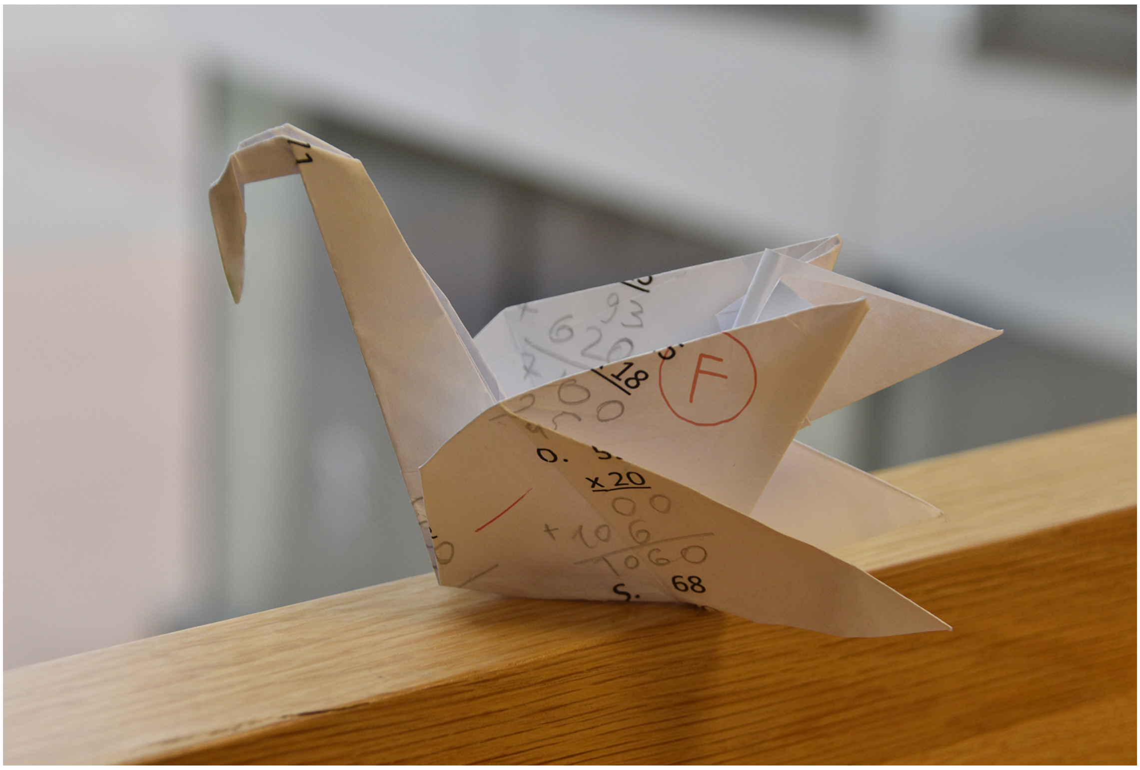
JYU DISSERTATIONS 741

Daria Khanolainen

Parental Factors in the Development of Foundational Academic Skills from Childhood to Adolescence



UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF EDUCATION AND PSYCHOLOGY

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ABSTRACT

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The present dissertation sought to examine how reading and mathematical skills developed from childhood to adolescence and how various family-related factors predicted this development. The three studies included in the dissertation addressed important knowledge gaps by utilizing multiple longitudinal data sets with unique features and extensive follow-ups. The research findings indicated that the two methods most often used for identifying parental reading difficulties (skill assessments and self-reports) yielded nearly equivalent levels of prediction for difficulties in children suggesting that the more cost- and time-efficient method, parental self-reports, could be effectively employed on a broader scale for identifying children at family risk. Importantly, however, self-reports were only as predictive as short reading assessments when they were comprehensive and included a variety of items. It was also found that parental reading and mathematical difficulties were significantly predictive of the corresponding skills in offspring measured in childhood, adolescence, and adulthood. Parental mathematical difficulties further predicted children's reading comprehension. The research findings also suggested that comorbid reading and mathematical difficulties were more prevalent than single difficulties in these domains. Moreover, the learners with single difficulties often underperformed in the other domain, most noticeably in early grades. Finally, out of all home learning activities organized with pre-school children, shared reading was the only positive predictor of children's skills measured at school age. At the same time parental academic support offered at school age was negatively associated with children's skills suggesting that parents recognized and tried to remediate their children's difficulties. Nevertheless, the gaps in skills between low-performing and typically performing children not only persisted but widened over time. Notably, parental own difficulties were not associated with the amount of any learning activities.

