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# Parental influences on the development of single and co-occurring difficulties in reading and arithmetic fluency

Daria Khanolainen [a,*], Tuire Koponen [a], Kenneth Eklund [b], Georgia Gerike [b,c,d], Maria Psyridou [b], Marja-Kristiina Lerkkanen [a], Mikko Aro [e], Minna Torppa [a]

[a] Department of Teacher Education, University of Jyväskylä, Finland
[b] Department of Psychology, University of Jyväskylä, Finland
[c] Centre for Interdisciplinary Brain Research, University of Jyväskylä, Finland
[d] Niilo Mäki Institute, Finland
[e] Department of Education, University of Jyväskylä, Finland

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ABSTRACT

This study investigated how single and co-occurring difficulties in reading and arithmetic fluency developed among Finnish children across Grades 1–9 ($N = 2151$). Latent profile analysis among 391 children who had reading and/or arithmetic fluency difficulties in Grade 9 revealed profiles that followed three distinct patterns: reading difficulties ($N = 121$), mathematical difficulties ($N = 94$), and comorbid difficulties ($N = 176$). The profiles and typical performers were compared on parental reading and mathematical difficulties, parental education, the early home learning environment, and parental assistance with school homework across Grades 1–9. Results showed that although parents whose children had difficulties provided them with domain-specific support across all grades, the amount of support gradually declined and the performance gap between the profiles increased.

## 1. Introduction

The end of comprehensive school is a critical time point—this is when adolescents face important choices regarding their future educational pathways. Unfortunately, these choices can be negatively affected by reading and mathematical difficulties (RD and MD, respectively), as poor foundational academic skills are a known risk factor for later lower academic motivation (Klauda & Guthrie, 2015), higher levels of school burnout and dropout after compulsory education (Korhonen et al., 2014), which can lead to unemployment and mental health problems in adulthood (Aro et al., 2019). International assessments show that many teenagers struggle with reading and mathematical tasks that are well below their grade level (Schleicher, 2018); nevertheless, longitudinal research on reading and mathematical skill development mostly focuses on early childhood and primary school education, rarely extending into education during adolescence. Moreover, reading and mathematical skills are interrelated (Cirino et al., 2018) and difficulties in these domains often co-occur (Moll et al., 2019), placing individuals at even higher risk for the negative outcomes. Nevertheless, most previous studies examining the comorbidity of RD and MD are cross-sectional and long-term developmental patterns leading to RD, MD, and comorbid difficulties remain to be identified and examined.

During the last decade, an increasing amount of research has examined the cognitive factors related to the co-variance of reading and mathematical skills (Cirino et al., 2018) and the comorbidity of difficulties in these domains (Landerl et al., 2009; Van Daal et al., 2012). However, notably less attention has been paid to the related environmental factors. Although numerous studies have shown positive correlations between home learning activities and children's reading (Dong et al., 2020) and mathematical skills (Dunst et al., 2017), whether the existing differences in the characteristics of the home learning environment could be related to divergent outcomes in adolescence is still unclear. Studying differential pathways to adolescent performance and identifying the environmental factors that predict them can elucidate the risk and protective factors operating in children's everyday life.

The main objective of this study is to gain new insights into the developmental patterns that result in RD and MD among adolescents. To this end, we identify latent profiles of reading and mathematical skill development among Finnish schoolchildren who demonstrate low performance in reading and arithmetic fluency at the end of comprehensive

* Corresponding author at: University of Jyväskylä, Huone RUU B325, Ruusupuisto, Alvar Aallon katu 9, 40600 Jyväskylä, Finland.
*E-mail address:* daria.p.khanolainen@jyu.fi (D. Khanolainen).

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school (Grade 9, age 16). We then compare the skill levels of the low performing profiles to the skill levels of their typically performing peers to see how the pace of their development differs. In addition, we examine the role of various family factors in the development of foundational academic skills. We include family risk status (parental RD and MD), parental education, and learning activities at home, as these all are linked with children's reading and mathematical skill development (Dong et al., 2020; Dunst et al., 2017; Esmaeeli et al., 2019; Van Bergen et al., 2014). To our knowledge, this is the first study with such an objective.

This study builds on our previous research (Khanolainen et al., 2020) where we examined the effects of parental difficulties and the early home learning environment on children's reading and arithmetic skills. In that study we showed that parental difficulties had small predictive effects on children's skills in the general population sample. The overall group level analyses are informative but assume that developmental patterns and associations are similar for all participants. This study is different as we focus on the group of children with learning difficulties and test if there are differential developmental paths leading to learning difficulties at the end of Grade 9. This approach allows us to investigate the possibility of heterogeneous long-term developmental pathways (including pathways with single and comorbid difficulties). This is an important extension of the previous research as we know that reading and arithmetic difficulties are often comorbid (Moll et al., 2019). Furthermore, in the previous study we specifically examined the role of the early home environment (measured when children were in kindergarten) in subsequent skill development. In this study, however, we incorporate parental academic assistance from Grades 1 to 9.

### *1.1. Developmental pathways of reading and arithmetic fluency development*

Reading fluency is most often defined as the skill that allows reading with speed and accuracy. It forms the foundation for developing more complex skills, such as reading comprehension (Florit & Cain, 2011; Pikulski & Chard, 2005). Similarly, arithmetic fluency can be understood as the skill needed for speed and accuracy in simple mathematical calculations (additions, subtractions, multiplications, and divisions). Strong arithmetic fluency is critical for further mathematical development and difficulties in arithmetic fluency are an important precursor of difficulties in higher-order mathematical skills (Cowan et al., 2011; Jordan et al., 2003).

Throughout this study we will refrain from using the terms “dyslexia” and “dyscalculia”, instead opting for “reading difficulties” and “arithmetic difficulties”. Our participants completed only skill assessments that are sufficient for identifying reading and arithmetic difficulties but are not sufficient for diagnosing either dyslexia or dyscalculia. Conducting extensive diagnostic assessments required for a diagnosis was beyond our study's objectives. In addition, identifying reading and mathematical difficulties (rather than diagnosing dyslexia and dyscalculia) is in line with the support system provided within Finnish education where support is made available based on teachers' identification of learning difficulties. No official diagnoses of dyslexia or dyscalculia are needed for special needs support. At the same time, it is likely that a sizable proportion of children who demonstrated reading and arithmetic difficulties in our sample had in fact dyslexia, dyscalculia, or both.

Existing research on adolescent reading development suggests that those who slightly lag in their reading fluency development during early grades often experience a significantly more pronounced lag in academic performance immediately after elementary school (ages 11–12), as the demands of the curriculum become increasingly rigorous and much of secondary school teaching starts taking place outside their zone of proximal development (Blanton et al., 2007; Deshler & Hock, 2007). Similarly in mathematics, high rates of acceleration in development have been noted among high performers compared with low performers, contributing to an increasing variance in skills over time and a gradually widening skill gap between low performers and high performers during the early grades (Aunola et al., 2004); however, this process has not been traced to adolescence.

Although longitudinal research is still lacking, existing evidence shows that both reading and arithmetic fluency have high inter-individual stability, suggesting that even though fluency develops over time, the individual rank order in skill is established in early years and remains fairly time-invariant (Hulslander et al., 2010). For this reason, early skills are strong predictors of later skills. For example, Aunola et al. (2004) reported the correlation between mathematical skills (arithmetic fluency tasks were included in the assessments) in Grades 1 and 2 to be 0.79, while Eklund et al. (2015) found that the correlation between reading fluency scores in Grades 2 and 8 was 0.78.

Despite such a high stability of reading and arithmetic fluency, large variances that are unexplained still remain, allowing room for change. This means that less predictable developmental patterns are possible, and they are usually studied within RD and MD research. For example, RD do not always demonstrate longitudinal stability (Torppa et al., 2015), even after controlling for measurement error and using a simulation-based analysis with buffer zones to counter the effects of arbitrary cut-offs (Psyridou et al., 2020). Torppa et al. (2015) found that only around 40 % of all children with RD in their sample had persistent difficulties identifiable in both elementary and lower secondary school (at ages 8 and 14). A similar longitudinal instability was recently observed in the identification of MD—only about 50 % of learners with an early diagnosis retained clear difficulties over the first two years of elementary school (ages 7 and 8) (Chan & Wong, 2020).

These studies, however, focused on the stability of either RD or MD without testing for their possible comorbidity and its impact on stability. In contrast, working with the same data set as we used in the present study Koponen et al. (2018) examined the stability of RD and MD as well as comorbid difficulties across Grades 1–4 and found lower stability in Grade 1 and higher stability thereafter. In addition, starting from Grade 2, comorbid difficulties were stable and more so than the single difficulties—68 % of second graders with comorbid difficulties demonstrated persistent difficulties in both domains and confirmed their status in Grade 4, whereas only 46 % and 39 % of those with single RD and MD, respectively, remained in the same developmental group. Interestingly, only 1 %, went from typical performance in both skills to comorbid difficulties over time; however, note that the study ended at Grade 4.

The fact that children frequently display comorbid difficulties and may transition from one deficit group to another over time is best explained by the multiple deficit model (Pennington, 2006), a theoretical framework that accounts for the emergence and dynamic nature of RD and MD by the complex interactions between multiple shared risk factors that are associated with the two types of difficulties probabilistically (rather than deterministically). However, further research focusing on RD and MD along with their comorbidity and longitudinal stability is needed to gain a better understanding of the possible factors that shape different developmental patterns from a long-term perspective.

### *1.2. Family risk for RD and MD*

The reasons behind the differences in the patterns of reading and arithmetic fluency development can be multiple, e.g. children's cognitive skills, motivation-related factors, family factors (both parental reading and mathematical skills and the home learning environment), etc. The present study focuses on a variety of family factors that might influence how children's skills develop. In reading, parental RD (family risk) are one of the best early predictors of children's reading skills (Esmaeeli et al., 2019; Puolakanaho, 2007; Van Bergen et al., 2014) while family risk studies are still rare in mathematics-related research (Shalev et al., 2001). Nevertheless twin, molecular genetic, and adoption studies indicate a high heritability of different mathematical skills

(Borriello et al., 2020; Docherty et al., 2010; Kovas et al., 2007), including skills such as arithmetic fluency, suggesting that parental MD could be a strong predictor of children's general mathematical skills over time. Existing research on the etiology of comorbid difficulties in reading and mathematics-related skills reported that the two types of difficulties stem largely from the same genetic factors (Daucourt et al., 2020). Moreover, reading and arithmetic fluency share considerable genetic overlap not only with one another but also with general cognitive ability (Hart et al., 2009). Nevertheless, there are few family risk studies that focus on the comorbidity of RD and MD (Nguyen et al., 2022). Our present study offers novel insights into how different parental learning difficulties (family risk for both RD and MD) influence children's reading and arithmetic fluency development.

