 words of increasing difficulty.

**English word reading fluency.** The English One Minute Test (OMT) (Fawcett & Nicolson, 1996) consists of 120 English words of increasing difficulty. The participant has to read aloud as many English words as quickly and accurately as possible in one minute. This task was not

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5 It is important to note that whereas we selected the poor readers as the lowest 25%, the means of word reading fluency of all four poor reading groups belonged at least to the lowest 12% according to national norms (Kuijpers et al., 2003; van den Bos et al., 1994). The means of word reading fluency of the typical reading groups all belonged to > 59% according to the national norms. To further investigate the equality of the typical readers across the four ages, we compared our typical reader samples to the typical reader samples of van den Bos et al. (2002) and van den Broeck et al. (2010). The comparability of the samples across age was large; compared respectively to van den Bos et al. and van den Broeck et al.: 71% and 85% in Grade 4, 82% and 91% in Grade 7, 96% and 75% in Grade 10, and 91% and 69% in the Adults.
administered in Grade 4, because no formal teaching of English has taken place at this stage.

Pseudoword reading fluency. The Klepel (van den Bos et al., 1994), a measure for unfamiliar word reading fluency, is a speeded reading test consisting of 116 pseudowords of increasing difficulty, which requires phonological recoding. The participants are required to read aloud as many words as possible in two minutes.

Rapid serial naming. The rapid naming card of digits (Denckla & Rudel, 1974) was used in all age-groups. The participants were required to name 50 digits (1, 3, 5, 6, 8, in random order) as quickly and accurately as possible, while time was recorded.

Speeded parallel symbol processing. The visual attention span test adapted from Bosse and colleagues (2007) was used in all age-groups, to measure parallel symbol processing. Thirty strings of two to four uppercase letters were flashed on a computer screen for 200 ms and were masked afterwards. The participant was asked to type all the letters in the correct order. Each letter string consisted of combinations of the same 10 consonants (B D F H L M P R S T) starting with 10 two letters to 10 three letters and 10 four letters. Every letter appeared once in each position within 10 items. No letter string contained repeated letters.

Phoneme awareness. A computerized word reversal task was used to measure phoneme awareness (see Bekebrede et al., 2009). The participants heard two pseudowords using headphones (e.g., saf – fas) and were asked to indicate on the keyboard whether the second word sounds as the reverse of the first. All items were monosyllabic pseudowords with one or two consonants at the beginning or at the end of the word. The Adults and Grade 10 participants received 60 items, Grade 7 36 items and Grade 4 40 items. Over all participants 22 items were exactly the same. These 22 items were used in the analyses.
Verbal ability. Per age-group different measures for verbal competence or vocabulary were used, none of the measures involved reading. For Grade 4 we used receptive vocabulary (Verhoeven, 1993) scores administered in Grade 2 that were obtained from the schools from the Dutch pupil monitoring system (Cito). This test consisted of 50 items of four pictures. The teacher named a word and the children had to mark the correct picture which belonged to the word. In Grade 7 an adaptation of the Peabody Picture Vocabulary test (Manschot & Bonnema, 1978) was used. This computerized test consisted of 81 items of four pictures. The student heard a word and had to click on the correct picture which belonged to the word (see Schijf, 2009). In Grade 10 and the Adults verbal competence was measured with the Similarities subtest of the Wechsler Adult Intelligence Scale (Wechsler, 1955, Dutch adaptation, 1970). The participants were asked in what way two words are similar. Responses to each of the 13 items were awarded 2, 1, or 0 points.

5.3.3 Analyses

Differences between the typical and poor readers were examined with a multivariate analysis of variance (MANOVA) with word reading fluency measures and reading-related processes measures as dependent variables and group (typical and poor) as between-subjects factor. In addition, differences between the age-groups were investigated for the typical and poor readers separately by using a multivariate analysis of variance with the measures as dependent variables and age-group (Grade 4, 7, 10, and Adults) as between-subjects factor. Post-hoc Bonferroni tests examined differences between each age-group. Finally, the multiple case study approach was used. To mark a poor reading student to have a weakness in one (or more) of the reading-related processes the criterion of below the 25th percentile (equal to the selection criterion) of the typical readers per age-group was used.
5.4 Results

5.4.1 Comparisons between poor and typical readers

In Table 5.1 the typical readers were compared to the poor readers at all four ages (see Appendix C for the means and standard deviations). In addition to the difference on word reading fluency, the selection measure, the poor readers from Grade 7, 10, and Adults performed below the typical readers on pseudoword and English word reading fluency, rapid serial naming digits, speeded parallel symbol processing, and phoneme awareness. There were no differences on verbal ability between the poor and typical readers at all ages.

Table 5.1
Main group effects for all typical and poor readers per age-group on word reading fluency, reading-related processes, and verbal ability

<table>
<thead>
<tr>
<th>Task</th>
<th>Grade 4</th>
<th>Grade 7</th>
<th>Grade 10</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F(1, 135) p^2</td>
<td>F(1, 450) p^2</td>
<td>F(1, 77) p^2</td>
<td>F(1, 83) p^2</td>
</tr>
<tr>
<td>D word reading fluency</td>
<td>178.87** .57</td>
<td>534.17** .54</td>
<td>135.46** .64</td>
<td>150.34** .65</td>
</tr>
<tr>
<td>E word reading fluency</td>
<td>88.15** .16</td>
<td>40.74** .35</td>
<td>64.91** .44</td>
<td></td>
</tr>
<tr>
<td>Pseudo reading fluency</td>
<td>127.77** .49</td>
<td>222.66** .33</td>
<td>54.27** .41</td>
<td>112.60** .58</td>
</tr>
<tr>
<td>Rapid serial naming</td>
<td>46.17** .26</td>
<td>129.87** .23</td>
<td>35.87** .34</td>
<td>60.47** .42</td>
</tr>
<tr>
<td>Par. symbol processing</td>
<td>10.34** .07</td>
<td>47.59** .09</td>
<td>13.67** .16</td>
<td>34.30** .29</td>
</tr>
<tr>
<td>Phoneme awareness</td>
<td>37.52** .22</td>
<td>22.11** .05</td>
<td>18.40** .21</td>
<td>19.78** .19</td>
</tr>
<tr>
<td>Verbal ability</td>
<td>1.47 ns .01</td>
<td>1.07 ns .002</td>
<td>.11 ns .001</td>
<td>2.42 ns .03</td>
</tr>
</tbody>
</table>

Note. | D = Dutch; E = English; Pseudo = pseudoword; Par. = parallel; different tests are used for the four age-groups. ** p < .01, ns = not significant.

5.4.2 Comparisons between the age-groups

Figure 5.1A indicates that typical readers performed better with age on Dutch and English word and pseudoword reading fluency. When the main effects of age and the post-hoc Bonferroni tests for between-typical group differences were considered (see Table 5.2), all younger typical readers were outperformed by older typical readers on Dutch and English word and
pseudoword reading fluency, except for Grade 7 and Grade 10 on pseudoword reading fluency. In contrast, only poor readers from Grade 4 were outperformed by the older groups on Dutch word and pseudoword reading fluency, whereas poor readers from Grade 7, Grade 10, and the Adults did not differ on Dutch word reading fluency. However, the Grade 7 poor readers performed better than the Adult poor readers on pseudoword reading fluency. Furthermore, only the Grade 7 poor readers were outperformed by the older poor readers on English word reading fluency, there was no difference between Grade 10 and the adults (see Figure 5.1A).

