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Title: Developmental profiles of reading fluency and reading comprehension from grades 1 to 9 and their early identification

Year: 2021

Version: Accepted version (Final draft)

Please cite the original version:

Psyridou, M., Tolvanen, A., de Jong, P. F., Lerkkanen, M.-K., Poikkeus, A.-M., & Torppa, M. (2021). Developmental profiles of reading fluency and reading comprehension from grades 1 to 9 and their early identification. Developmental Psychology, 57(11), 1840-1854. https://doi.org/10.1037/dev0000976

Developmental Profiles of Reading Fluency and Reading Comprehension From Grades 1 to 9 and Their Early Identification

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Authors note

The data that support the findings of this study, materials, and analysis code are available on request from the authors. This study was not preregistered.

Developmental Profiles of Reading Fluency and Reading Comprehension From Grades 1 to 9 and Their Early Identification

Abstract

This study examined developmental profiles of reading fluency and reading comprehension in Grades 1 to 9 (ages 7 to 15) in a large Finnish sample (n = 2,518). In addition, early predictors of the profiles were analyzed with respect to kindergarten cognitive skills (phonological awareness, letter knowledge, RAN, number counting, word reading, vocabulary, and listening comprehension), parental factors (level of education, reading difficulties), and gender. Four different profiles of reading fluency and reading comprehension development were identified using latent profile analysis. These comprised of one profile with persistent reading difficulties across the grades, one with early poor reading skills but with a resolving tendency, one with average reading skills, and one with good readers who started with very high reading fluency but scored average over time. Of the kindergarten measures, parental reading difficulties, being male, low paternal level of education, slow RAN, difficulty in reading easy words, and low scores in phonological skills, letter knowledge, number counting, and vocabulary predicted reading difficulties. The children belonging to the profile with the resolving tendency showed an increased rate of family risk and multiple cognitive deficits but managed to resolve their reading difficulties. Being female, and good number counting and vocabulary skills predicted a tendency to resolve early reading difficulties. The results confirm the previous findings on the early predictors of reading difficulties and add to the literature by identifying skills that predict resolving patterns.

Keywords: reading development profiles, Simple View of Reading, cognitive skills, family risk, gender

Developmental Profiles of Reading Fluency and Reading Comprehension From Grades 1 to 9 and Their Early Identification

One of the key objectives of formal education is to establish the proficiency required in the use of reading for learning, typically through effective engagement in a range of literacy practices. Reading is a critical skill, therefore, children with reading difficulties (RD) are at high risk for various negative consequences with regard to academic success and participation as active citizens. To develop effective support systems for children with RD, it is important to understand how reading difficulties develop and how we can identify the children in need of extra support from early on. Previous work has increased the understanding of the risk factors of RD, regarding both basic decoding skills, i.e., word reading accuracy and fluency (e.g., Caravolas et al., 2019; Clayton et al., 2020; Snowling et al., 2019) and reading comprehension (e.g., Florit & Cain, 2011; Petscher et al., 2018; Psyridou et al., 2018).

The majority of research in reading development has, however, focused only on the early primary school years, and much less is known about the development and predictors of reading skills throughout the school years. Extending analyses to later years is important, as there is evidence to suggest that reading development does not always follow a pathway set during the early grades, but varying profiles of RD, for example late-emerging and resolving patterns, seem to exist (e.g., Catts et al., 2012; Leach et al., 2003; Psyridou et al., 2020; Torppa et al., 2015). The late-emerging pattern refers to cases where RD was not yet visible during the early primary grade levels, but was identified later on (in Grades 4-8, depending on the study). The resolving pattern, on the other hand, refers to cases where RD was identified in the early grades but not later on. Given that such differential developmental pathways exist, it is also possible that the predictors of these differential developmental pathways vary. From both theoretical and practical perspectives, it would be important to understand the basis of these differences, and if the differential pathways could be predicted early on. In the present study, we investigate the long-term developmental pathways of both reading fluency and reading comprehension skills (from Grades 1 to 9; ages 7 to 15) and examine if there are differential subgroups of children. In addition, we identify kindergarten (age 6) predictors of the developmental profiles in reading. Based on the research literature, we chose to include several cognitive skills, parental reading difficulties, parental education, and child's gender as the potential predictors of the reading development pathways.

Long-Term Pathways in Reading Fluency and Reading Comprehension Difficulties

There are developmental changes in the association of reading fluency and reading comprehension. In the early phases of reading development, decoding (i.e., word reading accuracy and fluency) and reading comprehension are closely related skills, and reading comprehension can develop only after some basic decoding skills have been achieved (e.g., Florit & Cain, 2011). Over time, however, the initially strong relationship between decoding and reading comprehension diminishes. This typically happens when children become "fluent enough", that is, they are also able to focus on text comprehension instead of using all of their cognitive resources solely on decoding letters to phonemes (e.g., Florit & Cain, 2011; García & Cain, 2014; Nation, 2019). As the automaticity of decoding gradually increases, linguistic skills such as vocabulary or listening comprehension become stronger predictors of reading comprehension than decoding (e.g., Florit & Cain, 2011; Torppa et al., 2016; Verhoeven & van Leeuwe, 2008). When the automaticity of decoding reaches a certain threshold, even readers who are relatively slow in comparison to their peers have been shown to acquire average reading comprehension skills (e.g., Torppa et al., 2007, 2020). These findings are in accordance with the Simple View of Reading (SVR) model (Gough & Tunmer, 1986; Hoover & Gough, 1990), which states that reading comprehension is the product of two separate skills: decoding and linguistic comprehension. Based on the SVR, it is thus expected that although decoding and reading comprehension are closely related, not all children with RD will simultaneously have both decoding and reading comprehension difficulties (Nation, 2019; Torppa et al., 2007).

Furthermore, there seem to be individual differences in the long-term pathways of reading development. For instance, a child's difficulties in reading fluency and/or reading comprehension during the early grades of primary school do not necessarily persist into the later years. In fact, the customary assumption of the persistence of RD is not supported by recent studies examining the stability of RD over time (Catts et al., 2012; Etmanskie et al., 2016; Leach et al., 2003; Lipka et al., 2006; Psyridou et al., 2020; Torppa et al., 2015; van Viersen et al., 2019). These studies suggest that the trajectories of reading development are heterogeneous, and that persistent RD does not represent the only developmental RD profile observed among children. At least two other profiles have been reported: a late-emerging profile (i.e., RD identified during the later grades despite average early reading skills) (e.g., Catts et al., 2012; Etmanskie et al., 2016; Psyridou et al., 2020; Torppa et al., 2015) and a resolving profile (i.e., no RD in the later grades despite difficulties during the early grades) (Catts et al., 2012; Psyridou et al., 2020; Torppa et al., 2015; van Viersen et al., 2019).

The heterogeneity of decoding and comprehension as well as developmental heterogeneity over time suggests that we need to take a closer look at long-term reading development and the basis of the various profiles. Deeper understanding of these profiles can provide unique information on the developmental risk factors, supportive mechanisms, and resilience in the face of RD throughout the primary and lower secondary school years.

Cognitive Predictors of Reading Development

In the prediction of the different profiles of reading fluency and reading comprehension development, specific cognitive skills can be informative. Early word reading skills are, perhaps not surprisingly, a good predictor of later reading fluency development. A recent study (Snowling et al., 2019) showed that English-speaking children who developed dyslexia already had lower word-reading skills than typically developing children at the ages of 4 ½ and 5 ½. Among Finnish-speaking children, initial decoding skill at ages 6–7 has been found to be a good predictor of the development of reading fluency and reading comprehension skills in Grades 1 and 2 (Lerkkanen et al., 2004). In addition, phonological awareness, letter knowledge, and rapid automatized naming (RAN) have often been identified as the strongest early predictors of reading fluency development (e.g., Caravolas et al., 2019; Clayton et al., 2020; Snowling et al., 2019). The strength of the predictive relation, however, varies across languages (Caravolas et al., 2019; Landerl et al., 2019) because languages diverge in their orthographic transparency (i.e., in the consistency of the correspondence between graphemes and phonemes) and thus, also require somewhat different skills from readers. In a recent comparison of phonological awareness and RAN across five different orthographies (English, Dutch, German, Greek, and French), Landerl et al. (2019) showed that phonological awareness is a good predictor in less transparent orthographies (i.e., in orthographies with many inconsistencies of the correspondence between graphemes and phonemes). RAN, on the other hand, was a good predictor of reading development in both more and less transparent orthographies (Landerl et al., 2019; Moll et al., 2014).

In addition to the above-mentioned cognitive skills, recently number counting skills have also been reported as a unique predictor of reading fluency (Bernabini et al., 2021; Koponen et al., 2013, 2016). The two previous studies using Finnish-speaking children have suggested that number counting is a strong predictor of Grade 2 and 3 reading fluency even after controlling for phonological awareness, verbal short-term memory (Koponen et al., 2013, 2016), vocabulary, working memory, number concepts, and maternal education, surpassing even the effect of RAN (Koponen et al., 2016). This is noteworthy given that in transparent orthographies, such as Finnish, RAN has typically been identified as the strongest predictor of reading fluency (e.g., Landerl et al., 2019; Moll et al., 2014). This association between reading and number counting may stem from their shared nature as serial processes, which require monitoring and holding information in one's memory while processing stimuli. One-by-one processing is essential both in counting and in the early phases of reading development (see de Jong, 2011; Protopapas et al., 2013).