Keywords: reading fluency, reading comprehension, arithmetic fluency, family risk, home learning environment, reading difficulties, mathematical difficulties

TIIVISTELMÄ

Khanolainen, Daria
Perheen rooli lukemisen ja matematiikan taitojen kehityksessä lapsuudesta nuoruuteen
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Väitöskirjan tavoitteena on tutkia, miten lukutaito ja matemaattiset taidot kehittyvät lapsuudesta nuoruuteen ja miten erilaiset perheeseen liittyvät tekijät ennustavat tätä kehitystä. Väitöskirjaan sisältyneet kolme tutkimusta tarkastelivat laajoja pitkittäisaineistoja, joissa seurattiin samojen lasten kehitystä vuosien ajan. Tutkimustulokset osoittivat ensinnäkin, että kaksi yleisintä vanhempien lukivaikeuksien tunnistamiseen käytettyä menetelmää (taitoa arvioivat testit ja kyselylomakkeet) ennustivat lasten lukutaidon kehitystä yhtä hyvin. Tämä viittaa siihen, että kustannustehokkaampaa ja aikaa säästävää menetelmää, vanhempien itseraportointia, voidaan tutkimuksissa käyttää lukivaikeusriskin tunnistamiseen. On kuitenkin tärkeää huomata, että kyselylomakkeet toimivat hyvin vain, kun ne olivat kattavia ja sisälsivät monenlaisia kysymyksiä. Tutkimuksissa havaittiin myös, että vanhempien lukemis- ja matemaattiset vaikeudet ennustivat vastaavia taitoja lapsilla lapsuudessa, nuoruudessa ja varhaisaikuisuudessa. Tutkimustulokset viittasivat lisäksi siihen, että lukemisen ja matematiikan vaikeudet esiintyvät usein yhdessä ja vanhempien matemaattiset vaikeudet eivät ennustaneet vain lasten matemaattista taitoa vaan myös lasten lukemisen ymmärtämistä. Myös kodin oppimisympäristön havaittiin olevan tärkeä lasten lukutaidon ja matemaattisten taitojen kannalta. Esikouluikäisten lasten ja heidän vanhempiensa yhteinen lukeminen ennusti lasten taitoja positiivisesti kouluiässä. Oppimiseen tarjottu tuki kouluiässä oli kuitenkin negatiivisessa yhteydessä lasten taitoihin, mikä viittaa luultavasti siihen, että vanhemmat tunnistivat lastensa vaikeudet oppimisessa ja pyrkivät tukemaan heitä. Vanhempien omilla vaikeuksilla lukemisessa ja matematiikassa ei ollut yhteyttä siihen, miten usein kotona tehtiin lukemiseen ja matematiikkaan liittyviä asioita.

Avainsanat: lukutaito, tekstin ymmärtäminen, aritmeettinen sujuvuus, sukuriski, kotioppimisympäristö, lukuvaikeudet, matemaattiset vaikeudet

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Finally, before its publication, this dissertation was reviewed by Eliane Segers and Jo-Anne LeFevre. I am honored to have you as my reviewers, and I am thrilled by how positive and encouraging your feedback was. Thank you for accepting this job. I will forever be in your debt.

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LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on the following original publications:

I. Khanolainen, D., Salminen, J., Eklund, K., Lerkkanen, M. K., & Torppa, M. (2023). Intergenerational transmission of dyslexia: How do different identification methods of parental difficulties influence the conclusions regarding children's risk for dyslexia?. *Reading Research Quarterly, 58*(2), 220–239. https://doi.org/10.1002/rrq.482

II. Khanolainen, D., Psyridou, M., Silinskas, G., Lerkkanen, M. K., Niemi, P., Poikkeus, A. M., & Torppa, M. (2020). Longitudinal effects of the home learning environment and parental difficulties on reading and math development across grades 1–9. *Frontiers in psychology*, 11, 577981. https://doi.org/10.3389/fpsyg.2020.577981

III. Khanolainen, D., Koponen, T., Eklund, K., Gerike, G., Psyridou, M., Lerkkanen, M. K., Aro, M., & Torppa, M. (2023). Parental influences on the development of single and co-occurring difficulties in reading and arithmetic fluency. *Learning and Individual Differences, 105*, 102321. https://doi.org/10.1016/j.lindif.2023.102321

In all three studies, the dissertation author played an integral role in conducting statistical analysis, writing manuscripts, and handling the review process while considering all co-authors' critical comments and suggestions.

FIGURES

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CONTENTS

1 INTRODUCTION

Foundational reading and mathematical skills serve as the two most important building blocks needed for developing the higher-order skills valued in the modern professional world. Thus, educational systems across the world work towards fostering the development of strong foundational skills. In Finland, mother tongue studies and mathematics-related studies are the two subjects that have the highest number of lessons allocated in the comprehensive school curriculum (Krzywacki et al., 2016). Not all learners, however, achieve sufficient levels of reading and mathematical proficiency despite receiving adequate instruction. Indeed, both reading and mathematical difficulties are widespread, but the exact estimations vary depending on the chosen diagnostic measures and cut-off points. Roughly, up to a quarter of all children experience some form of reading and/or mathematical difficulty (Morsanyi et al., 2018). Experiencing persistent learning problems during numerous reading/mother tongue and mathematics lessons might make school an unbearable experience for some students.