In Figure 5.1B the profile plots for the reading-related processes indicated that, on average, the typical readers performed better with age on rapid serial naming, speeded parallel symbol processing and phoneme awareness (word reversal). When the main effects of age and the post-hoc Bonferroni tests for between-typical group differences were considered (see Table 5.2), Grade 10 performed similar to the Adults on rapid serial naming. In speeded parallel symbol processing Grade 7 and Grade 10, and Grade 10 and Adults, did not differ significantly. In phoneme awareness there were no differences between the typical readers of Grade 4 and Grade 7 and between Grade 10 and adults.

In the comparison of the poor readers a slightly different picture emerged (see Figure 5.1B and Table 5.2). On rapid serial naming poor readers in Grade 4 performed similar to the Adult poor readers, and poor readers in Grade 7 performed similar to poor readers in Grade 10. There was a main effect of age on speeded parallel symbol processing for poor readers, however, this lead only to a post-hoc Bonferroni significance between Grade 4 and Grade 7. On phoneme awareness there were significant differences between poor readers in Grade 4 compared to Grade 7 and the Adults (Post-hoc Bonferroni for Grade 4 - Grade 10 did not reach significance, \( p > .10 \)).
Figure 5.1
A) Ability profile plots of word reading fluency for the poor and typical readers per age-group

B) Profile plots of reading-related processes for the poor and typical readers per age-group

Note. The bars represented the mean for each group, the lines represented plus and min 1 standard deviation below the group mean. G = Grade; A = Adults.
Compared to the national norms on Dutch word reading fluency (EMT) (van den Bos et al., 1994), the Grade 4 poor readers had a reading delay of 1 to 2 years. The poor readers from Grade 7, Grade 10, and the Adults read at a typical level of Grade 4. For pseudoword reading fluency the reading delay was quite similar. However, the Adult poor readers read at a level normal for end Grade 3. Compared to English norms for English word reading fluency (Fawcett & Nicolson, 1996) the Grade 7 poor readers read at the level of halfway Grade 2, the Grade 10 poor readers at the level of Grade 3 and the Adult poor readers at the level of halfway Grade 3. Whereas the typical readers read respectively at the level of halfway Grade 2 in Grade 7, Grade 5 in Grade 10, and above Grade 6 in the Adult sample. There are no national norms for rapid serial naming digits, word reversal and speeded parallel symbol processing. In comparison to unpublished data (in possession of the first author), the performance of the poor readers on rapid serial naming in Grade 4 was two years behind, whereas poor readers in Grade 7, 10, and adulthood performed at a typical Grade 3 - 4 level.

Table 5.2

<table>
<thead>
<tr>
<th>Task</th>
<th>Typical MANOVA</th>
<th>Poor MANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F(1, 83)$</td>
<td>$\eta^2_p$</td>
</tr>
<tr>
<td>Dutch word reading fluency</td>
<td>110.36</td>
<td>.37</td>
</tr>
<tr>
<td>English word reading fluency</td>
<td>338.74</td>
<td>.60</td>
</tr>
<tr>
<td>Pseudoword reading fluency</td>
<td>72.60</td>
<td>.28</td>
</tr>
<tr>
<td>Rapid serial naming</td>
<td>44.82</td>
<td>.20</td>
</tr>
<tr>
<td>Parallel symbol processing</td>
<td>14.45</td>
<td>.07</td>
</tr>
<tr>
<td>Phoneme awareness</td>
<td>18.10</td>
<td>.09</td>
</tr>
</tbody>
</table>

Note. Significant between-group differences are indicated by subscripts: $a$ Grade 4 – Grade 7; $b$ Grade 4 – Grade 10; $c$ Grade 4 – Adults; $d$ Grade 7 – Grade 10; $e$ Grade 7 – Adults; $f$ Grade 10 – Adults. $p < .05$, ** $p < .01$, $p = .042$.

5.4.3 Multiple case studies

In three age-groups a small amount of poor reading students did not have a weakness on any of the three reading-related processes, rapid serial naming,
speeded parallel symbol processing or phoneme awareness, respectively 9% in Grade 4, 8% in Grade 7, 5% in Grade 10, and none in the Adults (see Table 5.3). These students had a serious word reading fluency problem, but did not display a weakness on one of the reading-related processes.

Table 5.3

<table>
<thead>
<tr>
<th>Combinations</th>
<th>Grade 4</th>
<th></th>
<th>Grade 7</th>
<th></th>
<th>Grade 10</th>
<th></th>
<th>Adults</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T (100)</td>
<td>P (33)</td>
<td>T (326)</td>
<td>P (120)</td>
<td>T (52)</td>
<td>P (21)</td>
<td>T (64)</td>
<td>P (21)</td>
</tr>
<tr>
<td>RAN-PA-SYM</td>
<td>8 (8)</td>
<td>39 (13)</td>
<td>4 (14)</td>
<td>20 (24)</td>
<td>6 (3)</td>
<td>43 (9)</td>
<td>5 (3)</td>
<td>48 (10)</td>
</tr>
<tr>
<td>RAN-PA</td>
<td>4 (4)</td>
<td>21 (7)</td>
<td>4 (14)</td>
<td>13 (15)</td>
<td>2 (1)</td>
<td>10 (2)</td>
<td>5 (3)</td>
<td>10 (2)</td>
</tr>
<tr>
<td>RAN-SYM</td>
<td>6 (6)</td>
<td>3 (1)</td>
<td>6 (18)</td>
<td>21 (25)</td>
<td>2 (1)</td>
<td>10 (2)</td>
<td>5 (3)</td>
<td>33 (7)</td>
</tr>
<tr>
<td>RAN</td>
<td>8 (8)</td>
<td>9 (3)</td>
<td>9 (30)</td>
<td>14 (17)</td>
<td>12 (6)</td>
<td>10 (2)</td>
<td>9 (6)</td>
<td>5 (1)</td>
</tr>
<tr>
<td>PA-SYM</td>
<td>6 (6)</td>
<td>12 (4)</td>
<td>5 (16)</td>
<td>10 (12)</td>
<td>8 (4)</td>
<td>10 (2)</td>
<td>6 (4)</td>
<td>5 (1)</td>
</tr>
<tr>
<td>PA</td>
<td>6 (6)</td>
<td>6 (2)</td>
<td>12 (38)</td>
<td>8 (9)</td>
<td>15 (8)</td>
<td>10 (2)</td>
<td>6 (4)</td>
<td></td>
</tr>
<tr>
<td>SYM</td>
<td>6 (6)</td>
<td>10 (34)</td>
<td>7 (8)</td>
<td>10 (5)</td>
<td>5 (1)</td>
<td>9 (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No weakness</td>
<td>56 (56)</td>
<td>9 (3)</td>
<td>50 (162)</td>
<td>8 (10)</td>
<td>46 (24)</td>
<td>5 (1)</td>
<td>55 (35)</td>
<td></td>
</tr>
</tbody>
</table>

% combinations occurring in

<table>
<thead>
<tr>
<th>Four age-groups</th>
<th>44</th>
<th>84</th>
<th>50</th>
<th>78</th>
<th>55</th>
<th>83</th>
<th>45</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three age-groups</td>
<td></td>
<td>6</td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Two age-groups</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

% per reading-related process

<table>
<thead>
<tr>
<th>RAN</th>
<th>26</th>
<th>72</th>
<th>23</th>
<th>68</th>
<th>22</th>
<th>73</th>
<th>24</th>
<th>96</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>24</td>
<td>78</td>
<td>25</td>
<td>51</td>
<td>31</td>
<td>73</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td>SYM</td>
<td>26</td>
<td>54</td>
<td>25</td>
<td>58</td>
<td>26</td>
<td>68</td>
<td>25</td>
<td>86</td>
</tr>
</tbody>
</table>

Note. \(^1\)T = Typical readers; \(^2\)P = Poor readers; \(^3\)A = Amount of participants; \(^4\)RAN = Rapid serial naming; PA = Phoneme awareness; SYM = Speeded parallel symbol processing.