Finally, reading comprehension has been shown to rely on a variety of oral language comprehension skills, including vocabulary (e.g., Florit & Cain, 2011; Nation et al., 2010; Psyridou et al., 2018) and listening comprehension (e.g., Florit & Cain, 2011; Nation et al., 2010). Vocabulary has also been found to account for variation in reading comprehension even after controlling for the effects of word reading (e.g., Olson et al., 2011). Weaknesses in oral language comprehension can manifest years before learning to read, suggesting a possible causal link from oral language comprehension to difficulties in reading comprehension (e.g., Eklund et al., 2018; Hulme et al., 2015; Nation et al., 2010; Psyridou et al., 2018).

Parental Factors, Gender, and Reading Difficulties

There is strong evidence that RD run in families, and a recent meta-analysis (Snowling & Melby-Lervåg, 2016) on family risk for RD (i.e., families with parental RD) suggested that, depending on the criteria, approximately 29%–66% of children with family risk will develop RD. Children with family risk for RD have been reported to show low scores in phonological awareness, RAN, letter knowledge, and vocabulary, even prior to school entry (Snowling & Melby-Lervåg, 2016; Torppa et al., 2010; van Bergen et al., 2012). In a recent study (Eklund et al., 2018), Finnish children with family risk were shown to perform significantly lower in reading fluency in Grades 1 to 8 as well as in reading comprehension in Grade 9, but the effect sizes for reading comprehension were smaller than those for reading fluency. Moreover, parental reading skills have been shown to be significant predictors of children's reading skills over and above cognitive factors (Torppa et al., 2011), as well as parental education and home literacy environment (Esmaeeli et al., 2019).

In addition to family risk, previous studies have reported significant correlations between parental education and children's reading skills (Kiuru et al. 2013; Torppa et al., 2006; van Bergen et al., 2017). One possible explanation for this link is the influence of parents' education on the ways in which they interact with their children during learning activities (Eccles, 2005). Previous studies have reported a link between low parental education and a less rich literacy and numeracy home environment (e.g., a lower extent of shared reading experiences, literacy resources, and parental teaching of reading) (Guo & Harris, 2000). The evidence of an association between less literacy-rich environments and children's lower language and vocabulary skills suggests that the home environment may have a mediating role in the transmission of parental reading skills and attitudes to their children (Scarborough & Dobrich, 1994; Torppa et al., 2006). However, as RD are known to be strongly heritable, these effects can also be explained by masked genetic effects that affect both parents' and their children's reading skills and, via parental RD, also affect parental education levels and the home literacy environment. In support of this notion, van Bergen et al. (2017) showed that the significant correlation between children's reading skills and parental education became insignificant when parental reading skills were taken into account.

Finally, a substantial number of studies have shown that females outperform males in reading (Clinton et al., 2014; Quinn & Wagner, 2015; Rajchert et al., 2014; Stoet & Geary, 2013) and that more males than females are identified with RD (Quinn & Wagner, 2015; Stoet & Geary, 2013). A recent study among Finnish-speaking Grade 9 students reported that the risk of scoring in the lowest 10% in reading fluency was 4.4 times higher for males than for females, and for reading comprehension, this risk was 2.4 times higher for males than for females (Torppa et al., 2018). However, some studies have shown no or very small differences in reading skills among males and females, and only in reading comprehension and not in reading fluency (e.g., Leppänen et al., 2008).

The Present Study

The aim of the present study is to examine what kind of developmental profiles of reading fluency and reading comprehension can be identified across Grades 1 to 9 (ages 7 to 16) and whether membership in the developmental profiles can be predicted using kindergarten-age measures (cognitive skills, parental measures, and gender). The unique additions to the extant literature include the following: first, both reading fluency and reading comprehension are included in the latent profile analysis; second, the developmental period spans a longer time period than before; and third, the profiles are identified using a methodology precluding measurement error and without using specific cut-off points in group identification. Finally, the large-scale longitudinal data set allows the inclusion of a wide range of kindergarten measures to examine the prediction of profile membership with measurers assessed before school entry.

We first examine whether heterogeneous developmental pathways can be identified, in line with what has been suggested in previous studies, with shorter follow-up periods, smaller samples, and/or with only two assessment time-points (e.g., Leach et al., 2003; Psyridou et al., 2020; Torppa et al., 2015). We use latent profile analysis, which is a stronger approach than the cut-off-based groupings (RD versus no RD) typically used in prior studies. One of its advantages is that, because the analysis is model-based, it provides specific criteria that can be used to determine the number of profiles to retain. Latent profile analysis is a person-oriented approach that focuses on identifying groups of individuals who show different combinations, profiles, or patterns of values in different variables (Bergman & Andersson, 2010). Thus, person-oriented analyses can reveal findings (e.g., nonlinear patterns) not found in standard variable-oriented analyses.

The research questions were set as the following: (1) What kind of profiles can be identified based on the development in reading fluency and reading comprehension from

Grades 1 to 9? (2) To what extent do child-related (i.e., gender, cognitive skills) and parent-related factors (i.e., maternal education, paternal education, parental RD) assessed in kindergarten predict membership in the identified profiles?

In line with the hypothesis for heterogeneous developmental groups, we expect to identify several distinct profiles: good reading skills, persistent RD across time, resolving RD, and late-emerging RD (e.g., Catts et al., 2012; Psyridou et al., 2020; Torppa et al., 2015). Moreover, based on previous studies, we expect that family risk, phonological awareness, letter knowledge, word reading, RAN, number counting, and vocabulary will predict profile membership (e.g., Landerl et al., 2019; Psyridou et al., 2018; Snowling & Melby-Lervåg, 2016; Snowling et al., 2019). We also expect that phonological awareness will be a better predictor of RD during the early grades, whereas RAN will more strongly predict RD manifesting later on (e.g., Torppa et al., 2015). Finally, we expect that males will be over-represented in the profiles with RD (e.g., Quinn & Wagner, 2015; Stoet & Geary, 2013), whereas females are expected to be over-represented in the group with resolving RD and under-represented in the group with late-emerging RD (Etmanskie et al., 2016; Torppa et al., 2015).

Furthermore, in line with the SVR, we expect that skill levels in reading fluency and reading comprehension do not always coincide, and we can identify profiles with different developmental patterns in reading fluency and reading comprehension. Previous studies examining reading fluency and comprehension have identified groups fitting with the SVR: difficulties only in reading fluency, difficulties only in reading comprehension, difficulties in both reading fluency and reading comprehension, and no difficulties (e.g., Spencer & Wagner, 2018; Torppa et al., 2007). Based on previous studies, we expect that kindergarten predictors differ depending on the type of RD. For those with difficulties only in reading fluency, the best predictors are expected to include family risk for RD (Snowling & Melby-Lervåg, 2016; Torppa et al., 2011), RAN (Landerl et al., 2019), number counting (Koponen et al., 2013;

2016), word reading (Snowling et al., 2019), letter knowledge (Torppa et al., 2010), and phonological awareness (Torppa et al., 2010; van Bergen et al., 2012). The best predictors for those with difficulties in reading comprehension only are expected to include vocabulary (Olson et al., 2011; Petscher et al., 2018; Psyridou et al., 2018) and listening comprehension (Florit & Cain, 2011; Nation et al., 2010). Those with difficulties in both reading fluency and reading comprehension are expected to have more broad-ranging difficulties.

Method

Participants

The present study is part of the large-scale Finnish longitudinal First Steps Study, a follow-up of a total of 2,518 children from kindergarten to Grade 9 (Lerkkanen et al., 2006). Children's cognitive skills were assessed in the fall and spring of kindergarten, and their reading fluency and reading comprehension skills were assessed at the end of Grades 1, 2, 3, 4, 6, 7, and 9. The sample was drawn from four municipalities: two in central, one in western, and one in eastern Finland. In three of the municipalities, the participants formed a population-based sample where the whole age cohort of children born in the year 2000 was recruited, and in the fourth municipality, the participating children comprised about half the age cohort. One municipality was a big city, two were medium-sized towns, and one was a smaller rural community. According to our data, across all assessment time-points, 98.5% of the children had Finnish as their first language. Parental education level was close to the national average for Finland (Statistics Finland, 2007). The First Steps Study was reviewed and approved by the Ethical Board of the University of Jyväskylä in 2006. At the beginning of the study, the children's parents and teachers provided informed written consent for their own participation, and the parents provided this consent for their kindergarten-aged children's participation.

Measures

The children were tested longitudinally nine times between kindergarten and Grade 9: kindergarten (fall 2006 and spring 2007), Grade 1 (spring 2008), Grade 2 (spring 2009), Grade 3 (spring 2010), Grade 4 (spring 2011), Grade 6 (spring 2013), Grade 7 (spring 2015), and Grade 9 (spring 2017).

Reading Fluency

There were three group-administered reading fluency tests at each grade (from Grade 1 onwards) assessed by trained testers: a word reading fluency task, a word-chain task, and a sentence reading task.