Importantly, reading and mathematical difficulties have been linked with a higher predisposition for academic burnout (Parviainen et al., 2020), low academic motivation (Klauda & Guthrie, 2015), and dropout after completing compulsory education (Korhonen et al., 2014). Academic difficulties can further translate into diminished life quality in adulthood – poor foundational academic skills are a known risk factor for unemployment, lower earnings, problems with legal matters, and physical and mental health problems (Aro et al., 2019; Bouck, 2014; Bynner & Parsons, 2006; Eloranta et al., 2021; McLaughlin et al., 2014). In addition to these far-reaching negative consequences found at the individual level, low foundational academic skills impose a substantial cost on the whole society by limiting its economic growth (Organisation for Economic Co-operation and Development [OECD], 2010).

Moreover, developmental processes related to reading and mathematical skills are linked (Cirino et al., 2018), and difficulties in these domains frequently co-occur (Moll et al., 2019), which possibly places individuals at an even higher risk for poorer outcomes in life (Willcutt et al., 2019). At the same time, in research, skill development is often examined with a focus on just one of the domains, which prevents researchers from seeing the full picture of skill development. It is also worth noting that the first years of life are a sensitive period – early identification and support that is delivered before children fall behind represent the most effective course of action for reducing academic failure (Cavanaugh et al., 2004; Dion et al., 2010; Lovett et al., 2017). It is perhaps for this reason that research rarely extends beyond early childhood and primary school education. However, international evaluation programs have demonstrated that not only many children but also many adolescents around the globe struggle to read and solve mathematical problems at their grade level (Schleicher, 2018). All of this makes it crucial to conduct research with the aim of tracing long-term developmental trajectories from early grades into adolescence that include both reading and mathematical skills. Without this knowledge, it is impossible to understand how early identifications of difficulties can be facilitated and how individuals with poor foundational academic skills can be effectively supported at different developmental stages to achieve better outcomes in life.

In developing better and more comprehensive support mechanisms, the role of parents should not be underestimated. Children spend most of their time with parents, their primary caretakers, who can influence their children's developmental processes through the learning activities they organize at home (Melhuish et al., 2008). At the same time, parents not only provide children with the home environment but also pass down their genes. Despite this being a well-known fact, research focusing on the home learning environment often overlooks the need to control for potential genetic confounding (Hart et al., 2021). Thus, it remains unclear how much influence on children's skills comes directly from genes and how much through the environment.

The goal of the present dissertation study was to examine 1) how reading and mathematical skills develop over the course of many years and 2) how a variety of parental factors can potentially predict this development. The list of predictors included children's family risk for reading and mathematical difficulties (which is a proxy measure that accounts for genetic influences) and various measures assessing the home learning environments. This dissertation starts with a study that evaluated how the use of different family risk measures can affect research findings and conclusions. The following two studies traced reading and mathematical development from childhood into adolescence and examined the influences of various parental predictors on academic skills from a long-term developmental perspective. When doing so, the use of available family risk measures was carefully considered before any conclusions were drawn. A variety of statistical methods was employed throughout the studies, combining both variable-oriented and person-oriented approaches to ensure a rigorous examination of the data that came from three longitudinal research projects, each of which had its own unique features. This all provided valuable new insights into reading and mathematical development.

This dissertation begins with the introductory section that follows, offering an overview of the key concepts and findings from previous research. More detailed introductions can be found in the respective articles included in this dissertation.

1.1 Reading Skills and Reading Difficulties

Reading is a highly complex process that involves recognizing symbols that form written language, associating these symbols with their corresponding sounds in spoken language, and assigning relevant meaning to them (Lonigan et al., 2000). In contrast to acquiring spoken language, the ability to understand written language (i.e., reading skills) can only be acquired through the guidance of a literate person, and it is the ability to read that essentially distinguishes humans from other animals.

A person who can be considered to have strong reading skills is equipped with several reading subskills (the present dissertation will focus on word reading accuracy, reading fluency/speed, and reading comprehension). Word reading accuracy and fluency refer, respectively, to the ability to decode text without errors and with speed. A struggling reader is someone who experiences difficulties with learning to read fluently and accurately, and their difficulties persist over an extended period despite receiving consistent, adequate instruction (Peterson & Pennington, 2012).

Reading fluency and accuracy form the foundation for developing an even more complex skill – reading comprehension (Eklund et al., 2018; Florit & Cain, 2011; Klauda & Guthrie, 2008; LaBerge & Samuels, 1974; Perfetti, 1985; Pikulski & Chard, 2005), which can be defined as the ability to understand what has been read (Hulme & Snowling, 2013). Out of all reading subskills, reading comprehension is viewed as "the essence of reading," which makes it a key educational outcome (Durkin, 1993). According to the direct and indirect effects model of reading (DIER; Kim, 2017), a theoretical model that integrates several influential theories and empirical evidence, reading comprehension is a higher-order skill that draws on multiple component skills, the most important of which are word reading and listening comprehension. In turn, these two skills are a function of their own component skills. Fluent word reading is facilitated by phonological skills and knowledge of semantics and orthography, while listening comprehension is supported by general language skills (Kim, 2019).