Table 5.3 displays the different combinations of weaknesses, regarding the cognitive profiles. All possible combinations occurred in all four age-groups, except for a single weakness of phoneme awareness in the Adults, and a single weakness in parallel symbol processing in Grade 4 and the Adults. This was also displayed in the percentages of how many profile combinations in an age-group occurred in all four age-groups. In Grade 4, 84% of the profile combinations occurred in all age-groups, 78% in Grade 7, 83% in Grade 10, and all of the profile combinations in the Adults occurred in all age-groups.

Besides demonstrating the combinations of the weaknesses, Table 5.3 also gives information about the existence of the separate weaknesses. Of
the poor readers with one or more weaknesses, most poor readers had a weakness in rapid serial naming, respectively 72% in Grade 4, 68% in Grade 7, 73% in Grade 10, and 96% in the Adults. A weakness in parallel symbol processing increased slightly more, respectively, 54% in Grade 4, 58% in Grade 7, 68% in Grade 10, and 86% in the Adults. A phoneme awareness weakness varied in the four age-groups, respectively 78% in Grade 4, 51% in Grade 7, 73% in Grade 10, and 63% in the Adults. When we applied the same criterion to typical readers, to investigate how many typical readers belonged to the lowest 25% among the typical readers on the three reading-related processes, 45% in Grade 4 had a combination of one or more weaknesses, 50% in Grade 7, 54% in Grade 10 and 45% in the Adults. The remaining typical readers had no weaknesses in the reading-related processes. The individual percentages in Table 5.3 show that the chance that a weakness occurred was up to three times higher among the poor readers.

5.5 Discussion

Confirming the expectation, poor readers were outperformed by typical readers on all measures at all ages except for verbal ability. In nearly all comparisons typical readers of an older age outperformed their younger counterparts in Dutch word and pseudoword reading fluency and English word reading fluency. With regard to the reading-related processes, rapid serial naming of typical readers showed the same pattern until end of secondary school. As expected, the findings of van den Bos et al. (2002) were supported that there were no differences between end of secondary school and adulthood on rapid serial naming in the typical samples. The task triggering parallel symbol processing only showed differences between the youngest group and the older groups and between beginning of secondary school and adults. The phoneme awareness task revealed a deviant and less clear pattern: no differences between typical readers at primary and beginning of secondary school on phoneme awareness, followed by a difference between beginning and end of secondary school, and no
difference afterwards between end of secondary school and adults. It may be concluded that word reading fluency keeps increasing well into adulthood, whereas progression in reading-related processes levels off in the course of secondary school.

Poor readers showed a different pattern of results. The influence of speed limitations on poor readers’ development was confirmed by the larger gap between typical and poor readers in reading fluency at later ages independent of frequency and language (words, pseudowords, and English words), and in rapid serial naming. When the performance of the poor readers was compared to normal levels (according to the national norms; Fawcett & Nicolson, 1996, for the English OMT; van den Bos et al., 1994, for the Dutch EMT and Klepel), the poor readers of Grade 4 were reading at a reading age of Grade 2, whereas the groups at older ages performed around or below levels of Grade 4, suggesting that the gap between typical and poor readers widens with age for (pseudo)word reading fluency. In English word reading fluency both typical and poor readers started at the same level in Grade 7, obviously because until then they had only received very little practice in English reading. However, the typical adult readers reached a level above Grade 6, whereas the poor adult readers did not surpass a reading age of halfway Grade 3. In rapid serial naming, the findings also indicate a widening gap according to unpublished data (see Result section). In parallel symbol processing and phoneme awareness, the gap between poor and typical readers was stable and did not widen with age, probably because there was no progress in the typical case after primary school.

Confirming our expectations, the poor readers had large variety in their cognitive profiles across age. The majority of single and combined weaknesses occurred in all four age-groups (see Table 5.3). This is in agreement with models of multiplicity of underlying deficits (Hulme et al., 2005; Pennington, 2006; Ziegler et al., 2008). However, the older readers had the most multiple weaknesses (96% of the Adults had combined weaknesses, against 75% in Grade 4, 64% in Grade 7, and 73% in Grade 10). In addition, the amount of poor readers with no additional weaknesses
was small in the three younger groups (5 - 9%), but did not exist at all in the Adult group. In particular when speed was involved, more individuals from the older groups of poor readers showed deficits. The proportion with problems in rapid serial naming increased from 72% to 96% in Grade 4 to Adulthood and in speeded parallel symbol processing from 54% to 86% in Grade 4 to Adulthood, supporting the hypothesis of speed limitations which frustrate automaticity (van der Leij & van Daal, 1999).

With regard to the difference in age-related findings of fluency and reading-related processes in the normal case, complexity of the measures and larger influence of experience can be an explanation. Reading fluency tasks are more complex than the tasks for the reading-related processes, especially the accuracy measure for phoneme awareness. Moreover, the impact of experience is larger in the fluency measures because of continued daily practice. Therefore, an increase into adulthood for reading fluency is expected.

Alternatively, there may be no development left for these measures after a certain level is mastered. The fact that rapid serial naming progresses until the end of secondary school suggests that a speed asymptote (and, therefore, automaticity; LaBerge & Samuels, 1974) is reached in the stage when adulthood is entered. The same may be true, but at an earlier age, for speeded parallel symbol processing. With regard to phoneme awareness, an unspeeded task, the interpretation may be that in the typical case there is no progress in the ability to process and manipulate phonemes according to the complex task demands (analysis of two pseudowords, reversal of the first string of phonemes, involvement of phonological loop, and executive control function). However, because there may have been a ceiling effect among the typical readers, our data are not conclusive.

The results of the present study suggest that in contrast to evidence against an increasing gap in primary school (Aarnoutse et al., 2001; Bast & Reitsma, 1998; Scarborough & Parker, 2003), there is an increasing gap in fluency and rate of symbol processing after primary school. This might give some confirmation to the presence of a Matthew effect (Stanovich, 1986) from secondary school onwards. The increasing gap between typical and
poor readers starting from secondary school could be due to more
differentiation in level of instruction and practice from this age onwards
(which is part of the Dutch system, see Method section) and consequently,
of reading experience and to differentiation in choices of further education
and occupation. Supporting this interpretation, our data indicate that, in
comparison to typical readers, the educational level of poor readers was
lower in Grade 7 and in adulthood, whereas the results showed a trend in the
same direction in Grade 10. In addition to increasing differences at the
outcome level of reading skills and educational level, Stanovich also
proposed in his “developmental version of the specificity hypothesis” that
slow reading acquisition also affects the development of other cognitive
skills and inhibit performance on many academic tasks. Our data confirm
the persistency of the specific deficiency and even suggest increasing
multiplicity of reading-related deficits (which is predicted by Stanovich,
1986). However, no differences in general verbal competence were found.
Unfortunately, our studies did not include other general cognitive abilities
so we cannot assess the spreading to more general cognitive abilities and
other academic tasks. Still, lower educational level may be regarded as a
proxy because it relates a variety of academic skills which, in turn, correlate
with general cognitive skills such as metacognition. It should be noted that a
cross-sectional study can only be suggestive with regard to the probability
of a developmental hypothesis.