Word Reading Fluency Task

The word reading fluency task is a subtest of the nationally normed reading test battery (ALLU–Ala-asteen lukutesti [ALLU–Reading Test for Primary School]; Lindeman, 2000). Each of the 80 items consists of a picture with four phonologically similar words attached to it. The child silently reads the four words and then draws a line to connect the picture with the word, semantically matching it. The words and pictures are frequently-used words familiar to young children. For example, an item consists of a picture of a bunny (in Finnish, *pupu*) and the correct word along with three distractors (English word is in parentheses): *pipo* (cap), *papu* (bean), and *apu* (help). Completing the test requires fluent decoding. The score is the number of correct answers within a 2-minute time limit. Because of the nature of this timed test, the score reflects both the child’s fluency in reading the stimulus words and his or her accuracy in making the correct choice from among the alternatives.

Word-Chain Task

The word-chain task (Nevala & Lyytinen, 2000) is a timed test with 10 rows of word chains, each comprising four to six words written together without spaces. The child silently reads the words and, while reading them, indicates the word boundaries by drawing a division line between the words. The score is the number of correct responses (maximum 40) within the time limit (1 min 25 s in Grades 1 and 2, 1 min 20 s in Grade 3, 1 min 5 s in Grade 4, 1 min in Grades 6 and 7, and 1 min 30 s in Grade 9).

Sentence Reading Task

The Test of Silent Reading Efficiency and Comprehension (TOSREC; Wagner et al., 2010; Finnish version by Lerkkanen et al., 2008) was used to assess silent reading efficiency in Grades 1, 2, 3, and 4. Children were given 3 minutes to read the maximum of 60 sentences and verify the truthfulness of as many sentences as possible. In Grade 6, the Finnish version of the Salzburg Lese-Screening test (Mayringer & Wimmer, 2003) was used, which is highly similar to the Woodcock-Johnson sentence verification task (Woodcock et al., 2001). Children were given 2 minutes to read the maximum of 69 sentences and verify the truthfulness of as many sentences as possible. In Grades 7 and 9, a standardized Finnish sentence-reading test for lower secondary school students was used (YKÄ; Lerkkanen et al., 2018). In this test, children were given 2 minutes to read the maximum of 70 sentences and verify the truthfulness of as many sentences as possible. The sum score in all tasks was the number of correct answers given within the time limit. All three tests had the same aim, the same instructions, and similar items, although a different number of items. Correlations between the tests used at the different ages corresponded closely with the across-age stability correlates within the tests, suggesting that the same skill was assessed despite changes in the test items. The Cronbach’s alphas for the reading fluency sum scores were .83 for Grade 1, .80 for Grade 2, .82 for Grade 3, .82 for Grade 4, .79 for Grade 6, .84 for Grade 7, and .84 for Grade 9.

Reading Comprehension

A group-administered subtest of a nationally normed reading test battery (ALLU; Lindeman, 2000) was used to assess reading comprehension. The children silently read the given text at their own pace, and then answered 11 multiple-choice questions and one question in which they had to arrange five statements in the correct sequence based on information gathered from the text. For each correct answer, 1 point was given (max = 12). The maximum time allotted was 45 minutes. The Kuder-Richardson reliabilities from the test manual were .85 in Grade 1, .80 in Grade 2, and .75 in Grade 3, .76 in Grade 4, and .74 in Grade 6. The test used in Grades 7 and 9 was a similar standardized reading comprehension test developed for the lower secondary grade levels (YKÄ; Lerkkanen et al., 2018). All the tests had the same aim and same instruction, as well as the same number of multiple tasks, but different texts and items. Cronbach's alphas were .69 in Grade 1, .75 in Grade 2, .66 in Grade 3, .67 in Grade 4, .66 in Grade 6, .68 in Grade 7, and .63 in Grade 9. The Cronbach alpha reliability estimates are not optimal. However, in a reading comprehension task with a text and questions this is not extraordinary. The questions run from easier fact retrieval items to more complicated interpretation items and cohesion of items cannot be perfect as children's skill levels differ. Furthermore, Cronbach's alpha is sensitive to the number of items in the scale. The tasks used, when possible, were taken from the only nationally validated test battery and as such well-developed tests. In addition to Cronbach's alpha, we also estimated Revelle's omega which provides more unbiased results than Cronbach's alpha when the assumptions of Cronbach's alpha are violated (McNeish, 2018). Revelle's omega in our sample was .82 in Grade 4, .78 in Grade 6, .81 in Grade 7, and .78 in Grade 9.

Kindergarten Measures

Kindergarten measures were assessed individually by trained testers in the fall of 2006 and the spring of 2007. They included initial phoneme identification (fall 2006), letter knowledge (fall 2006), vocabulary (spring 2007), RAN (spring 2007), word reading (spring 2007), listening comprehension (spring 2007), and number counting (spring 2007).

Initial Phoneme Identification

Initial phoneme identification was assessed using an individually administered subtest of the ARMI (Lerkkanen et al., 2006). Children were shown 10 sets of pictures, each set containing four pictures, one of which depicted an object with the target initial phoneme. The child was first asked to name all four objects in a set. Then the tester asked the child to identify the object in the set of pictures that had the same first sound (phoneme) as the one spoken aloud by the tester. The Cronbach's alpha was .77.

Letter Knowledge

The letter-naming task included 29 uppercase letters from the ARMI test (Lerkkanen et al., 2006). The letters were in random order, arranged in three rows, and shown one row at a time. As children in Finnish kindergartens are exposed only to capital letters, only uppercase letters were used in this test. Either a phoneme or a letter name was accepted as a correct answer. One point was given for each correct response (max = 29). The test was discontinued if a child was not able to name six letters in a row. The Cronbach's alpha for letter knowledge was .94.

Vocabulary

A Finnish version of the 30-item Peabody Picture Vocabulary Test—Revised (PPVT-R, Form L; Dunn & Dunn, 1981) was used as a measure of receptive vocabulary. The PPVT requires the child to select, from among four options, the picture that correctly depicts a spoken word. The raw sum score of correct items was used. The Cronbach's alpha was .60.

Rapid Serial Naming of Objects

Rapid serial naming of objects (RAN) was assessed using the standard procedure (Denckla & Rudel, 1976), in which the child is asked to name a series of visual stimuli consisting of pictures of objects (e.g., a ball, a house) as quickly as possible. Matrices of 50 items (five stimuli 10 times) were used. The total matrix completion time (in seconds) was used as the RAN score.

Word Reading

Word-reading accuracy was assessed using an individually administered list of 10 words (test from ARMI; Lerkkanen et al., 2006). The words were two-syllable (7 words), three-syllable (2 words), and five-syllable (1 word) words. The score was the number of correct items. The Cronbach's alpha was .85.

Listening Comprehension

A test of listening comprehension (Vauras et al., 1995) was used to assess children's listening comprehension skills at the end of kindergarten. The tester read a story about a fox aloud twice to a group of six children. Each child was then asked to fill in their answers to six questions in their own test booklet. The tester asked six questions based on the story, one question at a time. Three pictures accompanied each question, and the children responded to each question by marking the picture that matched the story. Two points were given for each correct answer (max = 12). The Cronbach's alpha was .31 and the Revelle's omega was .42.

Number Counting

Children's pre-math skills were assessed using a number sequence knowledge test. Knowledge of number sequences was assessed by means of four tasks in which children were asked to count aloud forward (from 1 to 31, and from 6 to 13) and backward (from 12 to 7, and from 23 to 1). The items were scored using a 3-point scale: 2 = *no errors*, 1 = *one small error* (e.g., the child stopped counting one number too early), and 0 = *two or more errors* (max = 8 points). The Cronbach's alpha for number counting was .64. In addition to Cronbach's alpha, we also estimated Revelle's omega which provides more unbiased results than Cronbach's alpha when the assumptions of Cronbach's alpha are violated (McNeish, 2018). Revelle's omega in our sample was .87.

Parental Questionnaire Measures

The mothers and fathers of the children were asked to fill in questionnaires in kindergarten spring.

Parental Education

Mothers and fathers were asked to indicate their own education level on a 7-point scale: 1 = *no vocational education*, 2 = *vocational courses (4 months)*, 3 = *vocational school degree*, 4 = *vocational college degree*, 5 = *polytechnic degree or bachelor's degree*, 6 = *master's degree*, and 7 = *licentiate or doctoral degree*. In the present study, their answers were recoded using a 3-point scale: basic education, vocational education, and university education.

Parental Reading Difficulties

Mothers and fathers were asked to complete a questionnaire about whether they had RD during their school years or afterward. They were asked to indicate on a 3-point scale whether they had clear difficulties, some difficulties, or no difficulties. A child was considered as having family risk if either the mother or the father reported that they had experienced RD.

Analysis Description

The first step of the analysis was to identify the different profiles of reading fluency and reading comprehension development. This was done by using a latent variable mixture model, referred to as "latent profile analysis" (LPA), with two added level factors, which allows the identification of groups of individuals that share similar profiles. Mixture models are based on the idea that the observed data can represent subpopulations (i.e., latent classes), and they can be identified, and their parameters can be estimated (Muthén & Asparouhov, 2006). The advantage of LPA is that it is model-based, and specific criteria can be used to determine the number of profiles to retain instead of determining RD profiles by using arbitrary cut-off points.