Comparative cross-country research on reading development shows that reading skills are usually acquired at a faster rate in countries with orthographically consistent languages (e.g., Greek, Finnish, Italian) compared with countries with less orthographically consistent languages (e.g., Danish, English, French) (Aro & Wimmer, 2003; Seymour et al., 2003). Around one-third of all Finnish children can already read upon their school entry (Leppänen et al., 2004; Lerkkanen et al., 2004). Notably, most Finnish children (including those struggling with reading) already achieve the ceiling level in their word reading accuracy in Grade 1 (Seymour et al., 2003). Reading fluency, however, develops at a slower rate and with much individual variation. Poor reading fluency, specifically, is considered to be a hallmark of reading difficulties in Finland (Aro & Wimmer, 2003). In other contexts, with more orthographically inconsistent languages, reading fluency and accuracy are highly related subskills, and both can be assessed to identify difficulties (Seymour et al., 2003).

Longitudinal research has shown that reading fluency difficulties can both gradually resolve and emerge at a later age (Eloranta et al., 2019; Torppa et al., 2015). When the possibility of reading difficulties following either resolving or late-emerging trajectories was first proposed, it was subjected to skepticism, and the role of the flawed identification process was discussed (Leach, 2003). Later, however, it was shown that children who later developed difficulties showed no sign of difficulties in earlier grades and had, in fact, late-emerging difficulties, not late-identified difficulties (Compton et al., 2008; Leach, 2003; Lipka et al., 2006). These findings remained robust even when measurement errors and arbitrary cut-offs were accounted for (Psyridou et al., 2020). In the Finnish context, Torppa et al. (2015) found that around 40% of Finnish children who struggled with reading had persistent difficulties identifiable at both elementary and secondary school levels (at ages 8 and 14), whereas 30% of children followed a resolving trajectory (demonstrating difficulties only at age 8 but not at age 14), and the rest of the children with difficulties (30%) had late-emerging difficulties that appeared only in lower secondary school. Furthermore, working with a sample of Finnish adults who were diagnosed with dyslexia as children, Eloranta et al. (2019) established that more than half of these individuals improved in their reading fluency so much that they did not meet the criterion for the same diagnosis as adults. Eloranta et al. (2019) additionally found that the deficit in rapid automatized naming specifically characterized individuals with both late-emerging and persistent reading difficulties. This could be the case because with age, students start encountering longer and longer words and texts, and the reliance on fast recognition of words progressively grows.

At the same time, even though differential trajectories are possible, longitudinal research has revealed high inter-individual stability of reading fluency (Foorman et al., 1997; Hulslander et al., 2010; Landerl & Wimmer, 2008). This means that despite everyone's reading fluency gradually developing, the individual rank established at the beginning of reading development often remains fixed over time in relation to others. Unfortunately, too many learners are left behind, never taking on a resolving trajectory in their development. In fact, the skill gap between good and poor readers often grows over time – as students with difficulties grow older, it becomes increasingly more difficult for them to catch up with typically developing peers, making early intervention and support crucial (Good et al., 1998).

Furthermore, both Finnish and international studies have shown that reading fluency is closely associated with reading comprehension, especially in the earliest stages of reading development (Betjemann et al., 2008; Santos et al., 2019; Torppa et al., 2016). Thus, as text decoding becomes an automatized process and children become increasingly fluent in reading, they can devote more and more cognitive processing resources to reading comprehension rather than text decoding; this leads to the developmental trajectories of reading fluency and comprehension gradually diverging (e.g., Catts et al., 2012; Florit & Cain, 2011; García & Cain, 2014; Nation, 2019). In practice, this means that in later grades, those who struggle with reading fluency do not necessarily experience problems with reading comprehension or vice versa, meaning that differential support is required.

Ultimately, to some extent, all reading skills are interconnected, and a better understanding of them from a long-term developmental perspective can help develop truly comprehensive support mechanisms that provide lasting positive effects that transfer to different sub-skills (Allor et al., 2010; Daniel et al., 2021; Kjeldsen et al., 2019; Suggate, 2016). Large-scale longitudinal research with long follow-up holds the key to making long-term support more effective for a diverse body of students.

1.2 Mathematical Skills and Mathematical Difficulties

In addition to reading, the second most important type of academic ability is mathematical skills. Mathematical skills encompass many different subskills, but in the present study, the focus was on arithmetic fluency, which is often defined as the skill that facilitates speed and accuracy in basic mathematical operations (addition, subtraction, multiplication, and division). Arithmetic fluency provides the foundation for more complex mathematical skills, which allows it to be a strong early predictor of later, more advanced mathematical skills (Cowan et al., 2011; Geary et al., 2013), for example calculations with fractions (Hecht & Vagi, 2010; Jordan et al., 2013) and pre-algebraic reasoning (Powell et al., 2016). It is important to note here that most studies available today on the development of foundational mathematical skills have assessed participants' mathematical ability and identified difficulties with the use of arithmetic measures (or at least part of their measurement batteries has consisted of arithmetic fluency measures). However, the term "mathematical difficulties" is still more commonly used in the literature than "arithmetic difficulties," even when difficulties are largely identified with arithmetic measures. In view of this, the term "mathematical difficulties" will be preferred throughout this dissertation, and they are defined as arithmetic fluency difficulties that persist over time despite receiving instruction that benefits most students.