5.5.1 Methodological aspects

Three methodological aspects that may have influenced the results of the
present study need comments: The cut-off criteria, the equivalence of the
participants, and the equivalence of the measures. With regard to selection,
the lowest 25% on word reading fluency was chosen to define poor readers.
This criterion was used for several reasons. First and most important, we
wanted to have substantial groups of poor readers to make statistically
reliable comparisons. Secondly, this criterion has been used in many other
studies. Thirdly, in Dutch school practice, readers below the 25\textsuperscript{th} percentile are labeled as poor readers. We have no reason to assume that this choice has influenced the results because our samples were representative for the Dutch population at the different ages. The representativeness for the Dutch population was also confirmed by the comparison to national norms (see below) and by the large comparability of our typical sample with two other recently published studies with the same age-groups (van den Bos et al., 2002; van den Broeck et al., 2010, see Footnote 5). As a consequence, the findings can be generalized to similar groups of typical and poor readers.

With regard to the equivalence of the participants in the four different age-groups, we have stated that all groups were representative samples reflecting the normal distribution of reading ability. Readers with low intellectual ability were excluded. This was confirmed by the normal levels of verbal ability of the poor readers. Moreover, participants with neuropsychological deficits were excluded. To ensure representativeness, three different educational levels were included (except for primary school, because no such distinction is present there). The important point is that this procedure prevented that the typical readers had only above average reading levels, which would enhance the possibility of differences with the poor readers. For example, Tallal (2006) criticized the study of White and colleagues (2006) by remarking that it may have suffered from an overrepresentation of above-average readers, implicating forced differences between poor and typical readers. In our case we did not include too many above-average readers, because we used the whole reading distribution. Furthermore, the standard deviation of the typical readers were as expected, and not extremely small. Selecting the 75\% higher scoring participants in our sample, the average reading fluency of all these groups according to national norms was above 59\% which indicates that there was not an overrepresentation of above-average readers. In contrast, the poor readers in the four age-groups certainly qualified as low achievers because they represented on average the bottom 12\% according to national norms (see Footnote 5).
With regard to the equivalence of participants, the adult age-group needs further comments, because there was a difference between the selection procedure of the adults and the other groups. The Adults were parents of children who were participating in the longitudinal study of the Dutch Dyslexia Program (e.g., van Herten et al., 2008) and applied voluntarily for participation. In contrast, the samples at the other ages were selected by the investigators. To make the samples equivalent, the same psychometric criteria and selection measure were used across samples. Although the adults with poor reading ability were on average comparable to the poor readers at the other age-groups, the selection procedure may have resulted in relatively more participants with specific reading disability, i.e., dyslexia. Because the parents applied voluntarily for participation, a larger proportion of dyslexia might be the case. Applying the same criteria (lowest 25%) as in the other age-groups could increase the representativity of the sample. This method of selection is likely to be comparable to a selection based with the same selection test in a ‘normal’ sample of adults with the criterion of lowest 25%, in which the relatively better readers and indistinct cases are not included.

However, there were some differences between the Adults and the other age-groups. The reason why the adult poor readers performed worse than secondary school students on pseudoword reading fluency and rapid serial naming may be because of an overrepresentation of dyslexics in the group of poor readers. When we compared the performances of the adults from this study to the adults from the study of van den Broeck et al. (2010) (the only known Dutch study with typical and poor reading adults with the same measures) on word reading fluency (EMT) the typical readers performed equally well (our study: $M = 102.46, SD = 13.41$; van den Broeck et al.: $M = 105.4, SD = 7.2$). With regard to the poor reading adults in our study the comparison is less conclusive. They read less words than the adults from van den Broeck et al. (poor was identified as < 10% in their study) (our study: $M = 59.90, SD = 11.73$; van den Broeck et al.: $M = 68.7, SD = 4.8$). This might suggest that there was an overrepresentation of severe poor readers in our adult sample. However, the poorly reading adult group
of van den Broeck et al. only consisted of 8 participants (in contrast to 21 in our study) which leaves the possibility of underrepresentation of severe poor readers in their sample.

The last methodological aspect involves the equivalence of the measures. To compare readers of different ages, the same tests with the same items are used. However, the sensitivity of the measures should allow detection of differences between poor and typical readers at all ages. Because the frequently used word and pseudoword reading fluency, and rapid serial naming measures involve speeded responding and there were enough items, there were no ceiling effects. These measures are appropriate in all age-groups. In the parallel symbol processing task the speed was put into the stimulus by using a flashed presentation. Previous studies indicated a large differentiation between poor and typical readers at different ages when using flashed presentations in comparable tasks (e.g., Bekebrede et al., 2009; 2010). Possibly, the measure most at risk for a ceiling effect was the phoneme awareness measure which involved only accuracy. All age-groups received a phoneme awareness measure of different length (see Method section) from which the scores on the same 22 items were selected. We saw in the oldest age-group a slight ceiling effect among the typical readers. However, this ceiling effect did not lead to serious problems, even based on these 22 items there were differences between the poor and typical readers in adulthood. In sum, we have reason to assume, that cut-off criteria, the equivalence of participants and measures are sufficient to allow for comparisons between poor and typical readers across age.

### 5.5.2 Heterogeneity

An important aspect of the present study is the relevance of the findings to understand the heterogeneity of poor readers. The majority of poor readers showed combined weaknesses in reading-related processes at all ages, whereas the groups with no additional weakness were small (Grade 4, 7, 10) or did not exist at all (Adults). These findings support the idea that in poor
Cognitive profiles of poor readers compared to typical readers

A variety of cognitive deficits or weaknesses is the rule (Ramus et al., 2003; the present study), or very common (Sprenger-Charolles et al., 2009; White et al., 2006). These results challenge the deterministic single cause model (see for example, Vellutino et al., 2004, and for a similar comment Ziegler et al., 2008), and they support the probabilistic, multifactorial model (e.g., Pennington, 2006). The fact that our study focused on poor readers and not on dyslexics does not affect this point. In addition, the finding in the present study that nearly all poor reading adults showed combined weaknesses suggests that the chance of multiple deficits is very high. In contrast to the poor readers at all ages, about half of the typical readers (46 - 56%) did not have weaknesses in any of the reading-related processes, whereas an additional 20 - 37% had only one weakness (see Table 5.3), which also supports the probabilistic, multifactorial model in the reverse direction. Furthermore, the findings suggest changes in the cognitive profiles across ages. When speed was involved, more individuals from the older groups had a weakness in rapid serial naming and/or speeded parallel symbol processing.

It should be noted, however, that the design of our study does not allow for making inferences about causes, only for indicating cognitive markers. Our findings corroborate with evidence that poor readers differ from typical readers on a variety of reading and reading-related tasks, but, at the same time, are characterized by heterogeneity in cognitive profiles, supporting the view that poor reading correlates to various positions in a multifactorial space. Finally, the findings support the view of persistent speed limitations in script processing resulting in an end state of poor readers at the typical average level of Grade 4.
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 letter clusters 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 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.