In the present analysis, LPA was based on a model with two continuous factors (one for reading fluency and one for reading comprehension) and one categorical latent variable, which represented the different latent profiles (Figure 1). For reading fluency, we used three tasks for each grade and calculated a composite variable for each grade, converting the scores for each reading fluency measure into z-scores and calculating mean composite scores. Because the measures of reading fluency and reading comprehension were not the same across grades, they were standardized before LPA. The variance was specified to be equal between the profiles. As the number of expected profiles was not known, we used an exploratory method to determine the optimal number of profiles (Muthen & Muthen, 1998–2017).

The optimal number of profiles was selected using the following four criteria: (1) model fit; (2) distinguishability of the latent groups; (3) latent class sizes; and (4) practical usefulness, theoretical justification, and interpretability of the latent groups (see also Bauer & Curran, 2003; Muthén, 2003). To ensure the validity of each profile, a large set of random starting values for the parameters is recommended. In the present study, we used 500 starting values.

The second step of the analysis was to determine the extent to which kindergarten cognitive skills, parental factors, and gender predict the identified profiles. We used the "Three-step Approach" (Asparouhov & Muthén, 2012), which allows covariates to be tested as predictors of latent classes in a multinomial logistic regression by using the Bolck-Croon-Hagernaars (BCH) method (Asparouhov & Muthén, 2014; Bakk & Vermunt, 2016). This method compares the profiles while allowing partial membership in profiles, and it accounts for classification error (see also Asparouhov & Muthén, 2014; Bolck et al., 2004). The BCH method uses weights based on the posterior probabilities to adjust classification error, thus handling the uncertainty from the relatively low probabilities of belonging to a specific profile that we had. Consequently, it provides more reliable results than forming groups and comparing them by using, for example, ANOVAs.

To analyze the relative contributions of cognitive skills, parental factors, and gender to the developmental profiles, we conducted hierarchical regression analysis in a structural equation framework (SEM) by applying a Cholesky model (de Jong, 1999). Eleven variables were included in the Cholesky model: three parental measures (family risk for RD, maternal education, and paternal education), gender, and seven measures of kindergarten-age cognitive skills (standardized values) (see Figure S1). Similar to a hierarchical regression model, the order in which the variables are entered into the model is important. For this reason, we tested all possible models with different orders of entry. Regardless of the order in which the variables were entered into the model, the conclusions regarding cognitive skills and gender were highly similar. Because it is not yet possible to combine the BCH method and a Cholesky model directly, we first calculated the Cholesky model and saved the ch1–ch11 factor scores. Next, we conducted the standard BCH-weighted analysis by using the saved factor scores. For the analyses, we used Mplus 7.4 (Muthén & Muthén, 1998–2017). Maximum likelihood estimation with robust standard errors (MLR) was used for the analysis.

For reading comprehension, number counting and listening comprehension, in addition to the Cronbach alpha, the Revelle's omega estimates were calculated. Cronbach alpha has certain assumptions (a. the scale adheres to tau equivalence, b. the scale items are on continuous scale and normally distributed, c. the errors of the items do not covary, d. unidimensionality of the scale) and in many circumstances, violating these assumptions yields very small reliability estimates, making the measure look less reliable than it actually is (McNeish, 2018). Omega on the other hand is designed for congeneric scales, where the items vary in how strongly they are related to the construct being measured (i.e., the tau equivalence is not assumed) (McNeish, 2018).

The sample size changed somewhat each year due to factors related to changes in teaching groups, families moving in or out of the municipality, or absences during the testing days (see Table 1). Therefore, we conducted a missing-value analysis in order to examine whether the missingness was completely at random. We used the Little's tests of Missing Completely at Random (MCAR; Little, 1988), which showed that the data were not missing completely at random, $\chi^2(525) = 856.19$, $p<.001$. The one-way ANOVA analysis comparing the reading fluency and reading comprehension performance of those who were not tested in reading fluency or reading comprehension in one of the grades with the performance of the participants in the rest of the grades showed that those without missing values were somewhat better readers in most grades. However, we had only one large effect size (d = .80) for those without data in reading fluency in Grade 3 and full data in Grade 4, and all the other effect sizes varied from small (d = .46) to negligible (d = .05). In addition, we performed the LPA using listwise analysis (N = 1,212) in order to examine whether the identified profiles were affected by the missing values. Listwise analysis yielded an almost identical solution with four profiles as the full sample analysis (Figure S2). Finally, because there were many missing values for the family risk, maternal education, and paternal education variables, we examined whether those with missing values in these variables have lower scores in reading fluency and reading comprehension in Grade 1-9. The results showed that those with missing values in the family risk, maternal education, and paternal education variables had lower scores in reading fluency and reading comprehension than those with data in these variables ($p<.05$ for all measures of reading fluency and reading comprehension). However, the effect sizes were small in all grades for both skills (Cohen's d ranged from .15 to .30).

The data that support the findings of this study, materials, and analysis code are available on request from the authors. This study was not preregistered.

Results

Descriptive Statistics

See Table 1 for descriptive statistics of the reading measures in Grades 1–9 and Table 2 for descriptive statistics of the cognitive skills, parental factors, and gender. Table S1 shows the correlations between all measures. For the reading fluency composite, the subsequent stability correlations were high, ranging from .79 to .85. In contrast, the stability correlations from one grade to the next for reading comprehension were moderate, ranging from .47 to .57. The correlations between the reading measures and cognitive skills ranged from .13 to .51, and correlations between the parental factors and gender and the reading measures ranged from .08 to .32.

Identification of Developmental Reading Profiles

LPA was conducted to examine whether there are developmental profiles in reading fluency and comprehension across Grades 1–9. LPA was based on the model in Figure 1. Eight latent profile solutions were tested and compared, each testing a different number of profiles (1 through 8; Table 3). The fit indices of the model with no classes were as follows: $\chi^2(76)$ = 1474.68 p<.001, RMSEA = .08, CFI = .92, TLI = .90, and SRMR = .05. Because the values of aBIC and AIC did not diminish much after the model with four profiles and because the VLMR and the LMR showed that from the model with the four profiles onward, the models were not significantly better, the model with the four profiles was considered the best-fitting model. The average latent class probabilities for belonging to a profile were as follows: .84 for Profile 1, .77 for Profile 2, .77 for Profile 3, and .85 for Profile 4.

As shown in Figure 2, the four identified profiles represented two profiles with below-average reading skills (one with persistent RD and one with early poor reading skills but with a resolving tendency) and two profiles with average or above-average performance. Of the two profiles with below-average reading skills, one profile, with 7.8% of the participants, had persistent difficulties across the grades (Profile 1). Their RD were persistent in both reading fluency and reading comprehension. We noticed a clear, unexpected drop in the Profile 1 reading comprehension scores in Grade 3. The data were double-checked and confirmed that the children had a real drop in standardized scores due to clearly lower-than-average performance. The grade-level text was still too difficult for their skills. The other profile with below-average reading skills encompassed 40% of the participants and had RD in the early grades but showed a resolving tendency (Profile 2). These students started in Grade 1 having below-average (and almost identical to Profile 1) scores in reading fluency and reading comprehension but approached the average skill levels over time. The third profile, with stable average scores in reading fluency and reading comprehension across the grades, included 42.3% of the participants. The fourth profile, with good readers, included 9.9% of the participants. They started with clearly above-average scores in both reading skills, but the gap between this group and the others diminished over time. In reading fluency, this profile scored higher than all the other profiles in every grade. In reading comprehension, they started slightly higher than the other profiles and had similar scores with the other profiles in Grades 2 to 9.

Kindergarten Predictors of Reading Profiles

The next step in our analysis was the modeling of the relative contributions of the cognitive skills, parental factors, and gender to the developmental profiles by using a hierarchical regression model (Cholesky decomposition model, Figure S1). The order of entrance reported here is as follows: family risk, paternal education, maternal education, gender, word reading, RAN, number counting, letter knowledge, phonological awareness, vocabulary, and listening comprehension.

Table 4 presents how cognitive skills, parental factors, and gender differentiate between the profiles. The results showed that compared to the profile with persistent RD (Profile 1), the probabilities of belonging to the two profiles with no RD (Profiles 3 and 4) were significantly higher when the child had no family risk for RD, higher level of paternal education, and higher scores in all cognitive skills except for listening comprehension. It was also significantly more likely for females to belong to the two profiles with no RD (Profiles 3 and 4) than males. Compared to those with poor early reading skills with a resolving tendency (Profile 2), the probabilities of belonging to the two profiles with no RD (Profiles 3 and 4) were significantly higher when the child had no family risk for RD, higher level of paternal education, and higher scores in reading words, RAN, number counting, and phonological awareness.

Consequently, it seems that both those with persistent RD and those with poor early reading skills with a resolving tendency had certain similarities that differentiated them from the other two profiles with no RD. However, they had certain differences from each other that could explain why some managed to resolve their RD while others faced persistent RD. The probability of belonging to the profile with the early poor reading skills with a resolving tendency (Profile 2) in comparison to the profile with persistent RD (Profile 1) was significantly higher with better number counting and vocabulary skills in kindergarten. It was also higher for females than for males.