### 1.3. Home learning environment and parental academic assistance

Children's skills develop under the influence of not only genetic but also environmental factors which has been understood through studying the home learning environment. In research, the home learning environment is commonly divided into the home literacy environment (HLE) and home numeracy environment (HNE) which refer to at-home interactions between parents and their children, learning materials, and parental attitudes related to literacy and numeracy, respectively. Multiple studies have produced compelling evidence indicating significant positive associations between the early home learning environment and both reading and mathematical development (Dong et al., 2020; Dunst et al., 2017). However these studies were conducted with young children who were not yet enrolled in formal schooling (Dong et al., 2020; Dunst et al., 2017). Studies with children of school age looking into parental academic assistance and involvement in homework are still quite rare and have provided mixed evidence. Some studies with general population samples of school-age children suggest that parental academic assistance is beneficial (Dumont et al., 2012; Patall et al., 2008), whereas other studies report a negative association between parental involvement and children's academic performance (Hill & Tyson, 2009; Pomerantz & Eaton, 2001). This negative association does not necessarily mean that parental involvement itself is detrimental for academic skill development but rather that children's lower academic achievement likely evokes more parental academic assistance (Silinskas et al., 2010; the researchers used the same data set as we did but only the data from early grades was available at that time). Contradicting and inconsistent findings could also be attributable to the use of different research measures. For example, Dumont et al. (2014) highlighted that some studies collect data on the quantity of all academic assistance activities whereas others differentiate between qualitatively different types of activities and show that only some of these activities help children learn.

Additionally, some researchers have pointed out that parental learning difficulties could be an important confounding factor that needs to be investigated in research on HLE and HNE (Puglisi et al., 2017; Van Bergen et al., 2014). Indeed, parents with learning difficulties could be organizing fewer learning activities at home but it is not necessary the reason why their children demonstrate lower academic skills, the real reason could be that these children have inherited parental learning difficulties. Therefore, the inclusion of both home environmental factors and parental skill measures is important.

### 1.4. The present study

Our review of previous research suggests that further investigation of different long-term patterns within skill development leading to RD and MD at the end of compulsory schooling is important. While research focusing on individuals with resolving difficulties is valuable because it can help identify protective and promotive factors, it is important to recognize that research with a specific focus on individuals with below grade level outcomes is also valuable because it can help establish and better understand specific risk factors. The heterogeneity of learning difficulties is multi-layered, as distinct groups of difficulties can be identified based on their stability, time of emergence, and co-occurrence with other difficulties. In view of this, the present study aims to address two main research questions. The first is, "What patterns of developmental progress can be identified among those leaving comprehensive school with lower foundational skills (reading and mathematical difficulties)?"

To identify the patterns of developmental progress, we used latent profile analysis (LPA), which is currently one of the most common scientific approaches to retrieve homogeneous subgroups (profiles) from heterogeneous populations. Based on previous findings about the prevalence of comorbid RD and MD (Moll et al., 2019), we expected to identify distinct groups of learners with RD, MD, and comorbid difficulties. Moreover, based on previous research on developmental changes in the domain of reading (Catts et al., 2012; Torppa et al., 2015) and mathematics (Chan & Wong, 2020), we expected to find persistent (emerging during early grades) and late-emerging (emerging only after Grade 3) difficulty profiles.

Our second research question focused on parental influences: "Do profiles of low performers differ from one another and from typical performers based on the family risk status (parental RD and MD), parental education, or home learning activities (the early home learning environment, assessed when children were in kindergarten, as well as parental academic assistance, repeatedly measured when children were in school—in Grades 1–9)?" Taking into account previous studies, we expected to find the following significant predictors of children's profiles: family risk as a negative predictor (Esmaeeli et al., 2019; Shalev et al., 2001; Van Bergen et al., 2014), the home learning environment as a positive predictor (Dong et al., 2020; Dunst et al., 2017; Van Bergen et al., 2017), and parental academic assistance as either a positive (Dumont et al., 2012) or a negative predictor (Hill & Tyson, 2009). To answer the second research question, we compared the low performers and typical performers using one-way ANOVAs. We additionally tested if any of the family factors predicted the low performing profiles using the three-step approach in our LPA (Asparouhov & Muthén, 2014).

## 2. Methods

### 2.1. Participants and procedure

This study is part of the First Steps Study (Lerkkanen et al., 2006) that followed children from kindergarten (aged 6–7 years) to Grade 9 (aged 15–16 years), the end of comprehensive schooling. The sample includes 2614 children. The study ensured balanced sampling of participants from rural, urban, and mixed areas in western, central, and eastern Finland. Marital statuses and educational levels of participating parents were very close to the national distribution. Overall, the sample can be considered representative of the Finnish population in terms of ethnic composition, family structure and educational levels (Statistics Finland, 2007). The current study complied with the guidelines of the Finnish National Board on Research Integrity (TENK, 2019). The Ethical Committee of the University of Jyväskylä reviewed the study and provided an ethical evaluation statement on June 6th, 2006. Throughout the whole study research was conducted in accordance with the ethical guidelines for research with human subjects. Around 83 % of all contacted families participated in the study and provided informed consent prior to participation.

### 2.2. Measures

In this study, we utilized data from eight available time points (kindergarten and Grades 1, 2, 3, 4, 6, 7, and 9). Children's assessments were conducted in schools, where trained researchers administered tests for reading and arithmetic fluency in classrooms. Parental questionnaires were administered at all time points when children's skills were assessed, starting at kindergarten. The children's fathers were less likely to report their home activities than mothers (e.g., in Grade 1, 3 % of mothers' replies were missing, whereas for fathers, this number was 33 %). Therefore, only mothers' self-reports were analyzed (except for the family risk questionnaire, explained in more detail in the section "Familial risk for RD and MD" below).

#### 2.2.1. *Reading fluency*

The measure of reading fluency comprised three standard group-administered tests. The first test was an 80-item word-reading task that is part of the nationally standardized reading test (ALLU; Lindeman, 2000). Each item offered a picture along with four phonologically similar written words. The task was to read the words silently and select the one that semantically matched the picture. Participants were allotted 2 min to complete this task, and their score was the sum of all correct answers. The pictures and words used in this test were simple and familiar to children. The second reading fluency test was a word chain task comprising 10-word chains, each with 4–6 words presented in a row without any spaces (Nevala & Lyytinen, 2000). Participants needed to read the chains silently and provide boundary lines between all words they could identify. This task was also time-limited (1.25 min in Grades 1 and 2, 1.20 min in Grade 3, 1.05 min in Grade 4, 1 min in Grades 6 and 7, and 1.30 min in Grade 9), and each participant's score was calculated as the sum of all correct answers. The third reading fluency test was a sentence reading task. In Grades 1–4, the Finnish version of the Test of Silent Reading Efficiency and Comprehension (TOSREC; Wagner et al., 2010; Finnish version by Lerkkanen & Poikkeus, 2009) was used. This task comprised 60 sentences, and the duration to complete the task was 3 min. Participants were asked to read each sentence and decide if it was true or not (e.g., apples are blue). In Grade 6, a similar task was administered—the Finnish adaptation of the Salzburg Sentence Reading Test (Pichler & Wimmer, 2006). Participants were asked to verify the truthfulness of 69 sentences in 2 min. In Grades 7 and 9, this test was replaced with a similar 3-min assessment—the standardized Finnish reading test for lower secondary school sentence reading (YKÄ; Lerkkanen et al., 2018). This test had the same instructions, but the items were designed for older children. The final sum of scores was also based on the number of correct answers. The mean of the three standardized fluency measures was used as the score. Cronbach's alpha reliability coefficients for the composite ranged in different grades between 0.78 and 0.84. The score in each grade was standardized before proceeding with analysis.

#### 2.2.2. *Arithmetic fluency*

The measure of arithmetic fluency allocated 3 min for completion and included one standardized group-administered subtest of the arithmetic test developed by Aunola and Räsänen (2007). In Grades 1–3, the measure comprised 14 addition (e.g., $2 + 4 = \_$, $5 + 3 + 7 = \_$) and 14 subtraction tasks (e.g., $8–2 = \_$, $18–5 - 4 = \_$). In Grade 4, the measure slightly changed and offered 25 addition and subtraction tasks (e.g., $117–9 + 13 = \_$; $485–42 = \_$; $1635 + 576 = \_$) as well as 1 multiplication and 2 division tasks (e.g., $40:8–3 = \_$, $240:80 = \_$, $12 \cdot 28 = \_$). In Grade 6, the measure included 23 addition and subtraction tasks, 3 division tasks, 1 multiplication task, and 1 task with decimal numbers (e.g., $106.2–30.04 = \_$). Finally, in Grades 7 and 9, the measure included 19 addition and subtraction tasks, 3 division tasks, 3 multiplication tasks, and 3 tasks with decimal numbers. The score on this measure reflected both the speed and accuracy of foundational mathematical calculations, allowing to assess children's arithmetic fluency. Cronbach's alphas varied in different grades between 0.68 and 0.94. The score in each grade was standardized before proceeding with analysis.

#### 2.2.3. *Familial risk for RD and MD*

When children were in kindergarten, mothers and fathers were asked if they themselves or their spouse had experienced learning difficulties in reading or mathematics. Responses were measured on a three-point scale: 1 (*no difficulties*), 2 (*some difficulties*), and 3 (*clear or serious difficulties*). Self-reports were given priority, whereas spouse reports were used to fill in missingness. The children were considered to be at family risk if they had at least one parent with some or clear difficulties. Although measuring parental RD and MD with a single item for each difficulty type does not capture all aspects of familial risk, previous large-scale research has shown that even a single familial risk item can be an important predictor of children's skills (Esmaeeli et al., 2019).