Children's development of arithmetic fluency has two main prerequisites (Xu et al., 2021). The first is understanding cardinal relations, which makes it possible for the child to count and compare numbers ("I have 3 apples, and 3 is bigger than 2 but smaller than 4."). The second is understanding ordinal relations, which enables the child to do verbal counting and understand that numbers have positions in relation to other numbers ("2 precedes 3, and 3 precedes 4."). Within the Finnish education system, typically developing children acquire arithmetic fluency sufficient for manipulating single-digit numbers during Grade 1 (Polet & Koponen, 2012). Then, children move on to do arithmetic calculations within 100, gradually becoming familiar with a growing number of computational procedures (Zhang et al., 2017). In Grade 4, Finnish children focus on performing calculations with multi-digit numbers as well as developing reasoning skills and looking for and analyzing patterns (Zhang et al., 2017).

Even though arithmetic fluency demonstrates a rather high interindividual stability over time (Aunola et al., 2004; Watts et al., 2014), this stability is far from perfect, suggesting that people can follow differentiated developmental patterns. During the first years of formal instruction, it is not uncommon for mathematical difficulties to resolve. In a study conducted in the US, around one-third of children who demonstrated poor mathematical skills in Grade 1 were found to reach the average skill level already in Grade 2 (Geary et al., 2001). A similar study conducted in Hong Kong found that only about 50% of those identified as having mathematical difficulties retained that status over the first two grades of elementary school (Chan & Wong, 2020). In later grades, mathematical difficulties appear to become more entrenched, and their presence becomes more predictive of adolescent and adult outcomes, although longitudinal research is still scarce. Shalev et al. (2007) reported that 95% of Israeli children diagnosed with mathematical difficulties in the fifth grade performed within the lowest quarter on a math test as adolescents (six years after the first diagnostic assessment). At the same time, only 40% of them did not sufficiently improve their skills, confirming their original diagnosis at the second assessment. It is unclear, however, if late-emerging mathematical difficulties are possible, as no research has yet found evidence for them. It is also unclear what predicts different trajectories in mathematical development, and large-scale longitudinal studies with long follow-up are lacking.

1.3 Comorbidity of Reading and Mathematical Difficulties

Comorbidity can be defined as the co-occurrence of at least two disorders or types of difficulties at a rate significantly higher than what is reasonable to expect by chance (Willcutt et al., 2019). Some of the current research is moving away from the term "comorbidity" in the direction of favoring "multidimensional deficit" and "deficit co-occurrence." This dissertation, however, treats these terms synonymously. Reading and mathematical difficulties have been consistently reported to co-occur at a high rate (30%–70%), though precise estimations vary, according to Joyner and Wagner (2020). The authors also noted that the most recent meta-analysis estimated that learners with mathematical difficulties are more than twice as likely to also have reading difficulties compared with those with typical mathematical skills.

At the same time, individuals with comorbid reading and mathematical difficulties have been found to be at a higher risk of worse long-term outcomes in life than those with single difficulties (Willcutt et al., 2019), most likely because their cognitive deficits are often more prominent (Cirino et al., 2015; Willcutt et al., 2019) and their difficulties are more resistant to intervention (Fuchs et al., 2010; Powell et al., 2009). Indeed, some evidence suggests that comorbid difficulties are more stable than single difficulties. In a recent Finnish study, almost 70% of those who demonstrated both types of difficulties in the second grade confirmed their comorbidity in the fourth grade, while for single difficulties, this percentage was around 40% with learners transitioning to either the group with the other type of single difficulties or the group with no difficulties (Koponen et al., 2018).

This all suggests that individuals with comorbid difficulties would benefit from early identification and differentiated support, but their development requires a deeper understanding of how comorbid difficulties emerge and develop. Considering this, it is surprising to see how scarce longitudinal research on comorbid difficulties is. Most studies available today are cross-sectional, and long-term developmental trajectories leading to later outcomes are yet to be traced.

1.4 The Home Learning Environment

Because foundational academic skills are learned rather than innate, it is important to study the effects of various learning activities offered to children, especially as the quality and quantity of these activities are subject to significant variation (Cheung et al., 2020; Hart et al., 2016; Susperreguy et al., 2020). In the modern scholarly literature, the sum of all at-home learning-orientated activities and factors is often referred to as the home learning environment. In research focusing on the development of foundational academic skills, two main types of the home learning environment are often distinguished: the home literacy environment (HLE) and the home numeracy environment (HNE), which can be, respectively, defined as learning-orientated interactions between children and their parents, parental attitudes, and at-home learning materials targeted at the development of children's reading and mathematical skills.