Finally, compared to the profile with average reading skills (Profile 3), the probability of belonging to the profile with good readers (Profile 4) was significantly higher when the child had no family risk for RD and with higher scores in word reading and RAN.

Discussion

We examined the development of reading fluency and reading comprehension over an extended period, from Grades 1 to 9, with LPA, which allowed us to examine the different trajectories of reading fluency and reading comprehension development without including measurement error and without using arbitrary cut-off points. In addition to the examination of whether there are differential developmental pathways, we examined whether they can be predicted by kindergarten-age cognitive skills, parental RD, parental education, or gender. Four developmental profiles were identified: persistent RD (7.8%) (Profile 1), early poor reading skills with a resolving tendency (40.0%) (Profile 2), average reading skills (42.3%) (Profile 3), and good readers (9.9%) (Profile 4). Overall, the strongest predictors of belonging to the profiles with RD (Profiles 1 and 2) were poorer performance in cognitive skills, family risk for RD, being male, and low paternal education. Furthermore, being female and good number counting and vocabulary skills predicted a resolving tendency in early RD.

Heterogeneous Developmental Profiles

The four profiles identified were not fully compatible with either the hypothesis for heterogeneous developmental groups (Catts et al., 2012; Etmanskie et al., 2016; Leach et al., 2003; Psyridou et al., 2020; Torppa et al., 2015; van Viersen, 2019) or the SVR model (Gough & Tunmer, 1986; Hoover & Gough, 1990).

Contrary to what was expected based on SVR, we did not find profiles with discordant fluency and comprehension development (poor comprehension despite average reading fluency or slow reading despite average comprehension). This finding contrasts with previous studies that have identified RD groups that supported the SVR model (e.g., Catts et al., 2012; Nation et al., 2010; Torppa et al., 2007). The results also seem to contrast with a previous study conducted among a different sample of Finnish-speaking children (Torppa et al., 2007) that used a similar analysis method and identified five groups that were well-fitted with the SVR: good readers, poor readers, average readers, slow decoders, and poor comprehenders. It is noteworthy that in the current sample, the best-fitting model had four groups, but the solutions with more groups did not yield similar solutions to the study by Torppa et al. (2007). However, their study examined reading development from Grade 1 fall to Grade 2 spring, while our study examined a longer window of nine years. It is possible that the difference in the assessment ages of the children and the longer follow-up explain the differences. However, when their results were compared with the results of the present study until Grade 2, we saw limited differences. When focusing only on that time frame (up to Grade 2), our analysis also identified good readers (Profile 4), poor readers (Profile 1), average readers (Profile 3), and slow readers (Profile 2, the resolving profile before they resolved). Therefore, our longer follow-up might have revealed that the profile with slow reading despite average comprehension in the early years changes to a resolving pattern later on. We did not, however, identify a profile with average reading skill but poor comprehension. It is unclear why poor comprehenders did not emerge in this study. It is likely that the analytical approach that focused on the identification of heterogeneous groups of individuals and not on the identification of RD may has an effect. Nevertheless, these results seem to be in line with other recent studies showing that children with poor decoding skills tend to have poor reading comprehension as well (Ferrer et al., 2015; Nation et al., 2019).

The profiles identified did not seem to fully fit to the hypothesis on heterogeneous developmental groups (e.g., Catts et al., 2012; Etmanskie et al., 2016; Psyridou et al., 2020; Torppa et al., 2015) either. We identified profiles with persistent RD and with a resolving tendency but did not identify a profile with late-emerging RD. However, the present study did not use arbitrary cut-off points for the identification of the different profiles, which was the case in all previous studies examining the stability of RD across time (e.g., Etmanskie et al., 2016; Leach et al., 2003; Psyridou et al., 2020; Torppa et al. 2015). Instead, we focused on similarities and differences between individuals in reading development across time. Psyridou et al. (2020) were able to identify the late-emerging group in the same sample as the present study, but they focused on the identification of RD with cut-offs and their stability at two time-points (Grades 2 and 6). The findings of Psyridou et al. (2020) suggested that most of the late-emerging cases were situated close to the cut-off for RD. It is thus possible that we were not able to identify the small late-emerging group, which does not seem to show a drastically different developmental pathway than the poor readers, with our analytical approach that focused on the identification of heterogeneous groups of individuals and not on the identification of RD.

The profile we identified with the resolving RD seems to be in line with previous studies examining the stability of RD over time (Catts et al., 2012; Psyridou et al., 2020; Torppa et al., 2015). The children belonging to this profile had the same catching-up tendency, despite their slow start, in both reading fluency and reading comprehension development. Even though children belonging to this profile had below-average reading fluency and reading comprehension skills at the beginning of primary school, they managed to resolve their early RD. Indeed, in Grade 9, the final assessment time point, they had scores very close to average.

The group with the resolving tendency was clearly larger than in the studies focusing on RD and identifying the difficulty with the lower end of the distribution (e.g., the lowest 10% of the sample in reading skill, or below 1 SD). Of our participants, 40% belonged to this profile, and they did not show severe RD even at the beginning of school. The mean of the profile with the resolving tendency in standardized scores was -.61 in reading fluency and -.62 in reading comprehension in Grade 1. The large proportion of the resolving cases may also be linked to the transparent nature of Finnish orthography, as increased levels of resolving cases were reported in the previous Finnish studies on RD stability (Psyridou et al., 2020; Torppa et al., 2015). However, as the analysis method differed, a direct comparison cannot be made.

Of the two profiles with no RD, there was one profile of children having average reading skills and one profile of children who were good readers. The good readers started with high reading fluency and reading comprehension scores in Grade 1. By Grade 9, however, the other children had caught up, with standardized scores approaching to average over time. Such strong early reading skills are expected for some children in Finnish, which is a highly transparent orthography with one-on-one correspondence between graphemes and phonemes (Aro, 2017). Children learning to read in transparent orthographies learn word reading skills during the first school year (Seymour et al., 2003). This means that by the first assessment time point during April, some of the children were already fluent readers. These children continued to be the fastest readers across all grades, but as there are limits to how fast one can be in the reading tasks, the others naturally caught up over the years.

Kindergarten Predictors of Differential Development

We also examined whether profile membership is predicted by cognitive skills, parental factors, and gender. The identification of early predictors can provide important information on how we could identify, early on, the children who will have differential developmental pathways.

Our results suggested that of the cognitive skills, low scores in word reading, RAN, number counting, phonological skills, letter knowledge, and vocabulary increased the probability of developing persistent RD. In addition, family risk, being male, and low paternal level of education also increased the probability of developing persistent RD. Those belonging to the profile with persistent RD (Profile 1) had lower scores in almost all kindergarten skills compared to those belonging to the two profiles with average or good reading skills (Profiles 3 and 4). This finding is in line with previous studies suggesting that lower performance in early cognitive skills could later lead to RD (e.g., Caravolas et al., 2019; Clayton et al., 2020; Peng et al., 2018; Suggate et al., 2018). Consistent with previous studies, our results suggested that having one or both parents with reported RD increases the probability of developing RD (Snowling & Melby-Lervåg, 2016; Torppa et al., 2010).

We also found increased vulnerability for RD in males. This is in line with previous studies showing that females perform better than males in reading (e.g., Clinton et al., 2014; Rajchert et al., 2014; Torppa et al., 2018) and that more males than females are identified with RD (Quinn & Wagner, 2015; Stoet & Geary, 2013). Finally, low paternal education seemed to predict belonging to the profile with persistent RD over the two profiles with no RD.

Surprisingly, maternal education did not account for unique variance. An explanation that has been proposed for the link between parental education and children's reading skills is that parental education affects the way parents interact with their children during learning activities (Eccles, 2005). However, it does not explain why in our study, only paternal education is associated with children's reading skills. Another explanation could be that this link reflects masked genetic effects (e.g., van Bergen et al., 2017), which means that the fathers' lower educational status would be due to their poorer skills, which is then transmitted to their children also through a genetic pathway. Again, however, this does not explain why only paternal education predicted children's persisting RD. Further studies are needed to examine how parents affect children's reading skills.

The children with the resolving tendency (Profile 2) had lower scores in word reading, RAN, number counting, letter knowledge, and phonological awareness than the children with average or good reading skills (Profiles 3 and 4). This finding is in line with the vast literature reporting that these skills are the key predictors of reading accuracy and fluency (e.g., Caravolas et al., 2019; Clayton et al., 2020; Koponen et al., 2016; Landerl et al., 2019; Snowling et al., 2019) and could explain the early RD these children experienced. As fluent reading is a necessary prerequisite for reading comprehension (Florit & Cain, 2011; García & Cain, 2014; Torppa et al., 2016), it is not surprising that these children also experienced difficulties in reading comprehension during the early years. Similar to the persistent profile, the resolving tendency profile also had more cases of familial risk. This is expected based on previous studies on the effects of familial risk on RD during the early grades (e.g., Snowling & Melby-Lervåg, 2016).