#### 2.2.4. *Parental education*

The parents were asked about their education level as well as that of the other parent using a seven-point scale: 1 (*no vocational education*) (5.1 % of mothers and 1.8 % of fathers), 2 (*vocational courses*) (3.1 % of mothers and 1.7 % of fathers), 3 (*vocational school degree*) (30.8 % of mothers and 14.3 % of fathers), 4 (*vocational college degree*) (23.2 % of mothers and 10.1 % of fathers), 5 (*polytechnic degree or bachelor's degree*) (9.7 % of mothers and 4.2 % of fathers), 6 (*master's degree*) (23.7 % of mothers and 8.0 % of fathers), and 7 (*licentiate or doctoral degree*) (4.4 % of mothers and 2.7 % of fathers). The information about parental education was collected when children were in kindergarten and the sum score was computed as an average of both parents' individual scores.

#### 2.2.5. *Home learning environment*

For kindergarteners, parents completed a questionnaire about the learning activities they organized at home. The questionnaire was based on items developed by Sénéchal et al. (1998) and Sénéchal (2006), which have been used successfully in the Finnish context (Silinskas et al., 2020). It included four questions about the frequency of home teaching activities (teaching letters, teaching reading, teaching numbers, and teaching arithmetic skills). In addition, the questionnaire had an item about shared reading: "How often do you read books to your child or together with your child?" All answers were given on a five-point Likert-type scale: 1 (*less than once a week*), 2 (*1–3 times a week*), 3 (*4–6 times a week*), 4 (*once a day*), and 5 (*more than once a day*). The sum scores for the three HLE and two HNE items were calculated by adding the individual scores of activities related to each domain. Cronbach's alphas for HLE and HNE were 0.79 and 0.86, respectively.

#### 2.2.6. *Parental academic assistance with literacy tasks*

In each grade, parents were asked to indicate the frequency of different literacy-related activities organized at home using a five-point scale ranging from 1 (*not at all*) to 5 (*on a daily basis*). In Grade 1, the questionnaire had two items about reading ("How often do you teach your child to read?" and "How often do you encourage your child to read independently?"). In Grades 2 and 3, the questionnaire included four items—two were the same as those in Grade 1 and two were about writing ("How often do you teach your child to write?" and "How often do you encourage your child to write independently?"). In Grade 4, in addition to the items in the previous grades, two items about parental assistance were included ("How often do you help your child with reading homework?" and "How often do you help your child with writing homework?"). In Grades 6, 7, and 9, to ensure that the questionnaire is age-appropriate in relation to school subjects, the items about reading and writing were replaced with equivalent items about Finnish language tasks. At these time points, the questionnaire included three items ("How often do you teach your child to do Finnish language tasks?", "How often do you help your child with Finnish language home assignments?", and "How often do you encourage your child to do Finnish language tasks independently?"). Similar items have been successfully used in earlier studies (e.g., Edwards, 2014; Haney & Hill, 2004; Silinskas, Kiuru, et al., 2013). Cronbach's alpha coefficients for the parental literacy assistance measure were 0.55, 0.80, 0.80, 0.89, 0.66, 0.62, and 0.63 in Grades 1, 2, 3, 4, 6, 7, and 9, respectively.

#### 2.2.7. *Parental academic assistance with numeracy tasks*

A similar five-point measure ranging from 1 (*not at all*) to 5 (*on a daily* *basis*) was used to collect information about the frequency of numeracy-related activities. In Grades 1–3, the questionnaire had two items about mathematics ("How often do you teach your child to do calculations?" and "How often do you encourage your child to do calculations independently?"). In Grade 4, one more item was added that asked about parental assistance ("How often do you help your child with calculation tasks?"). In Grades 6, 7, and 9, the items about calculations were replaced with equivalent items about mathematical tasks ("How often do you teach your child to do mathematical tasks?", "How often do you help your child with mathematical home assignments?", and "How often do you encourage your child to do mathematical tasks independently?"). The majority of these items were based on the literacy assistance items listed above (e.g., Edwards, 2014; Haney & Hill, 2004; Silinskas, Kiuru, et al., 2013) and have been used previously by Silinskas et al., 2010. Cronbach's alpha coefficients for the parental numeracy assistance measure were 0.67, 0.76, 0.72, 0.81, 0.73, 0.70, and 0.69 in Grades 1, 2, 3, 4, 6, 7, and 9, respectively.

### 2.3. Statistical analysis

A preliminary step was data preparation: the whole sample was checked for entry errors and outliers. Using Mahalanobis distance test, we identified and deleted 13 multivariate outliers. We then examined the patterns of missing data. Little's test of missing completely at random (which included all questionnaire items of literacy- and numeracy-related activities organized at home) confirmed that mothers' home activities reports were missing at random ($\chi^2$ (5068) = 5051.034, $p$ = .564), indicating that all mothers were equally likely to submit self-reports at different time points. Another Little's MCAR test was conducted (which included all reading and arithmetic fluency assessments from Grades 1 to 9) to determine whether children's skill performance was associated with the likeliness of data missingness. Results showed that children who performed lower in reading ($\chi^2$ (165) = 314.477, $p <$ .001) and in math ($\chi^2$ (178) = 339.301, $p <$ .001) were more likely to not be included in each wave of the study. More details on missing values can be found in Appendix 1.

Next, to answer the first research question and to examine the patterns of developmental progress that preceded students' graduation from a comprehensive school with below grade level foundational academic skills (reading and arithmetic fluency difficulties in grade 9), we ran a type of mixture model (LPA; Oberski, 2016) (Fig. 1). For this type of analysis, we decided not to use the whole sample ($N$ = 2151) because of the large variability in reading and arithmetic fluency present in a general population sample. This large variability can potentially prevent LPA from identifying distinct profiles that might exist in the data (see Huijsmans et al. (2020), who provided an example of such problem occurring in LPA). In view of this, we started our analysis by separating low performers from the rest of the sample to ensure that LPA could retrieve distinct profiles from the population of interest—that is, the participants with learning difficulties at the end of comprehensive school. Composite scores for reading fluency in Grade 9 and arithmetic fluency in Grade 9 were calculated and everyone who performed at least one standard deviation below the mean (the mean was calculated based on the whole sample) in either reading fluency or arithmetic fluency were considered to be a low-performing adolescent. In total, the scores of 391 adolescents were below the cut-off for reading fluency, arithmetic fluency, or both. Table 1 presents the descriptive statistics for this group.

Once the population of interest was selected (those graduating from school with low foundational academic skills), LPA was conducted for these 391 participants. Based on their performance on all reading and arithmetic fluency tasks (using continuous standardized variables) across all seven time points (Grades 1–9), we examined whether distinct profiles existed (Muthen, 2001) using Mplus version 7.3. Seven indicators for reading fluency and seven indicators for arithmetic fluency (one for each time point) were entered into our mixture model as indicators. The number of indicators were deemed appropriate for this research questions based on the findings of Wurpts and Geiser (2014), which established that adding more indicators in mixture models improves their performance and can compensate for small sample sizes. Our mixture model performed well without running into any problems

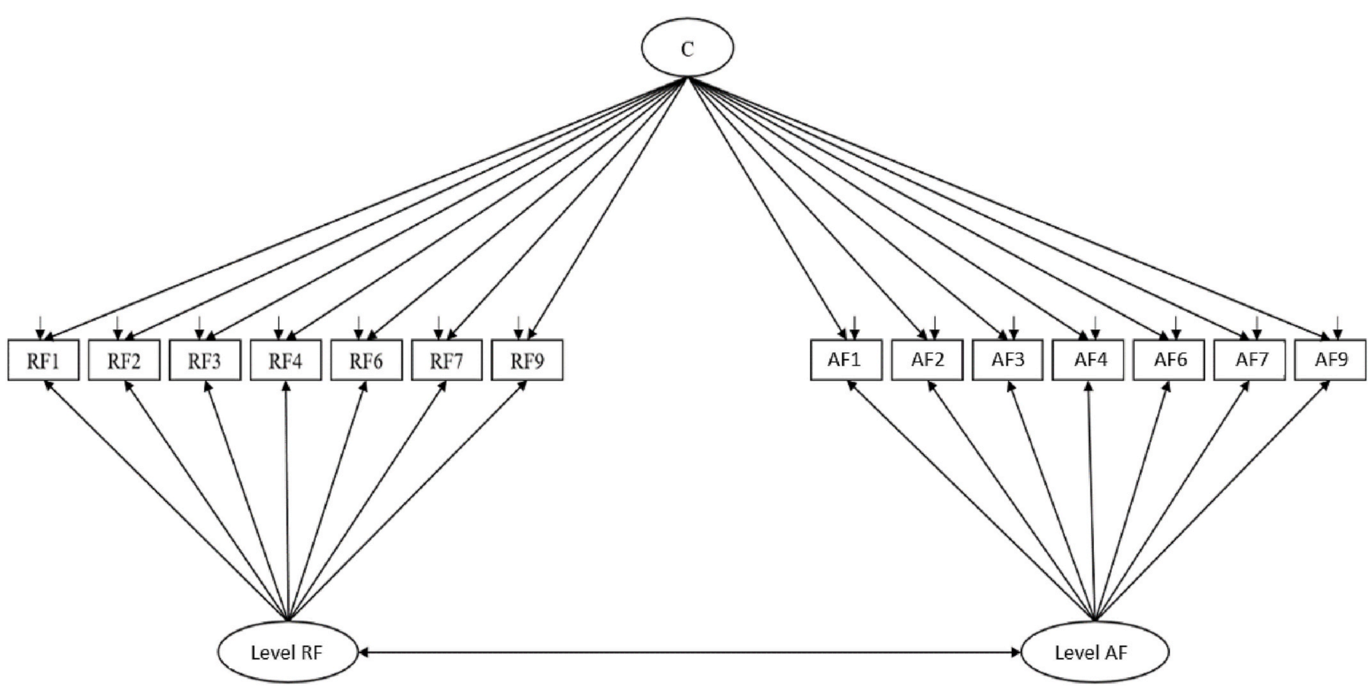


**Fig. 1.** Latent profile analysis model for the reading and arithmetic fluency measures.
*Note.* C represents the latent profiles, Level RF and Level AF represent the initial level of reading fluency (RF) and arithmetic fluency (AF). Numbers next to RF and AF indicate the assessment time point (grade).