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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 (Schatzneider, 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\textsuperscript{*} 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\textsubscript{−} 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.
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Appendix A  Questionnaire young adolescents
Chapter 3

Questions relating computer use:

1. Do you use a computer?
   Yes/ No
   If not, you can go on to question 6.
2. With how many fingers can you type?
   .................
3. Can you touch type?
   Yes/ No
4. How often do you work at a computer: At such times how many hours do you work at the computer on average?
   Every day… hours per day/ Several times per week… hours per week/ Once a week…hours per week/ Less than once a week…
5. Do you work at the computer only for school or also for your leisure?
   Only for school/ Only for leisure/ Both for school and for leisure

Questions relating to the English language:

6. How easy do you find reading English?
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all
7. After how many times do you recognize an unknown English word immediately?
   After one time/ After several times/ After many times/ Never
8. How easy do you find speaking English?
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all
9. When did you start learning English?
Appendix A

Before grade 5 (primary school)/ Grade 5 (primary school)/ Grade 6 (primary school)/ Grade 7 (secondary school)/ Grade 8 (secondary school)

10. Do you find it difficult learning English?
   Not difficult at all/ Not difficult/ Not difficult or easy/ Difficult/ Very difficult

11. How much time do you spend on learning English? At such times how many hours do you spend on learning English on average?
   Every day… hours per day/ Several days a week… hours per week/ Once a week… hours per week/ Less than once a week…

12. How easy do you find it to understand English?
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all

13. How many hours of English television programs do you watch on average?
   Less than one hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

14. How many hours of English television programs without subtitles do you watch on average (i.e., BBC/CNN)?
   Less than one hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

15. Do you have problems reading the subtitles on television?
   Yes/ No

16. How often do you listen to English spoken music on average?
   Every day/ Several times a week/ Once a week/ Less than once a week

17. On average how many hours a week do you spend on reading English (books, magazines, newspapers, internet)?
   a) For school: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) For leisure: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

18. On average how many hours a week do you spend on writing in English (email, letters, diary etc.)?
Questions relating Dutch:

20. Do you have problems with reading in Dutch?
   No problems/ A little/ Frequently/ Many/ Very much
21. After how many times do you recognize an unknown Dutch word immediately?
   After one time/ After several times/ After many times/ Never
22. On average how many hours a week do you spend on Dutch reading (books, magazines, newspapers, internet)?
   a) For school: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) For leisure: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
23. Do you have problems with spelling?
   No problems/ A little/ Frequent/ Many/ Very much
24. On average how many hours a week do you spend on writing Dutch (email, letters, diary etc.)?
   a) For school: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) For leisure: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
25. Are you better in reading English or Dutch?
   English/ Dutch/ Equally well
26. What was your latest mark for Dutch?
   ..................
27. Are you left or right handed?
   Left handed/ Right handed
28. Do you know if other family members have/had problems with reading and/or spelling? If yes, who?
   ..................
Appendix B  Questionnaire adults Chapter 4

Additional questions relating computer use:

1. With how many fingers can you type?  
   ....................
2. Can you touch type?  
   Yes/ No
3. How often do you work at a computer?  
   Every day/ Several times per week/ Once a week /Less than once a week
4. Do you work at the computer only at work or also for your leisure?  
   Only at work/ Only for leisure/ Both at work and for leisure

Questions relating to perceived easiness of the English language:

5. How easy do you find reading English?  
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all
6. After how many times do you recognize an unknown English word immediately?  
   After one time/ After several times/ After many times/ Never
7. How easy do you find speaking English?  
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all
8. How easy do you find understanding English?  
   Very easy/ Easy/ Not easy or difficult/ Not easy/ Not easy at all

Questions relating exposure of English

9. On average how many hours a week do you spend on reading in English (books, magazines, newspapers, internet)?
Appendix B

a) For work/study: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

b) For leisure: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

10. On average how many hours a week do you spend on writing in English (email, letters, diary)?
   a) For work/study: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) For leisure: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

Questions relating to preference for Dutch:

11. Do you have problems reading the subtitles on television?
   Yes/ No

12. Do you have problems with reading in Dutch?
   No problems/ A little/ Frequently/ Many/ Very much

13. After how many times do you recognize an unknown Dutch word immediately?
   After one time/ After several times/ After many times/ Never

14. Do you have problems with spelling?
   No problems/ A little/ Frequent/ Many/ Very much

15. Are you better in reading English or Dutch?
    English/ Dutch/ Equally well

16. Are you better in writing English or Dutch?
    English/ Dutch/ Equally well
Questions relating to exposure of Dutch

17. On average how many hours a week do you spend on reading in Dutch (books, magazines, newspapers, internet)?
   a) *For work/study*: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) *For leisure*: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week

18. On average how many hours a week do you spend on writing in Dutch (email, letters, diary)?
   a) *For work/study*: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
   b) *For leisure*: Less than 1 hour a week/ 1 to 3 hours a week/ 3 to 6 hours a week/ 7 to 10 hours a week/ More than 10 hours a week
Mean scores, standard deviations of all typical and poor readers per age on reading fluency, reading-related processes, and verbal ability

<table>
<thead>
<tr>
<th>Task (max)</th>
<th>Grade 4</th>
<th></th>
<th>Grade 7</th>
<th></th>
<th>Grade 10</th>
<th></th>
<th>Adults</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typ(^1) (102)</td>
<td>Poor(^2) (35)</td>
<td>Typ (332)</td>
<td>Poor (120)</td>
<td>Typ (58)</td>
<td>Poor (21)</td>
<td>Typ (65)</td>
<td>Poor (21)</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>D. word read. fluency(^3) (116)</td>
<td>73.02</td>
<td>11.71</td>
<td>44.77</td>
<td>7.39</td>
<td>86.05</td>
<td>9.46</td>
<td>64.38</td>
<td>6.65</td>
</tr>
<tr>
<td>E. word read. fluency(^4) (120)</td>
<td></td>
<td></td>
<td>42.85</td>
<td>13.51</td>
<td>30.26</td>
<td>9.58</td>
<td>68.76</td>
<td>15.86</td>
</tr>
<tr>
<td>Pseudo read. fluency(^5) (116)</td>
<td>64.16</td>
<td>14.83</td>
<td>34.29</td>
<td>8.32</td>
<td>83.67</td>
<td>13.99</td>
<td>60.96</td>
<td>15.09</td>
</tr>
<tr>
<td>Rapid serial naming (sec)</td>
<td>22.89</td>
<td>3.72</td>
<td>27.77</td>
<td>3.95</td>
<td>19.29</td>
<td>3.14</td>
<td>23.57</td>
<td>4.33</td>
</tr>
<tr>
<td>Par. symbol process.(^6) (30)</td>
<td>20.46</td>
<td>6.77</td>
<td>16.33</td>
<td>5.07</td>
<td>22.94</td>
<td>4.74</td>
<td>19.24</td>
<td>5.78</td>
</tr>
<tr>
<td>Phoneme awar.(^7) (22)</td>
<td>18.41</td>
<td>2.76</td>
<td>14.97</td>
<td>3.17</td>
<td>18.50</td>
<td>2.04</td>
<td>17.39</td>
<td>2.61</td>
</tr>
<tr>
<td>Verbal ability(^8)</td>
<td>42.69</td>
<td>3.92</td>
<td>41.75</td>
<td>3.44</td>
<td>43.92</td>
<td>8.97</td>
<td>42.93</td>
<td>9.22</td>
</tr>
</tbody>
</table>

*Note.* \(^1\)Typ= Typical readers, \(^2\)Poor = poor readers; \(^3\)D. = Dutch word reading fluency; \(^4\)E. = English word reading fluency; \(^5\)Pseudo = pseudoword reading fluency; \(^6\)Par. = parallel symbol processing; \(^7\)awar. = phoneme awareness; \(^8\)different tests are used for the four age groups.
Summary

To shift attention from learning to read to reading comprehension, a reader has to become a fluent reader. This means that the reading process is accurate and automatic (e.g., Kuhn & Stahl, 2003). To develop into a fluent reader, reading experience is needed. Every time a word is successfully decoded, word-specific information is obtained. This forms the basis of the self-teaching mechanism (Share, 1995). The self-teaching mechanism enables orthographic learning, in which the orthographic lexicon is amplified. In achieving reading fluency, the orthographic structure of words is helpful. Familiar parts of the words i.e., larger orthographic units, can be used to identify (pseudo)words.