The HLE has long been regarded as one of the key factors in the development of reading skills (see Bus et al., 1995; Dong et al., 2020; Flack et al., 2018; Grolig et al., 2019). According to Lundberg's (1991) informal literacy socialization model, literacy skills are "a cultural product depending on cultural transmission" and children are at an advantage in developing literacy skills when: 1) they are exposed to text-based learning activities, 2) they have access to written language (books and other text-based learning materials), and 3) they are exposed to positive attitudes and behavior models (parents enjoying reading around children). In their seminal study, Sénéchal and Lefevre (2002) proposed the home literacy model and demonstrated that the effects of the HLE can be accurately evaluated if literacy-related learning is separated into formal and informal activities. The formal HLE refers to direct parental instruction/teaching of literacy-related skills and has been found to predict early word recognition and decoding skills, whereas the informal HLE is often centered around meaning-related practices (i.e., sessions of shared reading and follow-up discussions), which have been specifically linked with the development of language skills and reading comprehension (Martini & Sénéchal, 2012; Mol et al., 2008; Sénéchal, 2006, 2015; Sénéchal & Lefevre, 2014).

At the same time, it is important to note that the significant positive effects of the HLE are not always found. Manolitsis et al. (2013) and Silinskas et al. (2020), for instance, conducted studies in countries with transparent orthographies (Greek and Finnish) and found that the formal HLE had significantly smaller effects compared with the effects reported earlier by studies that came from English- and French-speaking contexts (countries with opaque orthographies). The researchers attributed an important role to orthography in this area of research and argued that in their contexts the formal HLE provides only short-term positive influences that disappear after children enter school, where transparent orthography helps them learn to read very quickly.

A widespread research interest in the HNE has developed more recently, but existing evidence already convincingly suggests that the HNE could be a significant contributor to children's mathematical development (Daucourt et al., 2021; Dunst et al., 2017; Kleemans et al., 2012; Niklas et al., 2016). Similar to that of the HLE, HNE-related research is often centered around the home numeracy model, and the learning activities are also differentiated into formal and informal (Skwarchuk et al., 2014). Importantly, in their cross-sectional study, Skwarchuk et al. (2014) classified parental mathematical teaching as the formal HNE and the game-based mathematical activities as the informal HNE. Their study demonstrated that 5- and 6-year-old children's improvement in symbolic number knowledge was predicted by formal activities, while gains in non-symbolic mathematical skills were associated with informal learning.

Even though the positive effects of the HNE found by some studies make intuitive sense (Daucourt, 2021; Hart et al., 2016; Mutaf-Yıldız et al., 2020; Napoli & Purpura, 2018; Niklas & Schneider, 2014), it is important to acknowledge an existing body of research that has reported non-significant or even negative associations between the HNE and children's mathematical skills (Blevins-Knabe et al., 2000; Ciping et al., 2015; Missall et al., 2015; Silinskas, Leppänen et al., 2010; Zippert & Rittle-Johnson, 2020). To some extent, these inconsistent findings can be attributed to the use of the same HNE questions across different age groups and contexts — their wider relevance and applicability have been called into question (Thompson et al., 2017).

Furthermore, research has found cross-domain associations and demonstrated an important role of child language and literacy-related abilities (for example, phonological awareness, vocabulary acquisition, and grammatical ability) in their mathematical development (Dehaene et al., 2003; De Smedt & Boets, 2010; Durkin et al., 2013; Kleemans et al., 2011; LeFevre, Fast, et al., 2010). This has led to a more recent line of research exploring potential links between the HLE and early numeracy skills, while testing the hypothesis that it is the HLE that contributes to the development of children's literacy and numeracy rather than the HNE (Anders et al., 2012; Manolitsis et al., 2013; Segers et al., 2015). This is a plausible possibility, especially considering that a strong positive correlation has been reported between the HLE and HNE (Manolitsis et al., 2013; Segers et al., 2015). In view of this, research that omits the HLE altogether might find spurious correlations between the HNE and children's numeracy.

Notably, the terms HLE and HNE are often used in research in reference to the activities organized at home with kindergarten/pre-school children. The home learning environment, however, also includes homework support/assistance offered to school-aged children. In empirical research, the parental homework support is sometimes viewed as a separate concept, but the present dissertation considers it part of the formal home learning environment. Research on this type of at-home learning is far from plentiful and has produced mixed evidence so far. Some studies showed that parental homework support was associated with better academic outcomes (Dumont et al., 2012; Patall et al., 2008), while others suggested that more assistance predicted lower skills in children (Hill & Tyson, 2009; Silinskas et al., 2013).