**Table 1**
Descriptive statistics for all variables across time.

| | Whole sample | | | | | | | Low performers only | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Minimum | Maximum | Mean | SD | Skewness (std. error) | Kurtosis (std. error) | N | Minimum | Maximum | Mean | SD | Skewness (std. error) | Kurtosis (std. error) |
| Reading fluency (z-scores) | | | | | | | | | | | | | | |
| Grade 1 | 2037 | −2.44 | 4.02 | 0.00 | 1.00 | 0.62 (0.05) | 0.44 (0.11) | 276 | −1.98 | 2.03 | −0.54 | 0.68 | 0.55 (0.15) | 0.14 (0.29) |
| Grade 2 | 1991 | −2.89 | 3.89 | 0.00 | 1.00 | 0.26 (0.05) | 0.23 (0.11) | 280 | −2.16 | 2.69 | −0.58 | 0.74 | 0.47 (0.15) | 1.39 (0.29) |
| Grade 3 | 1980 | −4.42 | 3.19 | 0.00 | 1.00 | −0.04 (0.05) | 0.43 (0.11) | 287 | −2.72 | 2.46 | −0.59 | 0.83 | 0.47 (0.14) | 0.66 (0.29) |
| Grade 4 | 1939 | −4.62 | 2.76 | 0.00 | 1.00 | −0.17 (0.05) | −0.30 (0.11) | 286 | −2.64 | 2.16 | −0.62 | 0.84 | 0.34 (0.14) | 0.16 (0.29) |
| Grade 6 | 1807 | −3.58 | 3.28 | 0.00 | 1.00 | 0.10 (0.05) | −0.11 (0.11) | 365 | −2.92 | 2.61 | −0.75 | 0.90 | 0.58 (0.13) | 0.76 (0.25) |
| Grade 7 | 1755 | −4.20 | 3.04 | 0.00 | 1.00 | −0.07 (0.05) | −0.00 (0.12) | 369 | −4.13 | 2.11 | −0.87 | 0.90 | 0.25 (0.13) | 0.47 (0.25) |
| Grade 9 | 1706 | −2.98 | 2.99 | 0.00 | 1.00 | −0.09 (0.05) | −0.14 (0.12) | 391 | −2.98 | 2.88 | −1.02 | 0.93 | 0.82 (0.12) | 1.12 (0.25) |
| Arithmetic fluency (z-scores) | | | | | | | | | | | | | | |
| Grade 1 | 2035 | −2.55 | 4.25 | 0.00 | 1.00 | 0.33 (0.05) | 0.26 (0.11) | 275 | −2.55 | 2.07 | −0.44 | 0.78 | 0.25 (0.15) | −0.16 (0.29) |
| Grade 2 | 1986 | −3.28 | 2.44 | 0.00 | 1.00 | −0.09 (0.05) | −0.46 (0.11) | 278 | −2.47 | 1.83 | −0.53 | 0.86 | 0.27 (0.15) | −0.32 (0.29) |
| Grade 3 | 1979 | −4.25 | 1.82 | 0.00 | 1.00 | −0.64 (0.05) | 0.45 (0.11) | 287 | −3.39 | 1.60 | −0.56 | 0.96 | −0.07 (0.14) | −0.25 (0.29) |
| Grade 4 | 1938 | −4.18 | 2.44 | 0.00 | 1.00 | −0.63 (0.06) | 0.80 (0.11) | 286 | −3.20 | 1.71 | −0.65 | 0.89 | −0.33 (0.14) | 0.35 (0.29) |
| Grade 6 | 1802 | −4.14 | 2.63 | 0.00 | 1.00 | −0.27 (0.06) | 0.17 (0.11) | 365 | −4.14 | 2.09 | −0.80 | 0.88 | −0.21 (0.13) | 0.53 (0.25) |
| Grade 7 | 1734 | −3.61 | 3.50 | 0.00 | 1.00 | −0.16 (0.06) | 0.35 (0.12) | 367 | −3.61 | 1.39 | −0.81 | 0.86 | −0.06 (0.13) | 0.22 (0.25) |
| Grade 9 | 1690 | −3.56 | 3.09 | 0.00 | 1.00 | −0.11 (0.06) | 0.02 (0.12) | 391 | −3.56 | 1.56 | −1.03 | 0.88 | 0.41 (0.12) | 0.43 (0.25) |
| Parental academic assistance with literacy tasks (mean composites of items) | | | | | | | | | | | | | | |
| Grade 1 | 1474 | 1 | 5 | 2.94 | 0.91 | 0.19 (0.06) | −0.39 (0.13) | 203 | 1 | 5 | 3.24 | 0.91 | 0.28 (0.17) | −0.29 (0.34) |
| Grade 2 | 1430 | 1 | 5 | 2.29 | 1.05 | 0.69 (0.06) | 0.24 (0.13) | 200 | 1 | 5 | 2.60 | 0.83 | 0.44 (0.17) | −0.15 (0.34) |
| Grade 3 | 1360 | 1 | 5 | 2.06 | 0.95 | 0.79 (0.07) | 0.76 (0.13) | 198 | 1 | 4.50 | 2.31 | 0.72 | 0.64 (0.17) | 0.52 (0.34) |
| Grade 4 | 1269 | 1 | 5 | 1.85 | 0.97 | 0.92 (0.07) | 1.19 (0.14) | 187 | 1 | 4.50 | 2.05 | 0.67 | 0.55 (0.18) | 0.59 (0.35) |
| Grade 6 | 999 | 1 | 4 | 1.95 | 0.59 | 0.29 (0.08) | −0.08 (0.15) | 182 | 1 | 4 | 2.19 | 0.53 | 0.22 (0.18) | 0.73 (0.36) |
| Grade 7 | 768 | 1 | 3.67 | 1.83 | 0.57 | 0.30 (0.08) | −0.33 (0.18) | 141 | 1 | 3.67 | 2.03 | 0.57 | 0.11 (0.20) | −0.08 (0.41) |
| Grade 9 | 892 | 1 | 4 | 1.73 | 0.54 | 0.45 (0.08) | 0.02 (0.16) | 169 | 1 | 3.33 | 1.87 | 0.53 | 0.10 (0.19) | −0.44 (0.37) |
| Parental academic assistance with numeracy tasks (mean composites of items) | | | | | | | | | | | | | | |
| Grade 1 | 1470 | 1 | 5 | 2.93 | 0.89 | 0.13 (0.06) | −0.47 (0.13) | 202 | 1 | 5 | 3.18 | 0.93 | 0.10 (0.17) | −0.53 (0.34) |
| Grade 2 | 1440 | 1 | 5 | 2.45 | 0.91 | 0.44 (0.06) | −0.23 (0.13) | 203 | 1 | 5 | 2.77 | 0.96 | 0.23 (0.17) | −0.53 (0.34) |
| Grade 3 | 1362 | 1 | 5 | 2.31 | 0.82 | 0.49 (0.07) | 0.22 (0.13) | 197 | 1 | 4.50 | 2.55 | 0.77 | 0.18 (0.17) | −0.60 (0.34) |
| Grade 4 | 1280 | 1 | 5 | 2.16 | 0.76 | 0.68 (0.07) | 0.50 (0.14) | 188 | 1 | 5 | 2.42 | 0.78 | 0.54 (0.18) | 0.45 (0.35) |
| Grade 6 | 987 | 1 | 4.67 | 2.07 | 0.66 | 0.39 (0.08) | 0.20 (0.16) | 180 | 1 | 4 | 2.33 | 0.66 | 0.41 (0.18) | 0.26 (0.36) |
| Grade 7 | 765 | 1 | 5 | 1.90 | 0.65 | 0.57 (0.09) | 0.50 (0.18) | 140 | 1 | 3.57 | 2.09 | 0.66 | 0.10 (0.20) | −0.59 (0.41) |
| Grade 9 | 890 | 1 | 4 | 1.71 | 0.61 | 0.73 (0.08) | 0.45 (0.16) | 169 | 1 | 4 | 1.93 | 0.60 | 0.37 (0.19) | 0.12 (0.37) |

leading us to conclude that we had an adequate balance between the sample size and model indicators. Maximum likelihood with robust standard errors was used to estimate model parameters. Moreover, missing data was handled using full information maximum likelihood estimation (FIML). Mixture models do not have one commonly accepted criterion for deciding the number of classes (profiles); therefore, we relied on several statistical information criteria as well as on the interpretability of the final solution and graphic presentations of all possible solutions to decide the number of classes (profiles indicated by the model) (Yu & Park, 2014). Note that theory and past findings play an important role in the decision (Berlin et al., 2014; Geiser, 2012).

Next, we validated the classification by conducting repeated measures analysis of variance (ANOVA) on children's skills. To determine whether children's RD and MD were associated with family-related variables, we conducted chi-square tests and ANOVAs. This second part of the analysis was conducted in SPSS Statistics 26.

Finally, using the "three-step approach" we added all family-related factors as predictors to our mixture model (Asparouhov & Muthén, 2014). This statistical approach allows covariates to be tested as predictors of latent profiles in a multinomial logistic regression by using the Bolck-Croon-Hagernaars (BCH) method (Asparouhov & Muthén, 2014; Bakk et al., 2016). The BCH method uses weights based on the posterior probabilities to adjust for classification error. To analyze the relative contribution of each predictor to the identified latent profiles, we conducted hierarchical regression analyses in a structural equation modeling (SEM) framework by applying a Cholesky model (De Jong, 1999). Two separate Cholesky models were used, one model examined the relative contribution of the factors related to literacy (parental reading difficulties, teaching literacy at home when children were in kindergarten, parental assistance with literacy tasks in Grades 1–9, parental education) and the other model examined the relative contribution of the factors related to numeracy (parental math difficulties, teaching numeracy at home when children were in kindergarten, parental assistance with numeracy tasks in Grades 1–9, parental education). Parental education was treated as a general control measure and thus entered in both models. Maximum likelihood estimation with robust standard errors (MLR) was used as estimator for the analysis.

The second half of our analysis that included family-related factors (using chi-square tests, ANOVAs, and the three-step approach) was performed to answer the second research question. All these analytical procedures were performed with the same goal in mind, but they had important differences. Compared to ANOVAs and chi-square tests the three-step approach is a more reliable method to identify factors that are significantly associated with latent profiles, however in the present study the three-step approach could not include typical performers for comparison (this was only possible in ANOVAs). Thus, only the combination of different statistical approaches allowed us to answer the second research question comprehensively.