To predict the development of reading fluency several key predictors are identified. Phoneme awareness, knowing that a spoken word exists of a sequence of sounds and the ability to manipulate this, and rapid serial naming, the fast access and retrieval of well-known symbols from memory, are found to be universal predictors (Wagner & Torgesen 1987). Besides these two important predictors, orthographic processing is, more recently, seen as another important predictor of reading fluency (e.g., Cunningham, Perry, & Stanovich, 2001). However, the role of orthographic processing is still under debate; what does orthographic processing mean and is it independent from phonological processes, especially decoding (Burt 2006)?

Unfortunately, not all readers develop into fluent readers. Among the population of dyslexics there is a large heterogeneity in cognitive profiles (Pennington, 2006). The core deficit in dyslexia lies in a phonological processing deficit (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Although there is consensus about this phonological processing deficit, there is less consensus with respect to all reading-related subskills. A common way to address the issue of heterogeneity is to look for subtypes (e.g., Bosse, Tainturier, & Valdois, 2007; Castles & Coltheart, 1993; Wolf & Bowers, 1999). However, these subtype distinctions have been critized (Share, 2008a; Vellutino et al., 2004). Most subtypes are seen as
deterministic single “opposite” causes and overlook the multiplicity and complex patterns in the cognitive profiles (Pennington, 2006).

The aim of the present thesis is to shed light on the importance of orthographic processing. First, in examining orthographic processing as an important predictor of reading, besides phonological processing skills. Second, in investigating orthographic processing as an important source of heterogeneity in cognitive functioning in dyslexics, especially as a source of variable differences within the group of dyslexics.

In Chapter 2, the role of orthographic processing as an important predictor of (polysyllabic) word reading fluency, pseudoword reading fluency and spelling ability was investigated. This was investigated in addition to phoneme awareness, rapid serial naming, and vocabulary as possible predictors. A sample of 129 Dutch children was followed from Grade 2 to Grade 4. The results showed that in predicting both word and pseudoword reading fluency orthographic processing was important, besides phoneme awareness, and in addition there was an increasing role of rapid serial naming. The contribution of vocabulary was only evident in word reading fluency, but not in pseudoword reading fluency. In predicting spelling ability orthographic processing, in particular word-specific orthographic knowledge, was important, next to the increasing role of phoneme awareness. Vocabulary and rapid serial naming were not crucial predictors. In developing into a fluent reader and proficient speller all reading-related processes, as orthographic processing, phoneme awareness, rapid serial naming, and vocabulary, are needed to increase precise and redundant orthographic and phonemic connections, important for fluency (see Perfetti, 1992).

In Chapter 3, first, the predictive role of orthographic processing in word reading fluency was investigated in a sample of 37 dyslexic and 35 control Dutch secondary school students (Grade 10). Second, orthographic processing as an explanation for the heterogeneity in cognitive profiles of dyslexics was investigated, therefore, the phonological-core variable-orthographic differences (PCVOD) model (van der Leij & Morfidi, 2006) was examined. The first assumption of the model that orthographic and
phonological processing were independent contributors to predict word reading fluency, was confirmed. The second assumption of the model was that all dyslexics suffer from a phonological core deficit. The third assumption involved that within the group of dyslexics there existed larger variability in orthographic processing than in phonological processing. In order to investigate the second and third assumption of the PCVOD model, the dyslexics were divided into two subgroups with high (ORTH+) and low (ORTH-) orthographic processing skills. There were no differences between both dyslexic subgroups on phonological processing skills, verbal ability, and on reading experience. Both subgroups had lower levels of phonological processing and reading and spelling skills than the control readers. However, the ORTH+ subgroup outperformed the ORTH- subgroup on tasks that requires speeded processing, which is essential when words are briefly presented (“flashed”). In sum, the ORTH+ subgroup is better in identifying larger orthographic units.

In Chapter 4, first, the phonological core deficit was investigated among Dutch dyslexic adults. It was confirmed that 56 dyslexic adults performed worse on tasks tapping phonological processing (phonological awareness, rapid serial naming, and also phonological recoding) than 57 control adults and even 23 reading-age control students from Grade 8/9. Second, similar to the young adolescents in Chapter 3, the PCVOD model was examined as an explanation for the heterogeneity of dyslexics. Orthographic processing explained additional variance in word reading fluency after phonological processing was partialed out. Also it was confirmed that among dyslexics the variability in orthographic processing was significantly greater than in phonological processing compared to the control adults. To further investigate the orthographic variability, the dyslexic adults were subdivided on orthographic processing. The best performing dyslexics formed the ORTH+ subgroup, the lowest performing dyslexics formed the ORTH- subgroup. The ORTH+ subgroup outperformed the ORTH- subgroup on almost all reading and reading-related tasks. Also, the ORTH+ subgroup had near-normal levels of orthographic processing. Furthermore, alternative explanations for the PCVOD model were excluded.
Summary

The better performance of ORTH+ was not due to differences in reading experience, general cognitive ability, or educational attainment.

In Chapter 5, the focus changed from dyslexic readers to the broader defined category of poor readers (lowest 25%). The cognitive profiles of poor readers were compared to typical readers across four different age-groups: in mid-primary school – Grade 4, first class of secondary school – Grade 7, end of secondary school – Grade 10, and adulthood. The same selection test – Dutch word reading fluency –, and same selection criteria were used. The comparison of cognitive profiles was based on the same measures of reading-related processes of phoneme awareness, rapid serial naming, and speeded parallel symbol processing. At all tasks, both reading and reading-related processes, the differences between typical and poor readers were large, confirming a deficit in all three reading-related processes. With respect to reading fluency, the typical readers performed better with age on all reading fluency tasks (Dutch word and pseudoword, and English word reading fluency), whereas the poor readers only performed better when Grade 7 was compared to Grade 4. This indicates a widening gap between the typical and poor readers on reading fluency. The same holds for rapid serial naming. These findings, therefore, support persistent speed limitations in poor readers (e.g., van der Leij & van Daal, 1999), resulting in an average end stage for poor readers that is comparable to the mastery level obtained by the typical readers in Grade 4. In speeded parallel symbol processing and phoneme awareness, a same pattern of early leveling off was seen, however, this was more similar to the typical readers, indicating more stable differences.

This chapter also investigated the heterogeneity of cognitive profiles by using the multiple case study approach. The findings showed there was a large individual variety of persistent problems (confirming Pennington, 2006) in all reading-related processes at all age-groups. The majority of poor readers at all age-groups showed combined weaknesses in reading-related processes, whereas the group with no additional weaknesses was very small or did not exist (as was the case in adulthood). Furthermore, the findings also suggest changes in the cognitive profiles across age.
Weaknesses in rapid serial naming and speeded parallel symbol processing occurred more often at the higher age-groups.