Significant indicators for the resolution of RD (the difference between the profiles with persistent and resolving RD), on the other hand, included being female, good number counting skills, and strong vocabulary. Being female increased the probability of belonging to the profile with the resolving tendency over the profile with persistent RD. This is in line with a previous study conducted among Finnish-speaking children, using a different sample than that used in the present study, which showed the over-representation of females in the group with resolving RD (Torppa et al., 2015). Overall, many previous studies have reported that females outperform males in reading (Clinton et al., 2014; Quinn & Wagner, 2015; Rajchert et al., 2014; Stoet & Geary, 2013) and that more males than females are identified with RD (Quinn & Wagner, 2015; Stoet & Geary, 2013). In addition, a recent study among Finnish-speaking Grade 9 students using a different sample than that used in the present study reported that the risk of scoring in the lowest 10% in reading fluency or reading comprehension was higher for males than for females (Torppa et al., 2018). Studies that have focused on the explanation of gender differences in reading have suggested that gender differences in linguistic skills (Lange et al., 2016), processing speed (Irwing, 2012; Palejwala & Fine, 2015) or reading motivation (Lerkannen, 2018; Mol & Bus, 2011) could have a role in explaining the association between gender and reading development. There are still gaps in knowledge regarding the developmental paths leading to gender differences in reading. Answers to this question are important for the development of good teaching and support systems for those who struggle with literacy. However, in educational practice it is more important that teachers focus on the differences between individuals rather than the differences between genders to meet the individual needs of each child towards reading and reading related skills.

Our results suggested further that better scores in number counting and in vocabulary could also increase the probability of belonging to the profile with the resolving tendency instead of the persistent RD profile. Previous studies examining the contribution of number counting to reading fluency skills have shown that number counting is a significant predictor (Bernabini et al., 2021; Koponen et al., 2013, 2016) even after controlling for phonological awareness, verbal short-term memory (Koponen et al., 2013, 2016), vocabulary, working memory, number concepts, and maternal education, surpassing even RAN (Koponen et al., 2016). This is noteworthy given that in transparent orthographies, such as Finnish, RAN has typically been the strongest predictor of reading fluency (Landerl et al., 2019; Moll et al., 2014). Based on the hypothesis that RAN would predict low reading fluency skills in later grades in transparent orthographies, we would expect that those with the resolving RD would have better RAN scores than those with persistent RD, and their deficits would be more in decoding and phonological awareness. However, our results suggest that number counting may be a better predictor of a resolving tendency than RAN. Even though RAN and number counting are both serial processes, each requires different knowledge. In a RAN task, the child needs to name, as fast as possible, a series of visual stimuli, while in the number counting task, the child needs number sequence knowledge. Compared to the RAN task, in the number counting task, the child needed to hold information in his/her memory in order to find the correct responses. Nevertheless, more studies are needed to examine its association with reading skills.

There are certain limitations in this study that need to be addressed. First, we used only one measure to assess reading comprehension at each time point. By having more texts and items in the reading comprehension assessment, we could have increased the reliability of the reading comprehension assessment. Second, the reliability estimate of our listening comprehension measure was quite low and thus, the results should be interpreted with caution. However, given the young age of the participants this is not extraordinary. It is possible that the low reliability is one of the reasons why listening comprehension did not explain the differences between the profiles, and our results are likely underestimating the importance of listening comprehension in reading development. Third, our sample had missing values in the parental questionnaires, particularly in the paternal variables. The missing value analysis showed that missing values were more common for children with poorer reading skills. It is thus possible that the association between family risk, paternal education, and children's skills is, in fact, even stronger than this data suggests. Fourth, the missing values were not missing completely at random. Although we did the analysis using both full data and data from only those who were assessed at every time point, and we did not find major differences, we would have more statistical power and more reliable results if our data were missing completely at random. Fifth, in order to identify the developmental profiles, we used explorative latent profile analysis. There might be small profiles other than those identified (e.g., poor comprehenders or late-emerging difficulties), but their prevalence was too low. Sixth, it should be noted that not all those belonging to the two profiles with RD (persistent and resolving) would be identified as having RD. Finally, our family risk variables were based on self-reports with single questions and may not provide a very accurate estimate of the skill levels of the parents. However, even with these measures, the risk for belonging to the poorer-performing groups increased considerably.

In conclusion, the results of this study suggest that there are heterogeneous developmental trajectories across Grades 1–9. We identified four different developmental profiles in our sample: two with below and two with average or above-average reading skills. Of the profiles with below-average reading skills, one represented persistent RD across the grades, and the other a resolving tendency despite some early difficulties in reading. The children belonging to the group with the resolving tendency demonstrated significant difficulties in multiple cognitive skills, but at the same time they seemed to have certain strengths in early cognitive skills in comparison to the children belonging to the group with persistent reading difficulties. Specifically, the probability for the resolution of RD increased with higher scores in number counting and vocabulary in kindergarten. These skills may have acted as protective factors, or indicators of skills that better predict long-term reading outcomes. Furthermore, gender seemed to affect the trajectories of reading skills development, with girls being more likely to resolve their RD. These factors could be useful in designing more effective support systems.

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Figure Captions

Figure 1 Latent Profile Analysis Model for the Reading Measures

Figure 2 Profiles Identified with the Use of Latent Profile Analysis

Table 1

Descriptive Statistics for Reading Measures

		N	M	SD	Min	Max	Skewness	Kurtosis
Grade 1	Text reading	2051	18.28	8.97	.00	58.00	.66	.20
	Word chain	2047	6.91	5.08	.00	32.00	1.04	1.72
	Sentence reading	2049	17.91	8.19	.00	46.00	.35	.02
	Reading fluency composite	2052	.00	.86	-2.11	3.48	.62	.44
	Reading comprehension	2035	5.50	3.18	.00	12.00	.00	-.96
Grade 2	Text reading	2005	24.20	7.63	3.00	58.00	.40	.06
	Word chain	2001	11.33	6.10	.00	38.00	.67	.59
	Sentence reading	1996	29.83	8.53	.00	60.00	-.10	.28
	Reading fluency composite	2006	.00	.85	-2.47	3.31	.26	.23
	Reading comprehension	1974	8.52	2.71	.00	12.00	-.73	-.20
Grade 3	Text reading	1995	35.30	8.97	1.00	63.00	-.20	.37

	Word chain	1992	16.02	7.20	.00	40.00	.42	.00
	Sentence reading	1989	38.12	8.76	6.00	60.00	-.07	.22
	Reading fluency composite	1995	.00	.86	-3.82	2.75	-.04	.43
	Reading comprehension	1988	9.09	2.17	.00	12.00	-1.17	1.72
Grade 4	Text reading	1954	36.06	9.25	.00	66.00	-.02	.15
	Word chain	1951	17.03	7.12	.00	40.00	.28	-.22
	Sentence reading	1954	45.43	9.33	2.00	60.00	-.52	.46
	Reading fluency composite	1954	.00	.87	-4.01	2.39	-.17	.30
	Reading comprehension	1950	8.10	2.52	.00	12.00	-.47	-.34
Grade 6	Text reading	1820	47.23	10.94	10.00	80.00	.00	.00
	Word chain	1820	21.63	7.44	1.00	40.00	.09	-.36
	Sentence reading	1822	30.61	7.38	4.00	62.00	.15	.28

	Reading fluency composite	1822	.00	.84	-3.00	2.74	.12	-.07
	Reading comprehension	1821	7.15	2.55	.00	12.00	-.20	-.59
Grade 7	Text reading	1765	37.70	8.38	2.00	65.00	-.18	.35
	Word chain	1765	25.75	7.60	.00	40.00	.07	-.50
	Sentence reading	1764	33.14	7.41	.00	57.00	.00	.25
	Reading fluency composite	1770	.00	.87	-3.66	2.65	-.07	.00
	Reading comprehension	1758	6.59	2.54	.00	12.00	.05	-.64
Grade 9	Text reading	1707	41.47	9.07	11.00	72.00	-.02	.27
	Word chain	1704	46.06	11.55	8.00	76.00	-.17	-.10
	Sentence reading	1705	37.53	8.48	.00	70.00	-.05	.38
	Reading fluency composite	1721	.00	.87	-2.60	2.60	-.09	-.14
	Reading comprehension	1702	7.02	2.43	.00	12.00	-.15	-.57

Table 2

Descriptive Statistics for Cognitive Skills, Parental Factors, and Gender

	N	**M**	**SD**	**Min**	**Max**	**Skewness**	**Kurtosis**
Phonological awareness	1867	7.46	2.45	0	10	-.81	-.21
Letter knowledge	1867	16.95	9.01	0	29	-.25	-1.27
RAN	1835	173.71	17.78	34	210	-1.72	6.69
Word reading	1823	4.03	4.29	0	10	.44	-1.61
Number counting	1836	6.06	2.20	0	8	-1.10	.25
Vocabulary	1839	19.82	3.38	7	29	-.38	.31
Listening comprehension	1832	7.71	2.34	0	12	-.31	-.13
Maternal education	1558	2.30	.61	1	3	-.28	-.64
Paternal education	1117	2.27	.60	1	3	-.18	-.56
Maternal reading difficulties	1543	.14	.35	0	1	2.09	2.38
Paternal reading difficulties	1078	.21	.41	0	1	1.40	-.04
Family risk	1115	.36	.48	0	1	.59	-1.65
Gender	1880	1.52	.50	1	2	-.09	-1.99

Table 3

Fit Indices for Latent Profile Analyses

Number of profiles	BIC	aBIC	AIC	Entropy	p-value of LMR	p-value of VLMR
1	58499.66	58363.04	58248.92			
2	57682.91	57498.63	57344.70	.60	.00	.00
3	57425.35	57193.41	56999.67	.67	.00	.00
4	57247.44	56967.84	56734.29	.65	.01	.01
5	57192.28	56865.02	56591.66	.64	.13	.13
6	57120.46	56745.54	56432.37	.66	.10	.10
7	57091.83	56669.26	56316.28	.66	.28	.27
8	57069.63	56599.40	56206.61	.66	.31	.31

Note. BIC = Bayesian Information Criterion; aBIC = Adjusted Bayesian Information Criterion; AIC = Akaike's Information Criterion; LMR = Lo–Mendell–Rubin Adjusted Likelihood Ratio Test; VLMR = Vuong–Lo–Mendell–Rubin Likelihood Ratio Test

Lower values of BIC, aBIC, and AIC represent better model fit. The LMR and the VLMR compare the estimated model with the model having one fewer profile than the estimated model. A p-value of less than .05 shows that the estimated model is better and that the model with one fewer profile should be rejected. Entropy ranges from 0 to 1, and higher values show higher classification utility. In addition, the clarity of the latent profiles was examined by the average posterior probabilities for the most likely latent profile membership, which shows how distinct the profiles are.