Since studies reporting negative associations between children's skills and the home learning environment are not rare, exploring the question of direction in these associations for different age groups has been an important research challenge (Do skills predict the home environment, or does the home environment predict skills?). It is not difficult to imagine that parents can be guided by their children's preferences and needs when organizing at-home learning. For instance, van der Schuit et al. (2009) found in the context of the Netherlands that when parents observed learning difficulties in their pre-school children, they tended to reduce the difficulty level and the number of learning activities organized at home. In contrast, Ciping et al. (2015) reported that in their sample of Chinese families, parents provided more learning activities at home after noticing difficulties in their elementary school children. Overall, these findings indicate that children's learning-related behavior can elicit varying responses from parents (i.e., children's behavior has evocative effects on the home environment). Importantly, the different strategies selected by parents across contexts as a response to the observed skill level in their children could be related to different cultures, but they could also be related to children's age and difficulties becoming more apparent with time. However, the relevant research evidence is scant. Finnish studies available so far seem to suggest the following trend: when children are in kindergarten/pre-school their lower skills are associated with less learning at home (Silinskas, Parrila et al., 2010). Once children enter school, however, lower skills predict more parental support (Silinskas, Leppänen et al., 2010).

1.5 The Interaction of Genetic and Environmental Influences on Children's Reading and Mathematical Development

An important factor that needs to be taken into consideration in both HLE- and HNE-related research is parental skill level because having a parent with reading and/or mathematical difficulties places children at family risk for the same type of difficulties. Indeed, even though foundational academic skills are learned, they are still largely heritable, which makes children's learning trajectories to an extent pre-determined by their genes (de Zeeuw et al., 2015; Kovas et al., 2013; Little et al., 2017). This means that a genetic predisposition to learning difficulties could act as a confounding factor. Unfortunately, genetic confounding is often neglected in research, and when it happens, it is hard to tell if the home learning environment itself is influencing children's development, or rather, it only appears that way because genes are influencing both children's skills and the home environment (see Figure 1 for a visual representation of this idea) (Hart et al., 2021; Olson, 2002; Rutter et al., 1997; van Bergen et al., 2017). When genetically sensitive data are not at the researchers' disposal, then genetic confounding can be controlled for with the use of the familial control method, the most feasible genetic-proxy control design that uses information about parental skills as a control measure when examining the role of the environment (Hart et al., 2021; van Bergen et al., 2017). Having a parent with lower reading skills has long been viewed an important risk factor for children's reading development, and it has been widely accepted that parental reading skills can serve as a proxy for the genetic transmission of difficulties (Elbro et al., 1998; Esmaeeli et al., 2019; Hulme et al., 2015; Lyytinen et al., 2001; Snowling et al., 2003; van Bergen, de Jong et al., 2014).

Importantly, parents who have learning difficulties might be less inclined to provide learning activities for their children, but it is not necessarily the environment that is influential; rather, children's genetic predisposition for difficulties is what actually explains their slower skill development. Some studies have reported that parents with reading difficulties provide a more disadvantageous HLE for their children compared with parents with no such difficulties (Dilnot et al., 2017; Esmaeeli et al., 2018; Hamilton et al., 2016). However, other evidence indicates that parents organize learning activities at home irrespective of their own reading skills (Elbro et al., 1998; Laakso et al., 1999; Torppa et al., 2007; van Bergen, de Jong et al., 2014). It could be the case that in different contexts, parental difficulties get translated into the home environment differently, which is why it is crucial that analysis accounts for parental skills.

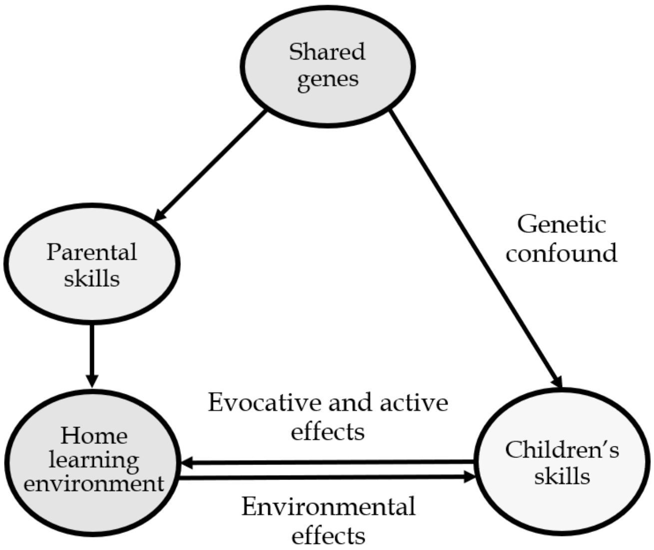

Figure 1 The Visual Explanation of Why It Is Important to Control for Genetic Confounding

Confounding influences of family risk have mostly been explored in reading-related research. For example, in the Netherlands, van Bergen et al. (2017) tested the influence of various HLE variables and found that once parental reading skills were controlled for, the only environmental variable that predicted children's reading fluency in elementary school was the number of books at home. Additionally, Puglisi et al. (2017) found that in the context of the US, shared reading stopped being a significant predictor of children's literacy skills after maternal language was accounted for. At the same time, the researchers reported that formal parental teaching retained its significance as a predictor of children's early reading, even after maternal language skills were controlled for. Interestingly, in the Finnish context, longitudinal research that followed children from age 2 to adolescence revealed that shared reading at home organized before children's school entry can have long-lasting effects on reading development, even after controlling for parental reading skills (Torppa et al., 2022).