## 3. Results

### 3.1. Descriptive statistics and group comparisons

Table 1 presents the descriptive statistics for children's skills and parental academic assistance measures for all participants. All of the measure distributions were close to normal distribution.

### 3.2. Identification of patterns within development leading to RD and MD in Grade 9

To examine the presence of differential patterns within skill development that lead to RD, MD, or both in Grade 9, we ran a series of LPA models. Fig. 1 depicts the LPA model, and Table 2 describes the LPA model outcomes for the first six profiling solutions. Models beyond six profiles became unstable and fitted the data poorly. Six- and five-profile models each had one very small profile (containing only seven people, which is <2 % of the sample). In the four-profile model, the average latent class probabilities declined below 0.80, suggesting greater uncertainty for this profile solution. In addition, BIC started increasing in the four-profile model, indicating a worsening fit, which continued through to the five and six profile models. The two-profile model had the highest entropy, and LMR and VLMR *p*-values suggested that two profiles are sufficient. However, the three-profile model had the lowest BIC value. We chose the three-profile model instead of the two-profile for two reasons. First, BIC has been reported to be the most efficient indicator for deciding the number of latent classes (profiles) (Yu & Park, 2014), especially when dealing with continuous variables (Fonseca & Cardoso, 2007). Second, the three-profile model was better fitted to theory, which is a strong argument in its favor (Geiser, 2012), because it included a distinct comorbid group whereas the two-profile model did not.

The first profile ($N = 121$) was named Reading Difficulties (RD), as the participants in this profile demonstrated low reading fluency but average arithmetic fluency. The second profile ($N = 176$) was named Reading and Mathematical Difficulties (RD&MD), as it was characterized by low reading and arithmetic fluency. Finally, the third profile ($N = 94$) was named Mathematical Difficulties (MD) in view of the participants having low arithmetic fluency but average reading fluency.

Fig. 2 shows the reading and arithmetic fluency development in the low-performing profiles contrasted with typical performers. As can be seen in both Fig. 2 and Table 3, children with only RD significantly underperformed not only in reading fluency tasks but also in arithmetic

**Table 2**
Fit indices for latent profile analyses (low performers only, $N = 391$).

| Number of profiles | BIC | aBIC | AIC | Entropy | p-Value of LMR | p-Value of VLMR | n in class 1 (ALCP) | n in class 2 (ALCP) | n in class 3 (ALCP) | n class 4 (ALCP) | n class 5 (ALCP) | n class 6 (ALCP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10,448.398 | 10,311.961 | 10,277.744 | | | | | | | | | |
| 2 | 10,304.732 | 10,120.701 | 10,074.547 | 0.83 | 0.0010 | 0.0010 | 287 (0.964) | 104 (0.925) | | | | |
| 3 | 10,278.694 | 10,047.068 | 9988.978 | 0.73 | 0.3347 | 0.3303 | 176 (0.853) | 121 (0.893) | 94 (0.902) | | | |
| 4 | 10,293.652 | 10,014.433 | 9944.406 | 0.72 | 0.1931 | 0.1902 | 79 (0.809) | 109 (0.776) | 82 (0.908) | 121 (0.875) | | |
| 5 | 10,316.166 | 9989.352 | 9907.390 | 0.76 | 0.8263 | 0.8258 | 57 (0.89) | 204 (0.84) | 70 (0.80) | 53 (0.84) | 7 (0.96) | |
| 6 | 10,340.258 | 9965.85 | 9871.951 | 0.77 | 0.2548 | 0.2542 | 160 (0.81) | 24 (0.88) | 64 (0.82) | 78 (0.88) | 58 (0.83) | 7 (0.97) |

*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; ALCP = Average Latent Class Probabilities for Most Likely Latent Class Membership by Latent Class.

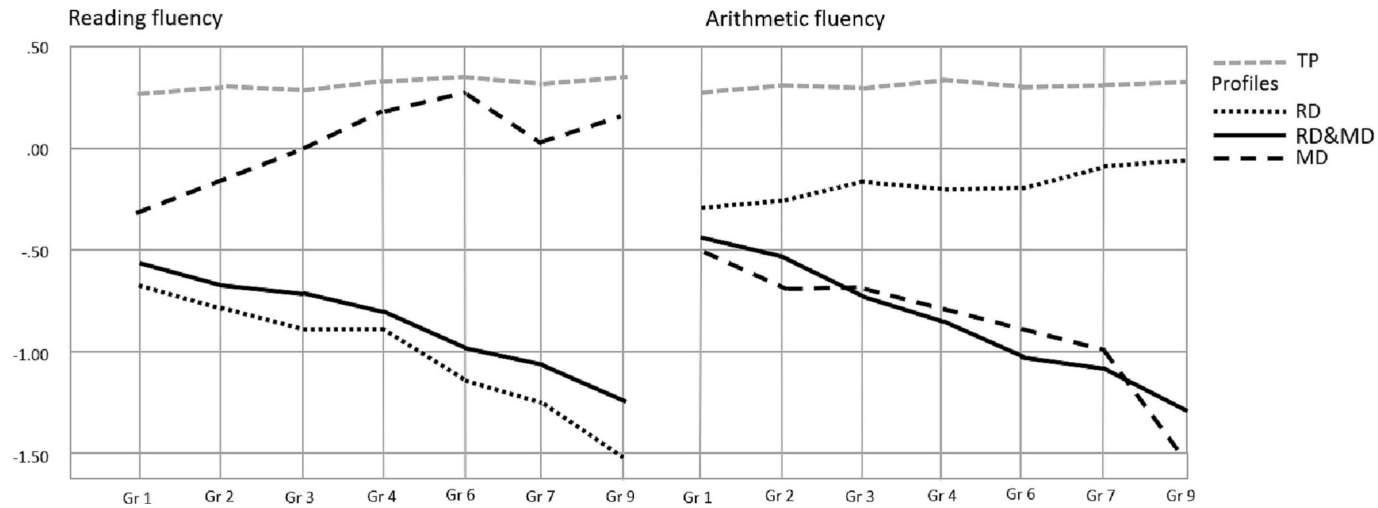


**Fig. 2.** Reading fluency (z-scores) and arithmetic fluency (z-scores) longitudinal pathways of different profiles across the seven time points.
*Note*. RD = Reading Difficulty Profile; MD = Mathematical Difficulty Profile; RD&MD = Comorbidity Profile; TP = typical performers (added here for comparison but was not identified in LPA). Even though children's skills across all profiles were continuously developing over time, the graph shows some downward patterns. This is because standardized scores for age-appropriate measures were used for plotting this line graph, representing the relative performance compared to grade level peers.

**Table 3**
Descriptive statistics and ANOVA comparisons for skill measures (z-scores) of different profiles.

| Measures | Time point | Typical performers (TP) | | RD | | RD&MD | | MD | | F | Partial eta sq | Significant pairwise differences between profiles (Bonferroni comparisons) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | M (SD) | N | M (SD) | N | M (SD) | N | M (SD) | | | |
| Reading fluency | Gr 1 | 1761 | 0.08 (1.01) | 99 | −0.69 (0.65) | 109 | −0.61 (0.60) | 68 | −0.23 (0.76) | 36.43*** | 0.05 | RD, RD&MD < TP; RD < MD |
| | Gr 2 | 1711 | 0.09 (1.00) | 100 | −0.79 (0.68) | 111 | −0.69 (0.64) | 69 | −0.09 (0.75) | 46.76*** | 0.07 | RD, RD&MD < TP, MD |
| | Gr 3 | 1693 | 0.10 (0.99) | 103 | −0.90 (0.67) | 112 | −0.72 (0.73) | 72 | −0.06 (0.84) | 57.68*** | 0.08 | RD, RD&MD < TP, MD |
| | Gr 4 | 1653 | 0.10 (0.99) | 103 | −0.93 (0.71) | 113 | −0.83 (0.67) | 70 | 0.18 (0.74) | 69.33*** | 0.10 | RD, RD&MD < TP, MD |
| | Gr 6 | 1442 | 0.19 (0.93) | 116 | −1.13 (0.61) | 158 | −1.06 (0.68) | 91 | 0.27 (0.76) | 162.90*** | 0.21 | RD, RD&MD < TP, MD |
| | Gr 7 | 1386 | 0.23 (0.89) | 117 | −1.30 (0.67) | 160 | −1.12 (0.73) | 92 | 0.12 (0.67) | 214.86*** | 0.27 | RD, RD&MD < TP, MD |
| | Gr 9 | 1315 | 0.30 (0.80) | 121 | −1.55 (0.43) | 176 | −1.34 (0.59) | 94 | 0.27 (0.68) | 427.01*** | 0.43 | RD, RD&MD < TP, MD |
| Arithmetic fluency | Gr 1 | 1760 | 0.07 (1.01) | 99 | −0.33 (0.89) | 108 | −0.47 (0.74) | 68 | −0.55 (0.67) | 21.87*** | 0.03 | RD, MD, RD&MD < TP |
| | Gr 2 | 1708 | 0.09 (0.99) | 100 | −0.31 (0.90) | 109 | −0.60 (0.89) | 69 | −0.74 (0.68) | 34.60*** | 0.05 | RD, MD, RD&MD < TP; MD < RD |
| | Gr 3 | 1692 | 0.09 (0.97) | 103 | −0.19 (1.00) | 112 | −0.80 (0.93) | 72 | −0.74 (0.79) | 46.32*** | 0.07 | RD, MD, RD&MD < TP; RD&MD, MD < RD |
| | Gr 4 | 1652 | 0.11 (0.97) | 103 | −0.23 (0.85) | 113 | −0.91 (0.87) | 70 | −0.84 (0.72) | 61.76*** | 0.09 | RD, MD, RD&MD < TP; RD&MD, MD < RD |
| | Gr 6 | 1437 | 0.20 (0.92) | 115 | −0.18 (0.72) | 159 | −1.12 (0.87) | 91 | −1.01 (0.64) | 147.67*** | 0.20 | RD, MD, RD&MD < TP; RD&MD, MD < RD |
| | Gr 7 | 1367 | 0.22 (0.92) | 115 | −0.07 (0.65) | 160 | −1.18 (0.73) | 92 | −1.08 (0.71) | 170.45*** | 0.23 | RD, MD, RD&MD < TP; RD&MD, MD < RD |
| | Gr 9 | 1299 | 0.31 (0.81) | 121 | −0.05 (0.63) | 176 | −1.40 (0.63) | 94 | −1.59 (0.38) | 405.09*** | 0.42 | RD, MD, RD&MD < TP; RD&MD, MD < RD |

*Note*. * p<.05, ** p<.01, *** p<.001.

fluency tasks compared with typical performers over all time points. However, RD gradually made more gains in arithmetic fluency than MD and RD&MD and progressed towards the skill level of typical performers by grade 9. Similarly, Fig. 2 suggests that children in early grades with only MD performed worse than typical performers in reading fluency tasks; however, the difference between these groups was not statistically significant (Table 3). Moreover, RD and MD gradually diverged in their skill gains (children with RD caught up with typical performers in arithmetic fluency, whereas children with MD only narrowed the gap with typical performers in reading fluency). RD&MD lagged increasingly on both skills over all time points. In view of the use of standardized reading and arithmetic scores, the downward patterns seen in Fig. 2 indicate a growing gap in grade level performance across the profiles, but they do not imply actual skill deterioration.