The last chapter (Chapter 6) discussed the main findings from the present thesis in light of three themes: first, the role of orthographic processing in addition to phonological processing as a predictor of reading fluency; second, universality and stability of phonological deficits across age; and third, heterogeneity among dyslexics. In this chapter, in particular, the concept of orthographic processing was investigated and discussed, and related to other reading-related processes. Two kinds of orthographic processing are suggested: “crystallized” orthographic processing (after Share, 2008b) for tasks addressing word-specific orthographic knowledge, that do not include the sublexical level (e.g., *rane - rain* paradigm of Olson, Forsberg, Wise, & Rack, 1994), and “fluid” orthographic processing for tasks that appeal to both lexical and sublexical level (e.g., in tasks using brief exposure for identification of larger orthographic units). Finally, the results of the thesis are discussed regarding diagnosing and remediating reading problems, practice, and future research.
Samenvatting (Dutch summary)

Vloeiend lezen is nodig om de aandacht te kunnen verplaatsen van het leren lezen naar begrijpend lezen. Dit betekent dat het leesproces accuraat en automatisch moet verlopen (e.g., Kuhn & Stahl, 2003). Voor vloeiend lezen is leeservaring nodig. Elke keer dat een woord succesvol wordt gedecodeerd verwerft de lezer woordspecifieke kennis, die de basis vormt van een ‘zelflerend’ mechanisme (Share, 1995). Dit zelflerende mechanisme zorgt voor orthografisch leren en versterking van het orthografisch lexicon. Om vloeiend lezen te realiseren, kan kennis van de orthografische structuur van woorden helpen. Bekende woorddelen, de zogenaamde ‘grote orthografische eenheden’ kunnen gebruikt worden om (pseudo)woorden te herkennen.

Een aantal sleutelfactoren voorspellen de ontwikkeling van vloeiend lezen. Het fonologisch bewustzijn (weten dat een gesproken woord uit een reeks klanken bestaat en het vermogen om deze klanken te kunnen manipuleren) en snel benoemen (snel toegang krijgen en het ophalen van door-en-door geleerde symbolen uit het geheugen) zijn universele voorspellers (Wagner & Torgeson, 1987). Recentelijk wordt ook orthografisch verwerken als een belangrijke voorspeller van vloeiend lezen gezien, naast fonologisch bewustzijn en snel benoemen (e.g., Cunningham, Perry, & Stanovich, 2001). De exacte rol van orthografisch verwerken is echter nog steeds onderwerp van discussie: wat betekent orthografisch verwerken precies en is het onafhankelijk van fonologische processen, in het bijzonder het fonologisch decoderen (Burt, 2006)?

Helaas ontwikkelen niet alle lezers zich tot vloeiende lezers. De cognitieve profielen van dyslectici zijn erg heterogeen (Pennington, 2006). Het kerntekort van dyslectici is een fonologisch verwerkingstekort (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Hoewel er overeenstemming bestaat over dit tekort, is de overeenstemming over alle leesgerelateerde deelvaardigheden minder groot. Een veelgebruikte manier om om te gaan met deze heterogeniteit is het zoeken naar subtypen (e.g.,
Samenvatting (Dutch summary)

Bosse, Tainturier, & Valdois, 2007; Castles & Coltheart, 1993; Wolf & Bowers, 1999). Maar deze subtype-indelingen zijn bekritiseerd (Share, 2008a; Vellutino et al., 2004). De meeste subtypen worden gezien als deterministische, afzonderlijke, tegenover elkaar staande oorzaken, die geen recht doen aan de veelheid en de complexe patronen van de cognitieve profielen (Pennington, 2006).

Het doel van dit proefschrift was: inzicht te krijgen in de belangrijke rol van orthografisch verwerken. Ten eerste door de rol van orthografisch verwerken te onderzoeken in het voorspellen van vloeiend lezen, naast fonologische verwerkingsvaardigheden. Ten tweede door orthografisch verwerken te bekijken als een belangrijk aspect in de verklaring van heterogeniteit in het cognitief functioneren van dyslectici en vooral als een bron van variabele verschillen binnen de groep dyslectici.

In hoofdstuk 2 werd de rol van orthografisch verwerken onderzocht als een belangrijke voorspeller van vloeiend lezen van meerlettergrepige woorden, pseudowoorden en van spellingvaardigheid, naast fonologisch bewustzijn, snel benoemen en woordenschat als mogelijke voorspellers. Een steekproef van 129 Nederlandse kinderen is gevolgd vanaf groep 4 tot en met groep 6. De resultaten lieten zien dat naast fonologisch bewustzijn en de toenemende invloed van snel benoemen, orthografisch verwerken belangrijk was in het voorspellen van zowel vloeiend lezen van woorden als pseudowoorden. Woordenschat leverde alleen een bijdrage aan het voorspellen van vloeiend lezen van woorden, niet van pseudowoorden. Orthografisch verwerken, in het bijzonder woordspecifieke orthografische kennis, was belangrijk in het voorspellen van spellingvaardigheid, naast de toenemende invloed van fonologisch bewustzijn. Woordenschat en snel benoemen bleken geen cruciale voorspellers van spellingvaardigheid te zijn. Voor de ontwikkeling tot vloeiende lezer en vaardige speller zijn alle leesgerelateerde processen van belang. Orthografisch verwerken, fonologisch bewustzijn, snel benoemen en woordenschat zijn nodig om te komen tot precieze en redundante orthografische en fonemische connecties die zo belangrijk zijn voor vloeiend lezen en spellen (zie Perfetti, 1992).

In hoofdstuk 3 werd als eerste de voorspellende rol van orthografisch
Samenvatting (Dutch summary)

verwerken onderzocht in een steekproef van 37 dyslectici en 35 controle lezers uit het voortgezet onderwijs (4e klas). Als tweede is orthografisch verwerken onderzocht als een verklaring voor de heterogeniteit in de cognitieve profielen van dyslectici. Hiervoor is gebruik gemaakt van het ‘fonologische-kern variabele-verschillen in orthografisch verwerken’ model (‘phonological-core variable-orthographic differences’ model, PCVOD-model; van der Leij & Morfidi, 2006). De eerste assumptie van dit model is dat orthografisch en fonologisch verwerken beiden een onafhankelijke bijdrage leveren aan het voorspellen van vloeiend woordlezen. De resultaten bevestigen dit. De tweede assumptie van het model is dat alle dyslectici een fonologisch kerntekort hebben. De derde assumptie is dat er binnen de groep dyslectici een grotere variabiliteit is in orthografisch verwerken dan in fonologisch verwerken. Om de tweede en derde assumptie van het PCVOD-model te onderzoeken zijn de dyslectici in twee subgroepen verdeeld: een groep met hoge (ORTH+) en een groep met lage (ORTH-) orthografische verwerkingsvaardigheden. Er waren geen verschillen tussen deze twee groepen wat fonologisch verwerken, verbale competentie en leeservaring betreft. Beide subgroepen hadden een lager niveau van fonologisch verwerken en van lees- en spellingvaardigheden dan de controle lezers. In tegenstelling daarmee presteerde de ORTH+ subgroep echter beter dan de ORTH- subgroep op taken die een beroep deden op verwerkings snelheid, die essentieel is wanneer woorden heel kort (in een flits) worden weergegeven. Dit betekent dat de ORTH+ subgroep beter was in het identificeren van grotere orthografische eenheden.