Table 4

Comparisons Between the Profiles for the Cognitive Skills, Parental Factors, and Gender

		Profile 2			**Profile 3**			**Profile 4**		
		Estimate	**Standard Error**	**p-value**	**Estimate**	**Standard Error**	**p-value**	**Estimate**	**Standard Error**	**p-value**
Reference group profile 1	Family risk	-.06	.41	.88	-1.86	.49	.00	-2.53	.53	.00
	Paternal education	.54	.33	.10	1.26	.37	.00	1.63	.40	.00
	Maternal education	-.04	.31	.89	.26	.35	.46	.17	.38	.66
	Gender	-1.50	.36	.00	-1.56	.40	.00	-1.63	.44	.00
	Reading words	-.60	.39	.13	1.71	.32	.00	2.83	.37	.00
	RAN	.14	.13	.30	1.06	.23	.00	1.61	.29	.00
	Number counting	.35	.13	.01	1.14	.22	.00	1.68	.33	.00
	Letter knowledge	.40	.21	.05	.66	.22	.00	.79	.28	.01
	Phonological awareness	.04	.17	.80	.64	.22	.00	.61	.27	.02
	Vocabulary	.36	.16	.02	.41	.19	.03	.51	.21	.02

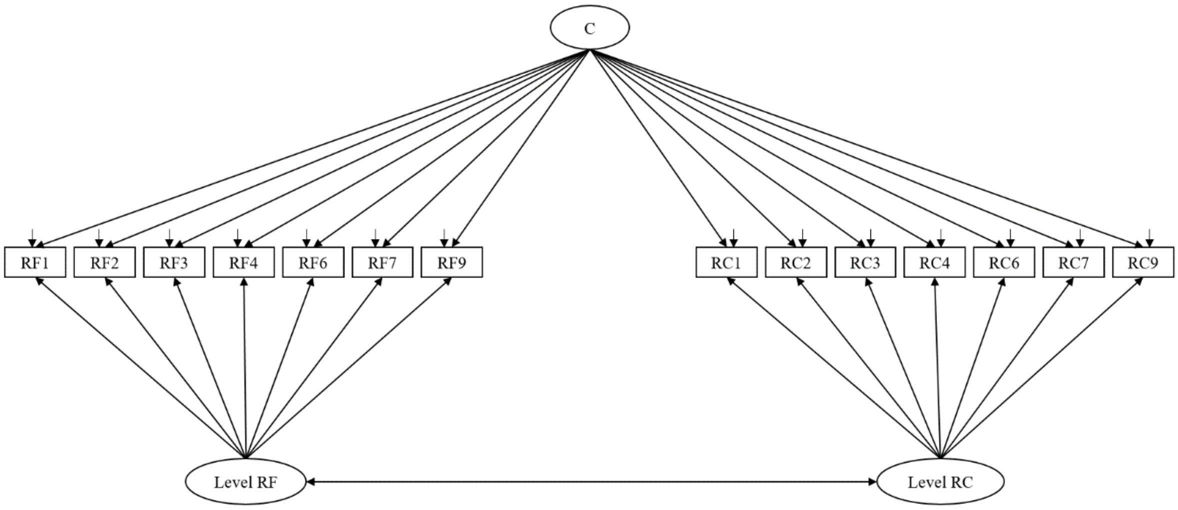
	Listening comprehension	.18	.17	.29	.18	.17	.29	.15	.19	.44
Reference	Family risk				-1.80	.48	.00	-2.47	.51	.00
group	Paternal education				.72	.35	.04	1.09	.37	.00
profile 2	Maternal education				.30	.33	.36	.21	.35	.55
	Gender				-.06	.31	.84	-.12	.35	.72
	Reading words				2.32	.42	.00	3.43	.46	.00
	RAN				.92	.24	.00	1.47	.29	.00
	Number counting				.79	.21	.00	1.33	.31	.00
	Letter knowledge				.27	.19	.17	.39	.25	.12
	Phonological awareness				.60	.20	.00	.56	.24	.02
	Vocabulary				.05	.18	.77	.16	.20	.44
	Listening comprehension				.01	.16	.97	-.03	.18	.88
Reference	Family risk							-.67	.32	.04
group	Paternal education							.37	.23	.10
profile 3	Maternal education							-.09	.23	.69
	Gender							-.06	.24	.80

Reading words	1.12	.23	.00
RAN	.55	.21	.01
Number counting	.54	.28	.05
Letter knowledge	.13	.22	.55
Phonological awareness	-.03	.21	.88
Vocabulary	.10	.14	.45
Listening comprehension	-.03	.12	.79

Note. The estimates presented are not standardized. For the interpretation, the estimates and their significance (p-values) were examined. A positive sign means that the probability for the categorical variable (profile variable with values 1–4) is increased when the predictor value increases. A larger magnitude means that the probability increases faster.

Figure 1

Latent Profile Analysis Model for the Reading Measures



Note. C represents the latent profiles, Level RF and Level RC the initial level of reading fluency and reading comprehension. Numbers in reading fluency and reading comprehension measures indicate the assessment time point (grade).

Figure 2

Profiles Identified with the Use of Latent Profile Analysis

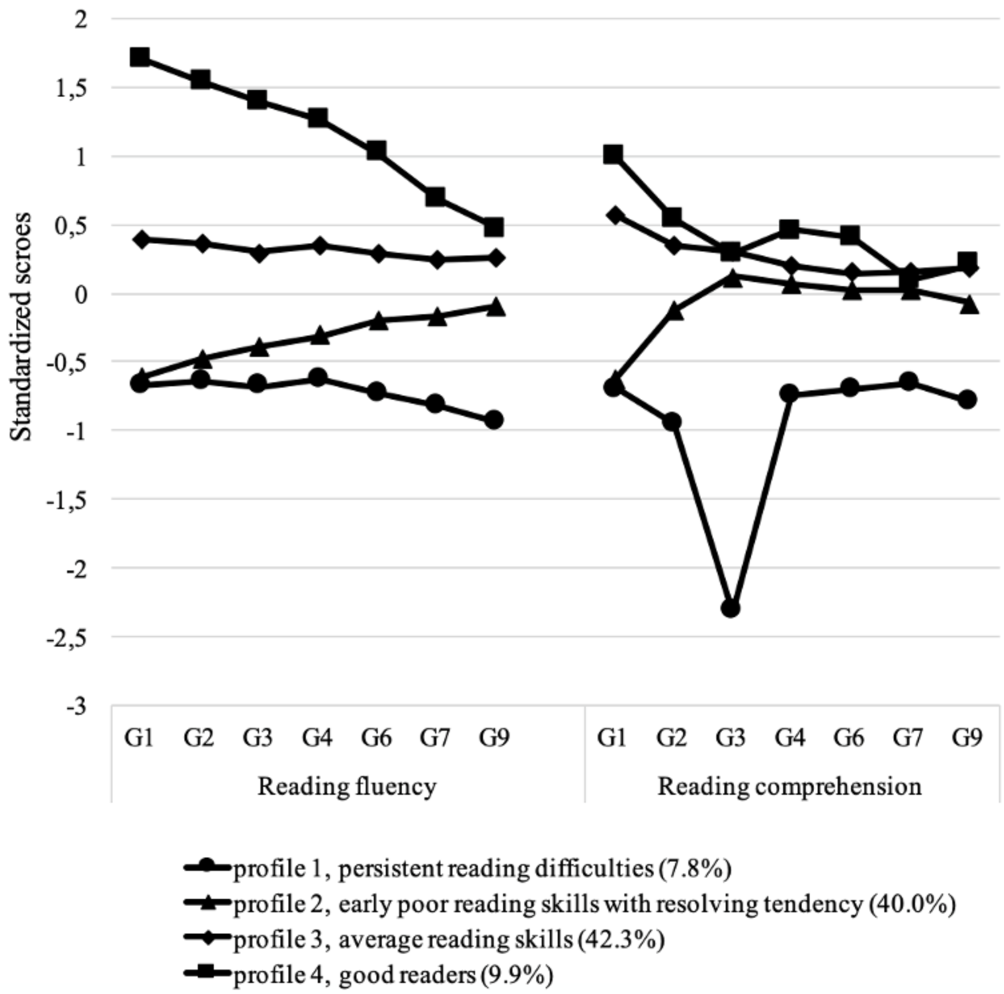


Table S1

Correlations of Reading Measures in Grades 1–9, Kindergarten Measures, Parental Factors, and Gender