### 3.3. Profile differences in parental characteristics

First, chi-square tests were performed to examine the relationship between parental difficulties (family risk) and profile membership, including typical performers (Table 4). Family risk for RD was not

**Table 4**
Numbers (and percentages) of children with RD, MD, RD&MD, and typical performance in Grade 9 according to risk group (no family risk and family risk for either reading or mathematical difficulties).

| Profiles | Family risk for reading difficulties | | Family risk for mathematical difficulties | |
|---|---|---|---|---|
| | No, N (% within the profile), ASE | Yes, N (% within the profile), ASE | No, N (% within the profile), ASE | Yes, N (% within the profile), ASE |
| TP | 904 (68.4 %), 2.3 | 417 (31.6 %), −2.3 | 890 (67.2 %), 3.2 | 434 (32.8 %), −3.2 |
| RD | 45 (60.0 %), −1.4 | 30 (40.0 %), 1.4 | 41 (56.9 %), −1.6 | 31 (43.1 %), 1.6 |
| MD | 27 (56.3 %), −1.7 | 21 (43.8 %), 1.7 | 24 (46.2 %), −3.0 | 28 (53.8 %), 3.0 |
| RD&MD | 52 (63.4 %), −0.8 | 30 (36.6 %), 0.8 | 51 (61.4 %), −0.8 | 32 (38.6 %), 0.8 |
| Total | 1028 (100 %) | 498 (100 %) | 1006 (100 %) | 525 (100 %) |

*Note.* TP = typical performers; RD = reading difficulties; MD = mathematics difficulties; RD&MD = comorbid RD and MD; ASE = adjusted standardized errors.

associated with profile membership, $\chi^2$ (3, $n$ = 1526) = 5.81, $p$ = .121, whereas family risk for MD was $\chi^2$ (3, $n$ = 1531) = 13.29, $p$ = .004. The adjusted standardized errors suggest that family risk for MD was higher than expected by chance in MD and lower than expected by chance among typical performers. Of all MD profile members (with information on family risk for MD available), 28 out of 52 (53.8 %) had family risk for MD. Participants with family risk for MD were also significantly less likely to be typical performers in Grade 9 than those without family risk for MD; nevertheless, 82.7 % of them were typical performers. In comparison, of all the participants without family risk for MD, 88.5 % were typical performers. No statistically significant differences were found in the proportions of children ending up with RD or RD&MD depending on their family risk for MD.

Second, a one-way ANOVA (Table 5) was conducted to test for the differences in parental education levels between the profiles and typical performers. Results showed a weak but significant association between child profile and parental education (F(3, 1480) = 3.306, $p$ = .020, partial eta-squared = 0.01). The Bonferroni-corrected paired comparisons indicated that parental education in RD&MD was significantly lower than that in the group of typical performers. Effect size (Cohen's d) was small (0.31) for the typical performers and RD&MD group difference in education (Table 6). No statistically significant differences between other profiles were observed. To ensure that the large size of the typically performing group (compared with the low-performing profiles) did not influence the results, we conducted separate ANOVAs with and without typical performers, and the results were the same.

**Table 5**
ANOVA comparisons of home learning activities and parental education between the profiles.

| Measures | Time point | Typical performers (TP) | | RD | | RD&MD | | MD | | F | Partial eta sq | Significant pairwise differences between profiles (Bonferroni comparisons) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | M (SD) | N | M (SD) | N | M (SD) | N | M (SD) | | | |
| Literacy teaching | K | 1344 | 2.59 (0.90) | 75 | 2.39 (0.69) | 83 | 2.53 (0.83) | 53 | 2.81 (0.90) | 2.56 | 0.00 | RD < MD |
| Shared reading | K | 1337 | 2.92 (1.15) | 73 | 2.86 (1.12) | 83 | 2.72 (1.14) | 53 | 3.09 (1.13) | 1.26 | 0.00 | |
| Parental assistance with literacy tasks | Gr 1 | 1259 | 2.90 (0.90) | 71 | 3.14 (0.91) | 81 | 3.35 (0.95) | 51 | 3.19 (0.85) | 8.80*** | 0.02 | TP < RD&MD |
| | Gr 2 | 1218 | 1.94 (1.04) | 75 | 2.37 (0.94) | 75 | 2.51 (1.13) | 50 | 2.26 (1.01) | 11.53*** | 0.02 | TP < RD, RD&MD |
| | Gr 3 | 1151 | 1.70 (0.94) | 74 | 2.12 (0.92) | 75 | 2.18 (0.90) | 49 | 1.91 (0.99) | 10.45*** | 0.02 | TP < RD, RD&MD |
| | Gr 4 | 1073 | 1.45 (0.97) | 67 | 1.77 (0.97) | 75 | 1.90 (0.90) | 45 | 1.60 (1.05) | 8.38*** | 0.02 | TP < RD, RD&MD |
| | Gr 6 | 808 | 1.89 (0.59) | 64 | 2.10 (0.57) | 70 | 2.23 (0.53) | 48 | 2.24 (0.48) | 13.38*** | 0.04 | TP < RD, RD&MD, MD |
| | Gr 7 | 616 | 1.78 (0.56) | 48 | 2.05 (0.55) | 52 | 2.03 (0.53) | 41 | 2.01 (0.66) | 7.60*** | 0.03 | TP < RD, RD&MD |
| | Gr 9 | 714 | 1.70 (0.54) | 62 | 1.90 (0.48) | 61 | 1.86 (0.54) | 46 | 1.84 (0.56) | 4.41** | 0.01 | TP < RD |
| Numeracy teaching | K | 1345 | 2.59 (0.85) | 75 | 2.51 (0.74) | 83 | 2.61 (0.87) | 52 | 2.64 (0.92) | 0.29 | 0.00 | |
| Parental assistance with numeracy tasks | Gr 1 | 1256 | 2.90 (0.88) | 71 | 2.93 (0.98) | 80 | 3.37 (0.88) | 51 | 3.22 (0.87) | 8.91*** | 0.02 | TP, RD < RD&MD |
| | Gr 2 | 1225 | 2.26 (1.10) | 76 | 2.36 (1.00) | 77 | 2.74 (1.23) | 50 | 3.10 (0.91) | 13.42*** | 0.03 | TP < RD&MD, MD, RD < MD |
| | Gr 3 | 1154 | 2.12 (1.03) | 74 | 2.28 (0.81) | 75 | 2.65 (0.84) | 48 | 2.58 (0.93) | 9.70*** | 0.02 | TP < RD&MD, MD |
| | Gr 4 | 1083 | 1.92 (0.99) | 68 | 2.05 (0.97) | 76 | 2.42 (0.91) | 44 | 2.61 (0.80) | 12.42*** | 0.03 | TP < RD&MD, MD; RD < MD |
| | Gr 6 | 798 | 2.01 (0.64) | 63 | 2.15 (0.69) | 70 | 2.28 (0.59) | 47 | 2.64 (0.59) | 17.65*** | 0.05 | TP < RD&MD, MD; RD&MD, RD < MD |
| | Gr 7 | 614 | 1.85 (0.64) | 47 | 2.02 (0.59) | 52 | 2.13 (0.68) | 41 | 2.12 (0.72) | 5.60** | 0.02 | TP < RD&MD, MD |
| | Gr 9 | 712 | 1.66 (0.60) | 62 | 1.88 (0.52) | 61 | 1.98 (0.70) | 46 | 1.93 (0.57) | 9.12*** | 0.03 | TP < RD, RD&MD, MD |
| Parental education | K | 932 | 3.46 (1.39) | 51 | 3.20 (1.41) | 54 | 3.05 (1.29) | 30 | 3.20 (1.09) | 2.28 | 0.00 | |

*Note.* * p<.05, ** p<.01, *** p<.001.

**Table 6**
Effect sizes of differences (Cohen's ds) between home learning activities and parental education across the profiles.

| Measures | Time point | TP vs RD | TP vs MD | TP vs RD&MD | RD vs MD | RD vs RD&MD | MD vs RD&MD |
|---|---|---|---|---|---|---|---|
| Literacy teaching | Gr 1 | 0.27 | 0.33 | 0.49 | 0.06 | 0.23 | 0.18 |
| Shared reading | Gr 2 | 0.43 | 0.31 | **0.52** | 0.11 | 0.13 | 0.23 |
| Parental assistance with literacy tasks | Gr 3 | 0.45 | 0.22 | **0.52** | 0.22 | 0.07 | 0.29 |
| | Gr 4 | 0.33 | 0.15 | 0.48 | 0.17 | 0.14 | 0.31 |
| | Gr 6 | 0.36 | **0.65** | **0.61** | 0.27 | 0.24 | 0.02 |
| | Gr 7 | 0.49 | 0.38 | 0.46 | 0.07 | 0.04 | 0.03 |
| | Gr 9 | 0.39 | 0.25 | 0.30 | 0.12 | 0.08 | 0.04 |
| Numeracy teaching | Gr 1 | 0.03 | 0.37 | **0.53** | 0.31 | 0.47 | 0.17 |
| Parental assistance with numeracy tasks | Gr 2 | 0.10 | **0.83** | 0.41 | **0.77** | 0.34 | 0.33 |
| | Gr 3 | 0.17 | 0.47 | **0.56** | 0.34 | 0.45 | 0.08 |
| | Gr 4 | 0.13 | **0.77** | **0.53** | **0.63** | 0.39 | 0.22 |
| | Gr 6 | 0.21 | **1.02** | 0.44 | **0.76** | 0.20 | **0.61** |
| | Gr 7 | 0.28 | 0.40 | 0.42 | 0.15 | 0.17 | 0.01 |
| | Gr 9 | 0.39 | 0.46 | 0.49 | 0.09 | 0.16 | 0.08 |
| Parental education | | 0.19 | 0.21 | 0.31 | 0.00 | 0.11 | 0.13 |

*Note*. Effects that are >0.50 are highlighted with bold font.

