The role of orthographic and phonological processing in dyslexia and reading

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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.

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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

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; van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994).

Grade 7. The second group of participants existed 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].

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

[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 25^{th} 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

Task	Grade 4		Grade 7		Grade 10		Adults	
	$F(1, 135)$	η^2_p	$F(1, 450)$	η^2_p	$F(1, 77)$	η^2_p	$F(1, 83)$	η^2_p
D word reading fluency[1]	178.87**	.57	534.17**	.54	135.46**	.64	150.34**	.65
E word reading fluency[2]			88.15**	.16	40.74**	.35	64.91**	.44
Pseudo reading fluency[3]	127.77**	.49	222.66**	.33	54.27**	.41	112.60**	.58
Rapid serial naming	46.17**	.26	129.87**	.23	35.87**	.34	60.47**	.42
Par. symbol processing[4]	10.34**	.07	47.59**	.09	13.67**	.16	34.30**	.29
Phoneme awareness	37.52**	.22	22.11**	.05	18.40**	.21	19.78**	.19
Verbal ability[5]	1.47ns	.01	1.07ns	.002	.11ns	.001	2.42ns	.03

Note. [1]D = Dutch; [2]E = English; [3]Pseudo = pseudoword; [4]Par. = parallel; [5]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

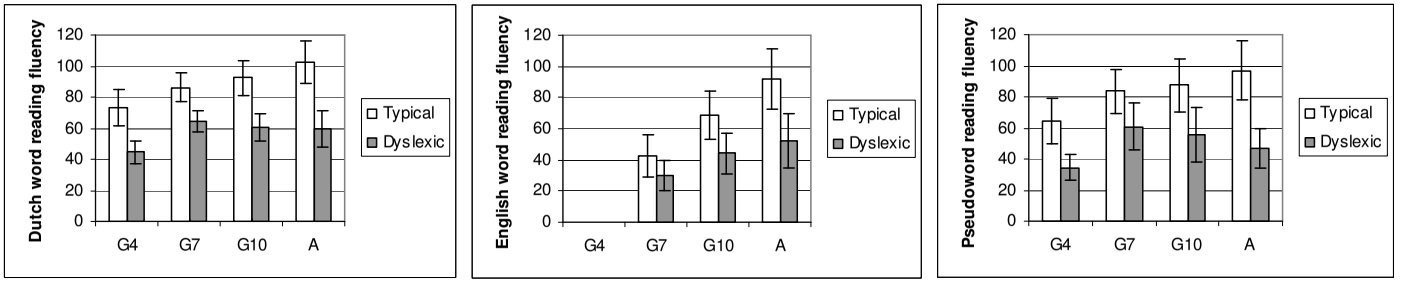
pseudoword reading fluency, except for Grade 7 and Grade 10 on pseudoword reading fluency. In contrast, only poor readers from Grade 4 were outperformed by the older groups on Dutch word and pseudoword reading fluency, whereas poor readers from Grade 7, Grade 10, and the Adults did not differ on Dutch 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.

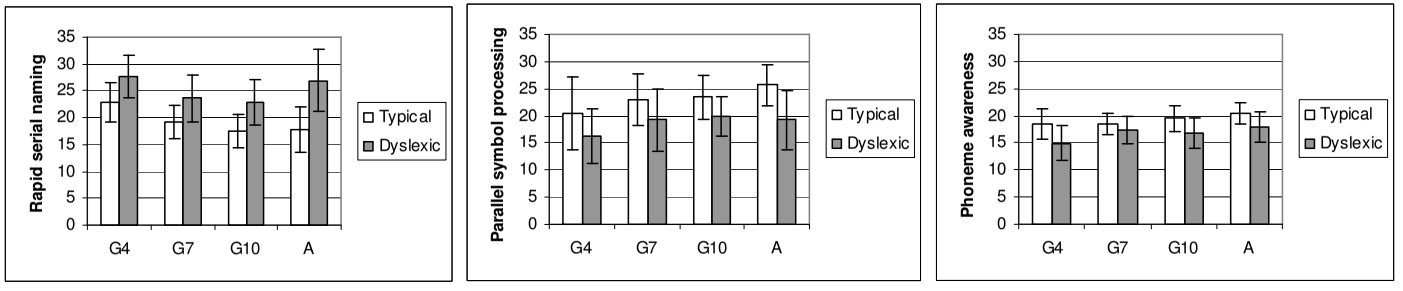
In the comparison of the poor readers a slightly different picture emerged (see Figure 5.1B and Table 5.2). On rapid serial naming poor readers in Grade 4 performed similar to the Adult poor readers, and poor readers in Grade 7 performed similar to poor readers in Grade 10. There was a main effect of 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
Main age-group effects for typical and poor readers separately on word reading fluency and reading-related processes

Task	Typical MANOVA		Poor MANOVA	
	$F(1, 83)$	η^2_p	$F(1, 83)$	η^2_p
Dutch word reading fluency	$110.36^{**}_{a, b, c, d, e, f}$	.37	$61.694^{**}_{a, b, c}$	.49
English word reading fluency	$338.74^{**}_{d, e, f}$	.60	$40.66^{**}_{d, e}$	.34
Pseudoword reading fluency	$72.60^{**}_{a, b, c, e, f}$	.28	$33.74^{**}_{a, b, c, e}$	.35
Rapid serial naming	$44.82^{**}_{a, b, c, d, e}$	.20	$11.85^{**}_{a, b, e, f}$	.16
Parallel symbol processing	$14.45^{**}_{a, b, c, e}$	.07	$2.82^{*}_{a\dagger}$	.04
Phoneme awareness	$18.10^{**}_{b, c, d, e}$	.09	$8.16^{**}_{a, c}$	.11

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.
* $p < .05$, ** $p < .01$, $_{\dagger}$ $p = .042$.

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
Multiple case studies identification of typical and poor readers per combination of weakness(es)

combinations	Grade 4				Grade 7				Grade 10				Adults			
	T[1] (100)		P[2] (33)		T (326)		P (120)		T (52)		P (21)		T (64)		P (21)	
	%	(A)[3]	%	(A)	%	(A)	%	(A)	%	(A)	%	(A)	%	(A)	%	(A)
RAN-PA-SYM[4]	8	(8)	39	(13)	4	(14)	20	(24)	6	(3)	43	(9)	5	(3)	48	(10)
RAN-PA	4	(4)	21	(7)	4	(14)	13	(15)	2	(1)	10	(2)	5	(3)	10	(2)
RAN-SYM	6	(6)	3	(1)	6	(18)	21	(25)	2	(1)	10	(2)	5	(3)	33	(7)
RAN	8	(8)	9	(3)	9	(30)	14	(17)	12	(6)	10	(2)	9	(6)	5	(1)
PA-SYM	6	(6)	12	(4)	5	(16)	10	(12)	8	(4)	10	(2)	6	(4)	5	(1)
PA	6	(6)	6	(2)	12	(38)	8	(9)	15	(8)	10	(2)	6	(4)		
SYM	6	(6)			10	(34)	7	(8)	10	(5)	5	(1)	9	(6)		
No weakness	56	(56)	9	(3)	50	(162)	8	(10)	46	(24)	5	(1)	55	(35)		
% combinations occurring in																
four age-groups	44		84		50		78		55		83		45		100	
three age-groups			6				8				10					
two age-groups							7				5					
% per reading-related process																
RAN	26		72		23		68		22		73		24		96	
PA	24		78		25		51		31		73		22		63	
SYM	26		54		25		58		26		68		25		86	

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 25th 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

readers 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.