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Phonological awareness	1											
2. Letter knowledge	.58***	1										
3. RAN	.26***	.34***	1									
4. Reading words	.57***	.67***	.33***	1								
5. Number counting	.37***	.50***	.31***	.39***	1							
6. Vocabulary	.32***	.34***	.19***	.24***	.27***	1						
7. Listening comprehension	.18***	.18***	.11***	.17***	.14***	.29***	1					
8. Gender	-.10***	-.13***	-.05*	-.15***	.09***	.00	-.07*	1				
9. Maternal education	.17***	.17***	.10***	.12***	.11***	.17***	.11***	.05	1			
10. Paternal education	.14***	.16***	.12***	.15***	.10***	.15***	.12***	.05	.43***	1		

11. Family risk	-.12***	-.19***	-.14***	-.19***	-.16***	-.08*	-.10***	0.04	-.18***	-.13***	1	
12. RF1	.42***	.50***	.37***	.58***	.39***	.23***	.15***	-.15***	.10***	.12***	-.20***	1
13. RF2	.38***	.46***	.36***	.49***	.39***	.27***	.17***	-.16***	.13***	.14***	-.23***	.80***
14. RF3	.36***	.43***	.34***	.46***	.38***	.24***	.16***	-.19***	.10***	.12***	-.18***	.75***
15. RF4	.33***	.42***	.34***	.42***	.38***	.25***	.18***	-.19***	.13***	.15***	-.18***	.71***
16. RF6	.29***	.37***	.31***	.39***	.34***	.21***	.14***	-.25***	.11***	.13***	-.15***	.67***
17. RF7	.26***	.34***	.30***	.37***	.29***	.19***	.13***	-.24***	.11***	.14***	-.15***	.61***
18. RF9	.26***	.36***	.29***	.39***	.27***	.16***	.13***	-.32***	.15***	.13***	-.12***	.58***
19. RC1	.39***	.47***	.27***	.51***	.39***	.33***	.23***	-.10***	.14***	.17***	-.18***	.63***
20. RC2	.38***	.39***	.24***	.44***	.32***	.34***	.28***	-.15***	.13***	.17***	-.16***	.48***
21. RC3	.28***	.34***	.22***	.30***	.26***	.30***	.24***	-.17***	.15***	.16***	-.14***	.33***
22. RC4	.34***	.38***	.23***	.36***	.28***	.41***	.29***	-.16***	.20***	.18***	-.16***	.38***
23. RC6	.30***	.32***	.18***	.31***	.22***	.33***	.23***	-.10***	.19***	.20***	-.11***	.31***
24. RC7	.30***	.29***	.15***	.28***	.19***	.30***	.22***	-.14***	.18***	.16***	-.09*	.26***
25. RC9	.26***	.27***	.19***	.30***	.19***	.26***	.21***	-.19***	.18***	.16***	-.08*	.29***

	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
1. Phonological awareness													
2. Letter knowledge													
3. RAN													
4. Reading words													
5. Number counting													
6. Vocabulary													
7. Listening comprehension													
8. Gender													
9. Maternal education													
10. Paternal education													
11. Family risk													

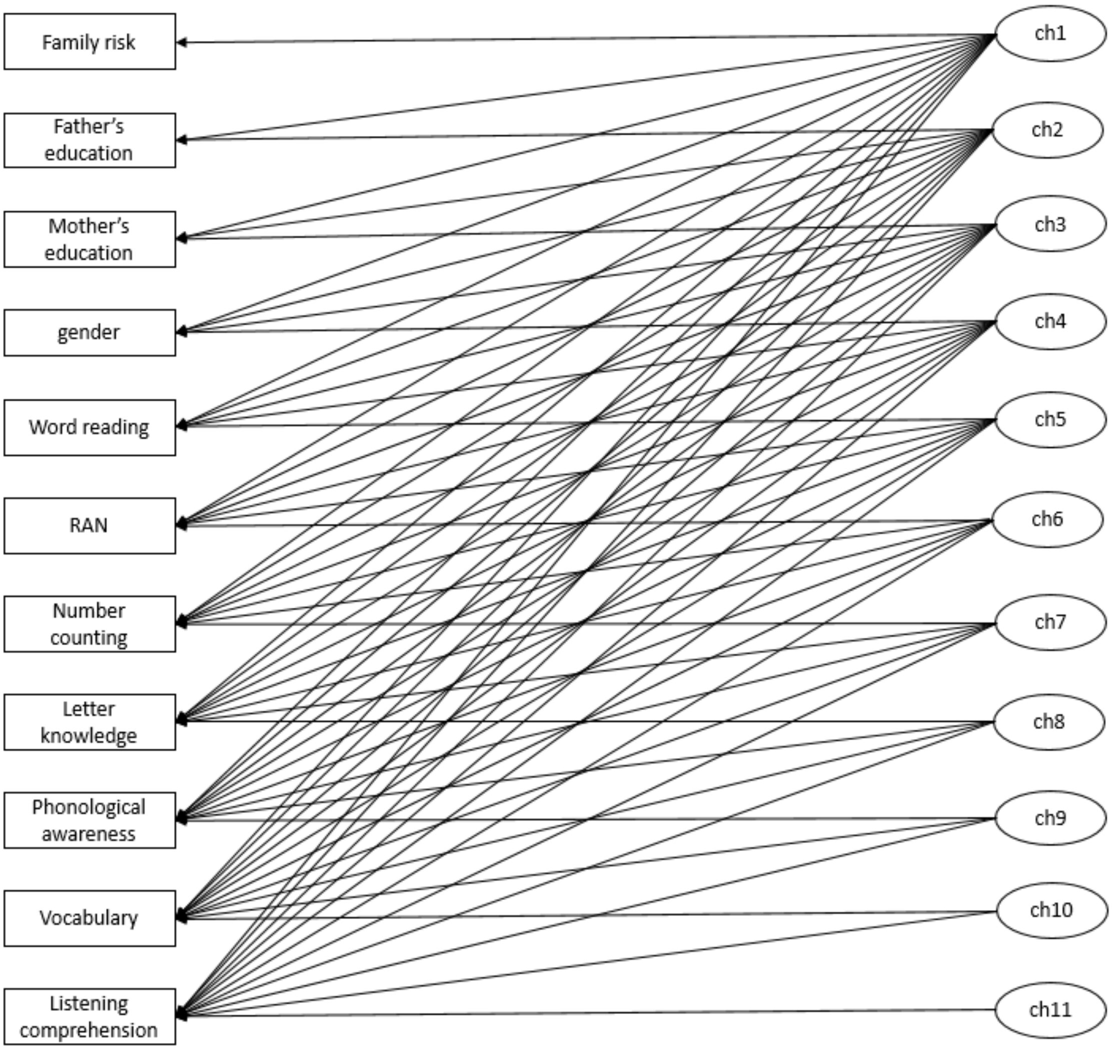
12. RF1													
13. RF2	1												
14. RF3	.82***	1											
15. RF4	.79***	.85***	1										
16. RF6	.73***	.78***	.81***	1									
17. RF7	.67***	.71***	.75***	.79***	1								
18. RF9	.64***	.67***	.72***	.77***	.81***	1							
19. RC1	.60***	.55***	.56***	.50***	.47***	.45***	1						
20. RC2	.49***	.47***	.47***	.46***	.42***	.43***	.53***	1					
21. RC3	.35***	.34***	.37***	.34***	.34***	.35***	.39***	.48***	1				
22. RC4	.39***	.40***	.41***	.38***	.41***	.39***	.44***	.55***	.47***	1			
23. RC6	.34***	.31***	.35***	.36***	.39***	.38***	.42***	.49***	.42***	.57***	1		
24. RC7	.30***	.26***	.30***	.31***	.37***	.39***	.36***	.46***	.40***	.51***	.49***	1	
25. RC9	.32***	.28***	.30***	.30***	.35***	.40***	.37***	.43***	.36***	.43***	.46***	.51***	1

Note. *** p<0.001, **p<.01, *p<.05.

RF=Reading fluency composite score, RC=Reading comprehension. Numbers indicate the assessment time point (grade).

Figure S1

Cholesky Decomposition for the Prediction of the Developmental Profiles



Note: In the Cholesky model, one Cholesky factor is estimated for each observed variable (here ch1, ch2, ch3, ch4, ch5, ch6, ch7, ch8, ch9, ch10, ch11), and the residuals of the observed variables are set to zero. The first Cholesky factor (ch1) is fixed to explain all the variance of the first observed variable and all the variance of the other observed variables that covaries with the first variable. The second Cholesky factor (ch2) is fixed to explain the rest of the variance in the second observed variable not already explained by ch1, as well as all the variance of the other observed variables that covaries with the second observed variable. The remaining Cholesky factors are estimated in a similar fashion.

Figure S2

Latent Profile Analysis Using Listwise Analysis