### *3.4. Profile differences in home learning environment and parental academic assistance*

Finally, using one-way ANOVAs, we compared the profile groups and typical performers in terms of their home learning environment and parental academic assistance. Table 5 and Fig. 3 show how the academic assistance provided by parents varied over time in each group. In general, a tendency of decreasing home support over time was observed. In Grade 1, parents were supporting their children's learning on average "Once or twice a week," but the amount of support gradually decreased and reached the level of "Never" in Grade 9.

Group descriptive measures and comparisons in home support are reported in Table 5. The paired effects sizes (Cohen's d) are presented in Table 6. Significant group differences were found in the home learning activities in Grades 1–9 but not in kindergarten (the partial eta effect size was 0.00 at the first time point). The Bonferroni-corrected paired comparisons revealed that almost in all grades, typical performers received significantly less literacy assistance from parents compared with RD&MD (with an exception in Grade 9) and RD (with an exception in Grade 3). Similarly, typical performers received significantly less numeracy

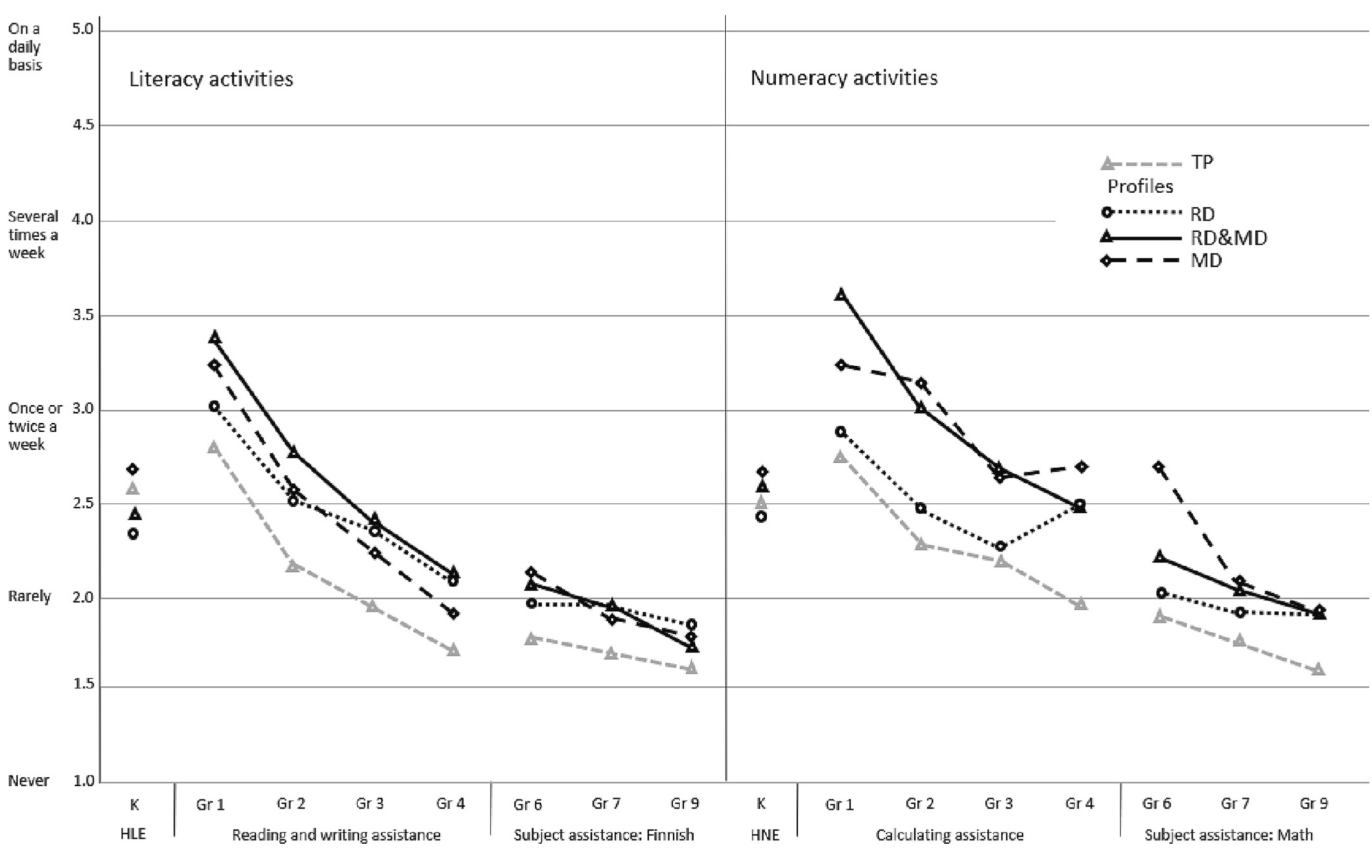


**Fig. 3.** Literacy and numeracy activities the children of the different profiles received at home across the eight time points.
*Note*. RD = Reading Difficulty Profile; MD = Mathematical Difficulty Profile; RD&MD = Comorbidity Profile; TP = typical performers; K = Kindergarten; HLE = Home Literacy Environment; HNE = Home Numeracy Environment. In the reading and writing assistance measures, writing items were included from Grade 2 onwards. In all measures tapping parental assistance, items on helping the child were included in addition to items on teaching and encouragement from Grade 4 onwards. Lines are not continuous (disrupted after Kindergarten and Grade 4) to reflect that the measures were changed to make them more age-appropriate, however the same 5-point scales were used throughout the years.

assistance at home in comparison with RD&MD and MD (with an exception in Grade 3). Overall, the effect sizes (partial eta-squared) for group differences in parental academic assistance only ranged from small to moderate (0.01–0.05). Cohen's d values (Table 6) for the pairwise comparisons indicated the strongest effects in Grades 4 and 6, especially for numeracy assistance, between typical performers and MD (d = 0.77 and 1.02, respectively) as well as between RD and MD (d = 0.63 and 0.76, respectively), with MD receiving the most of numeracy assistance. Considering that typical performers were a much larger group than the profiles of low performers, we conducted separate ANOVAs with and without typical performers. The results remained the same.

### 3.5. Profile prediction with the three step approach

The three-step approach revealed that very few family factors were significantly predictive of the low performing profiles and these additional results were generally consistent with the results that previously came from the ANOVAs and chi-square tests. Below we summarize all significant findings acquired with the three-step approach (for full details, see Appendix 2). Firstly, compared to RD, the probability of belonging to MD was significantly higher when more teaching of literacy was organized at home when children were in kindergarten. Indeed, if we compare this finding to the ANOVA results (Table 5), we see that before entering school learners in MD were receiving more literacy teaching than any other group, while learners in RD were receiving the least amount of this type of teaching. Nevertheless, in the ANOVA the difference between RD and MD was not found to be significant. Secondly, the three-step approach showed that compared to RD, the probability of belonging to RD&MD was significantly higher when more assistance with numeracy tasks was provided by parents in Grade 1. Thirdly, compared to RD, the probability of belonging to MD was significantly higher when more assistance with numeracy tasks was provided by parents in Grade 2. These two findings are fully consistent with the ANOVA results that also revealed that RD&MD and MD were receiving significantly more numeracy support than RD in Grade 1 and 2, respectively. Additionally, the three-step approach revealed that compared to RD&MD, the probability of belonging to profile MD was significantly higher when the child was at family risk for math difficulties and when more assistance with numeracy tasks was provided by parents in Grade 6. These two findings are consistent with the previous statistical tests: the chi-square tests also showed that family risk for math difficulties was significantly higher among the learners in MD, while ANOVAs also indicated that MD was receiving more numeracy teaching than any other group in Grade 6, though the difference between MD and RD&MD was not found to be significant. All in all, the three-step approach identified more significant associations between family factors and low-performers than previous statistical tests, suggesting that this statistical approach is more sensitive.

## 4. Discussion

Our main goal was to better understand how the reading and arithmetic skills of adolescents with single and co-occurring difficulties in reading and arithmetic fluency developed over time (between Grades 1 and 9). To this end, we first identified the different latent profiles leading to low foundational math and a reading skills in adolescence. Second, we tested if parental RD and MD, parents' education levels, and their engagement in literacy and numeracy tasks at home were associated with the identified profiles. This is the first study that traced the development of single and comorbid fluency difficulties over such a long period while testing a number of parental factors as potential predictors.

Three distinct profiles of low-performing children (one for each difficulty group) emerged in our analysis. Most students belonged to the MD&RD profile ($N$ = 176). The RD ($N$ = 121) profile had less students than RD&MD group, while the MD profile contained the fewest students overall ($N$ = 94). In line with previous research (Joyner & Wagner, 2020; Moll et al., 2019), we found a very high rate of co-occurring RD and MD: in Grade 9, 59 % of all adolescents with RD in the sample also demonstrated MD, whereas 65 % of those with MD showed co-occurring RD.