In hoofdstuk 4 is bij Nederlandse dyslectische volwassenen het fonologisch kerntekort uitgezocht. Op de fonologische verwerkingstaken (fonologisch bewustzijn, snel benoemen, en ook fonologisch decoderen) presteerden 56 dyslectische volwassenen zwakker dan 57 controle volwassenen en zelfs zwakker dan 23 controle lezers uit de 2e en 3e klas van het voortgezet onderwijs. Daarnaast is het PCVOD-model getest als verklaring voor de heterogeniteit van dyslectici, net als in hoofdstuk 3 bij de leerlingen uit het voortgezet onderwijs. Orthografisch verwerken verklaarde variantie in het vloeiend lezen van woorden, nadat er gecontroleerd was op
Samenvatting (Dutch summary)

fonologisch verwerken. Er bleek bij de dyslectici ook een grotere variabiliteit in orthografisch verwerken dan in fonologisch verwerken vergeleken met de controle volwassenen. Om de orthografische variabiliteit verder te kunnen onderzoeken, zijn de dyslectische volwassenen ingedeeld naar hun prestaties bij orthografisch verwerken in een ORTH\(^+\) subgroup en een ORTH\(^-\) subgroup. De ORTH\(^+\) subgroup presteerde beter dan de ORTH\(^-\) subgroup op bijna alle lees- en leesgerelateerde taken. Daarnaast had de ORTH\(^+\) subgroup een bijna-normaal niveau van orthografisch verwerken. De betere prestaties van ORTH\(^+\) waren niet te wijten aan verschillen in leeservaring, algemeen cognitief vermogen, of opleidingsniveau. Daarmee zijn alternatieve verklaringen voor het PCVOD-model uitgesloten.

In hoofdstuk 5 is de focus verlegd van dyslectische lezers naar een breder gedefinieerde categorie van zwakke lezers (laagste 25\%). De cognitieve profielen van zwakke lezers werden vergeleken met normale lezers in vier verschillende leeftijdsgroepen: midden basisschool (groep 6), eerste klas voortgezet onderwijs, vierde klas voortgezet onderwijs, en volwassenen. Dezelfde selectietest – de Een Minuut Test waarmee het vloeiend kunnen lezen van woorden wordt onderzocht – en dezelfde selectiecriteria zijn gebruikt. De vergelijking van de cognitieve profielen was gebaseerd op dezelfde instrumenten van drie leesgerelateerde processen: fonologisch bewustzijn, snel benoemen, en snel parallel symbool verwerken. Op alle taken, zowel bij het lezen als bij de leesgerelateerde processen, waren de verschillen tussen de normale en zwakke lezers groot. Dit bevestigt een tekort in alle drie de leesgerelateerde processen. Bij alle vormen van vloeiend lezen presteerden de normale lezers beter naarmate ze ouder werden (vloeiend lezen van Nederlandse woorden, pseudowoorden en Engelse woorden). In tegenstelling tot de zwakke lezers, die alleen beter waren in de 1\(^e\) klas voortgezet onderwijs vergeleken met groep 6. Dit wijst op een groter wordend verschil tussen de normale en zwakke lezers wat betreft vloeiend lezen. Hetzelfde gold voor snel benoemen. Deze bevindingen ondersteunen de herhaaldelijk gevonden hardnekkige snelheidsbeperkingen in het lezen van zwakke lezers (e.g., van der Leij & van Daal, 1999). Dit leidt ertoe dat het eindstadium van zwakke lezers gelijk
is aan het vaardigheidsniveau dat normale lezers bereiken in groep 6. In het snel parallel symbool verwerken en fonologisch bewustzijn is eenzelfde vroeg afvlakkende patroon te zien, maar dit lijkt meer op het patroon van de normale lezers, wat wijst op meer stabiele verschillen.

Hoofdstuk 5 onderzocht ook de heterogeniteit van cognitieve profielen door ‘multiple case study’ methodiek toe te passen. De resultaten lieten een grote individuele variatie zien in de hardnekkige problemen (bevestiging voor Pennington, 2006) in alle leesgerelateerde processen op alle leeftijden. De meeste zwakke lezers van alle leeftijden lieten gecombineerde problemen zien in leesgerelateerde processen, terwijl de groep zwakke lezers met geen problemen in de leesgerelateerde processen heel klein was of niet bestond (zoals bij de volwassenen). Tevens laten de resultaten veranderingen zien in de cognitieve profielen met de leeftijd. Problemen met snel benoemen en snel parallel symbool verwerken kwamen meer voor bij de oudere groepen.

In het laatste hoofdstuk (6) werden de belangrijkste bevindingen van het proefschrift besproken in het kader van drie thema’s: ten eerste de rol van orthografisch verwerken in het voorspellen van vloeiend lezen naast fonologisch verwerken; ten tweede de universaliteit en stabiliteit van fonologische tekorten op verschillende leeftijden; ten derde de heterogeniteit van dyslectici. In dit hoofdstuk werd in het bijzonder het concept van orthografisch verwerken onderzocht, bediscussieerd en gerelateerd aan andere leesgerelateerde processen. Twee soorten van orthografisch verwerken werden gesuggereerd: ‘crystallized’ orthografisch verwerken (naar Share, 2008b) bij taken die een beroep doen op woordspecifieke orthografische kennis die niet het sublexicale niveau omvat (zoals het rane - rain paradigm van Olson, Forsberg, Wise, & Rack, 1994); en ‘fluid’ orthografisch verwerken bij taken die een beroep doen op zowel het lexicale als het sublexicale niveau (bijvoorbeeld in taken met korte aanbieding voor het identificeren van grotere orthografische eenheden). Ten slotte werden de resultaten van dit proefschrift besproken in het licht van diagnosticeren en remediëren van leesproblemen, de praktijk van het onderwijs en toekomstig onderzoek.
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Biography

Judith Ilse Bekebrede was born in Amsterdam, the Netherlands on February 11th 1981. After completing secondary education at “Vossius Gymnasium” in Amsterdam in 1999, she studied Educational Sciences at the University of Amsterdam (UvA). During her study she came in contact with Prof. dr. Aryan van der Leij while working as a research assistant (2002-2004), and as her supervisor for her master thesis regarding reading and orthographic knowledge in English and Dutch. Judith wrote a second master thesis about youth memories - children in World War II and the consequences of traumatic experiences, before deciding to graduate in 2004. Her second master thesis was awarded the third price at the Educational Sciences thesis award 2004.

From January 2005 to July 2010, she carried out her PhD project in the Research Institute of Child Development and Education at the University of Amsterdam. Her research focused on orthographic processing as an additional predictor of reading fluency, and as an explanation for the heterogeneity in dyslexia.

Between 2005 and 2009 Judith was a member of PhD committee of ISED (Institute for the Study of Education and Human Development), and during the last year the PhD representative in the ISED board. In June 2008, she was co-organizer of the ISED two-day Symposium “Domain General and Domain-Specific Cognitive Processes in the Development of Learning Disabilities” in Amsterdam. Concurrently to her PhD project, she co-developed the “Interactive Dyslexia test Amsterdam-Antwerp” (IDAA), a diagnostic instrument for dyslexia in secondary school, and for vocational education (IDAA-mbo), in collaboration with the Research Institute of Child Development and Education (UvA), Lessius University College in Antwerp, Belgium, and Muiswerk Educatief. Since September 2010 she is working as an instructor special educational needs at the Center for Educational Training, Assessment, and Research at the Free University (‘Onderwijscentrum VU’).