Contrary to our expectations, we did not retrieve separate profiles with persistent and late-emerging difficulties, which were shown to exist in some previous studies on RD (Torppa et al., 2015). Our findings rather concur with studies reporting high stability for reading (Eklund et al., 2015) and arithmetic fluency (Aunola et al., 2004). The results do not necessarily imply, however, that groups with late-emerging and persistent difficulties do not exist: these groups may have been too small in our sample of 391 low performers to be identified with LPA. Another explanation for why these profiles were not observed here could be our analytical strategy that included both reading and mathematical skills in the same model (children with persistent and late-emerging difficulties might have very similar developmental paths in the other domain, which led to them being placed together in the RD profile). This decision was nevertheless necessary, as running separate models for reading and mathematics would have prevented us from identifying the group with comorbid difficulties. Our findings also showed that skill differences between the low-performing profiles (arithmetic fluency for MD and RD&MD; reading fluency for RD and RD&MD) and typical performers gradually increased with each grade—the differences were significant but relatively small in early grades, but the gap between low performers and their typically performing peers steadily widened through Grade 9.

In addition, through Grades 1–9, the children with RD underperformed on arithmetic fluency tasks compared with typical performers, which is in line with earlier research (De Smedt & Boets, 2010; Moll et al., 2019). However, contrary to our expectation, no statistically significant difference between MD and typical performers in reading fluency was observed at any time point. Indeed, the trajectory of MD started off relatively close to that of the RD and RD&MD profiles in reading fluency, but over time it gradually reached the level of typical performers. A similar trend of catching up was seen in arithmetic fluency for RD, but they did not reach the level of typical performers during the comprehensive school follow-up period.

Does this imply that reading fluency is more important for arithmetic development, but arithmetic fluency is not so crucial for reading development? One possibility is that indeed some reading-related cognitive deficits additionally weaken children's arithmetic fluency, whereas mathematics-related cognitive deficits do not have an equivalent influence on reading fluency development. For example, two core predictors of reading, rapid naming and phonological processing, have been shown to influence the development of mathematics-related subskills, such as learning and retrieving arithmetical facts (De Smedt & Boets, 2010). At the same time, children with single RD often have intact number sense/magnitude processing skills (Moll et al., 2019), which can serve as a solid ground for good conceptual understanding in mathematics and explain why children with RD perform better in arithmetic fluency tasks than those with MD. Nevertheless, children with RD still perform calculations more slowly than typical performers (Simmons & Singleton, 2008), who have intact numerical and language skills. Further longitudinal research will help us understand how different deficits in one domain influence the skill development in the other domain.

Following profile identification, we examined whether parental characteristics, HNE and HLE, and parental academic assistance were associated with the profiles. First, children whose parents reported MD were significantly overrepresented in the MD profile. This finding is in line with previous studies on the intergenerational transmission of MD (Shalev et al., 2001). The association was rather modest, however, and most of the children with family risk owing to parental MD did not have MD (88.6 % did not have MD, and 82.8 % had neither RD nor MD). In addition, contrary to previous studies, we did not find familial risk for RD to be a significant predictor of RD or any other profile (Esmaeeli et al., 2019; Torppa et al., 2015; Van Bergen et al., 2014). This unexpected finding could be attributed to the fact that we used very short and simple parental self-reports to identify children with familial risk. Although the correlation between formally tested reading skills and self-reported difficulties (identified with a long and comprehensive questionnaire) has been reported to be as high as 0.80 (Van Bergen et al., 2014), our findings suggest that future studies on this topic should carefully consider the measures used to collect parental information.

Second, the level of parental education was significantly lower among parents of children with comorbid difficulties than among parents with typically developing children. The association between children's skills and parental education has been previously reported (Pishghadam & Zabihi, 2011); however, note that in our study, lower level of parental education was specifically predictive of the comorbid profile but not of the profiles with single difficulties. In view of this, we recommend future research on comorbidity to include parental education to better understand why this specific link with comorbid difficulties may exist.

Finally, we examined if home learning activities were associated with the identified profiles. Previous research has mostly focused on the correlations between the home learning environment and children's skills during early years of reading and mathematical development (Dong et al., 2020; Dunst et al., 2017), and little is known about their long-term associations. Our ANOVAs showed that the home learning environments measured in kindergarten did not significantly differ across the profiles, suggesting that early activities at home do not predetermine later child skill development. At the same time, a more sensitive statistical method, the three-step approach, revealed that children in MD were receiving significantly more literacy teaching than children in RD, indicating that at this time point parents to some extent avoided organizing the learning activities that corresponded to their child's specific skill deficit. This avoidance could be possibly attributed to parents having the same type of deficit. Why MD received more literacy teaching than both the RD&MD and RD groups respectively, is something that requires more investigation, however this finding suggests that there is an emphasis on early literacy activities compared to math activities before children with MD enter school.

At the same time, we observed large differences between the profiles at school in each grade based on parental academic assistance. In particular, compared with other profiles, RD and RD&MD had more literacy-related assistance, whereas MD and RD&MD received more numeracy-related assistance. This finding is consistent with previous research reporting the negative associations between parental academic assistance and child development (Hill & Tyson, 2009; Silinskas, Niemi, et al., 2013). The study by Silinskas, Niemi, et al. (2013) is especially important to consider here because they used the same dataset as we did (focusing on Grades 1 and 2 only) and found that children's academic difficulties evoked parental assistance. Our study extends their work by showing that the same negative relationship between children's skills and parental assistance continues throughout the duration of compulsory schooling (through Grade 9). Interestingly, parental assistance in Grades 1 to 9 was mostly deficit-specific in our study, indicating parental sensitivity to their children's specific academic weaknesses. In addition, the finding that profile membership is moderately associated with parental academic assistance in Grades 1–9 but only marginally associated with the home learning environment during pre-school years. We also see that these associations change to be more targeted to the children's specific deficits only after kindergarten, suggesting that parents realize the need for specific support only after their children enter school. This is in line with earlier research showing how parents reconsider and adjust their home activities when children transition to elementary school (Silinskas et al., 2010). Early deficit-specific parental assistance could be possible if pre-school children are screened for signs of potential difficulties and their parents are advised on appropriate learning activities. Finland has long been working towards developing a more effective education system for pre-school children and early screenings for learning difficulties along with teaching towards foundational skills in pre-schools are not uncommon. This work needs to be continued and expanded to allow for more targeted parental involvement that encourages home learning activities related to both literacy and numeracy prior to school entry.

Unlike some previous studies (Dumont et al., 2012; Patall et al., 2008), we did not aim to examine if parental academic assistance was beneficial for child skill development; this remains to be investigated in future. However, we noticed that although the adolescents were consistently receiving assistance that corresponded to their type of difficulties, one common trend was prevalent across the profiles: the frequency of parental assistance steadily declined over time, reaching the level of “rarely” in all low-performing profiles by Grade 9. This trend could be attributable to parents gradually realizing their inability to help their children with homework. Steadily declining parental assistance might also be reflective of children growing up and gaining more independence from their parents. Additional assistance from the education system is one way to address this situation.

## 5. Limitations and future directions

The main limitation of this study lies with its measures. Similar to most previous studies (e.g., Esmaeeli et al., 2019; Sénéchal & Lefevre, 2014; Silinskas et al., 2010), this study relied on parental self-reports on parental activities at home. However, self-reports are liable to social desirability bias. For this reason, parents may have over-reported the frequency with which they participated in learning activities together with their children. Nevertheless, self-report is a valuable research tool for studying parental activities because it provides unique insights into the home environment and is a feasible means of data collection in large samples. Research has also shown that it is important to measure not only the amount of parental involvement but also its nature and quality (Dumont et al., 2014). Moreover, many constructs related to the home environment in this study were rated very briefly (two-three items). For this reason, the results of this study should be interpreted with caution. Notably, Cronbach's alpha coefficients for parental academic assistance in Grade 1 were rather low. The most likely reason for this was that the number of items used at this time point was the lowest out of all time points. Internal consistency improved once more items were added. In view of this, we suggest that future researchers collect information about different qualitative types of parental support in addition to the measures of quantity using more extensive batteries.

Another potentially important reason to interpret the findings with caution is that the collection of the data used in the present study was completed in 2015. Recent changes to the Finnish education system could have affected how children's foundational skills are now developing reducing the relevance of our findings. For example, pre-school education has become compulsory for all Finnish children in 2015. Nevertheless, pre-school curriculums and parental recommendations are an important area of study and longitudinal research that looks across many years of development is still an invaluable tool for helping shape these recommendations based on long term outcomes.

Furthermore, we would like to highlight that our LPA allowed us to trace how different profiles were developing over years in relation to other profiles by examining the gaps in reading and arithmetic performance between the profiles at different time points. This means that our analysis offered only limited evidence in terms of individual change in the level of their skills over time. Future studies may attempt to use identical measures across years as this would enable researchers to construct growth models that would provide further insight into individual development over time. However, this might be difficult to achieve in a study with a long follow-up. In our case, during 9 years of the study children went from a complete absence of skill to proficiency and finding one measure that would work well or meaningfully represent skill maturation at all 9 time points represents a serious challenge. Moreover, the re-use of the same items 9 times is not without potential side effects.

## 6. Conclusion

The present study extends previous research on comorbidity by showing how RD, MD, and RD&MD develop over nine years of comprehensive schooling. Our unique large-scale, long-term study allowed us to observe how distinct developmental patterns leading to adolescent RD and MD emerged and gradually crystallized. In line with previous research, we found that RD and MD often co-occur—around 60 % of all children with difficulties demonstrated co-occurring difficulties in the other domain. In addition, our findings suggested that once children began school, Finnish parents provided relevant academic assistance based on the type of their children's difficulties, although this assistance consistently declined over the years. Distinct groups of learners with low reading and arithmetic fluency skills clearly exist, and this heterogeneity needs to be further investigated. Doing so will ensure earlier and more precise risk predictions and lead to differential and more effective support. Moreover, it remains to be seen what type of support would benefit learners with difficulties the most and if this support can help narrow the skill gap between typical learners and those with difficulties.

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## CRediT authorship contribution statement

**Daria Khanolainen:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Tuire Koponen:** Writing – review & editing. **Kenneth Eklund:** Supervision, Writing – review & editing. **Georgia Gerike:** Formal analysis, Writing – review & editing. **Maria Psyridou:** Formal analysis, Writing – review & editing. **Marja-Kristiina Lerkkanen:** Funding acquisition, Project administration, Methodology, Investigation, Data curation. **Mikko Aro:** Writing – review & editing. **Minna Torppa:** Conceptualization, Supervision, Formal analysis, Writing – review & editing.

## Declaration of competing interest

The authors have no conflict of interest to disclose.

## Appendices 1 and 2. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lindif.2023.102321.

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