Similar research on the HNE that controls for parental mathematical skills is lacking, and it remains to be seen if equivalent mechanisms work in mathematical development. Some emerging research (Cheung et al., 2020; Hart et al., 2016; Salminen et al., 2021) has suggested that the HNE has significant positive influences, even when parental math skills are factored in. For example, Cheung et al. (2020) conducted a study with low- and middle-income families in the Philippines and found that the influence of parental arithmetic fluency on children's mathematical development was significantly mediated through the home numeracy environment, meaning that parental skills not only directly predicted children's skills, but they also had an indirect influence, through the environment — parents with higher skills provided richer HNE, which in turn contributed to higher skills in children. Importantly, Cheung et al. (2020) assessed parental skills with tests of arithmetic fluency and collected information about both formal and informal home activities but did not differentiate them in the analysis using a sum score of all learning activities.

Salminen et al. (2021), on the other hand, had a sample in which parents with higher levels of education were slightly over-represented and reported only direct links between parental and children's skills, as well as the HNE and children's skills. The researchers found no association between parental math skills and the environment and, thus, no significant mediation effects. Salminen et al. (2021) used a very short self-report measure to collect information about parental academic difficulties and included only informal math activities in their analysis.

Finally, Hart et al. (2016) collected a general population sample and found that more general math activities organized at home directly predicted children's skills, but there was no association between parental skills and the HNE. Importantly, the main difference between this study and the two previously mentioned is that the authors measured child math ability with only parental reports, which are likely not as accurate as direct skill assessments organized by a trained administrator. Indeed, some research suggests that, on average, parents tend to overestimate their children's mathematical abilities (Zippert & Ramani, 2017). Moreover, since both HNE and children's skills were reported by the same person, it is likely that the significant association between them can be, at least partly, attributed to common rater variance. It is clear that there are a lot of methodological differences between these studies, which makes comparison difficult. Much more research is needed before any conclusions can be drawn.

1.6 Theoretical Underpinnings

The present dissertation is anchored in several seminal scientific works. To begin with, the theoretical framework that explains such a prevalent co-occurrence of reading and mathematical difficulties as well as the ability of learners to follow a resolving trajectory or to transition from one type of difficulty to another is the multiple deficit model (Pennington, 2006). This theoretical model posits that the dynamic nature of learning difficulties stems from the fact that different types of learning difficulties have multiple shared risk factors that lead to the occurrence of these difficulties probabilistically and not deterministically, but much empirical work is still needed to better understand the exact developmental mechanisms. Importantly, existing research has indicated so far that there is no one "core" cognitive deficit that can be used as a stand-alone measure for identifying those with and without a specific type of learning difficulty at the individual level (McGrath et al., 2020). Research has also shown that different cognitive deficits can be shared across different types of difficulties. For example, slow processing speed, oral language weaknesses, and poor working memory have been found to affect multiple learning domains (De Weerdt et al., 2013; Peterson et al., 2017; Snowling et al., 2021).

Research guided by the multiple deficit model aligns with the Research Domain Criteria (RDoC) framework that was developed for the purpose of finding new approaches to investigating mental disorders (Morris et al., 2022). The development of the RDoC has been driven by mounting evidence of mental disorders' etiological heterogeneity and their comorbidity being more of a rule than an exception (Cuthbert, 2014). The RDoC adopts a broader transdiagnostic approach to understanding disorders and considers all presenting symptoms, even if they do not fit the standard diagnostic criteria. In doing so, the RDoC reflects an emerging emphasis on both differences and similarities across disorders and acknowledges that the boundaries between different disorders are not so clear-cut and are often permeable.

Another important theoretical model in the field of learning disorders is the generalist gene hypothesis, which states that the same genes are largely responsible for the development of different learning abilities (up to 70% of the genes could be generalist), but there are also specialist genes that shape the development of one specific type of learning ability (Kovas & Plomin, 2007; Plomin & Kovas, 2005). The multiple deficit model, RDoC, and generalist gene hypothesis do not contradict but complement each other. Combining ideas from these theoretical frameworks, van Bergen, van der Leij et al. (2014) developed a hybrid model that supports further research examining how different types of learning difficulties develop in relation to each other and focusing on the overlap in genetic and environmental factors that contribute to the occurrence of different learning difficulties.

Studying genes and the environment together holds the key to identifying the most influential environmental factors. This knowledge can inform the design of more effective interventions and support programs for individuals born at genetic risk for certain disorders and difficulties (Asbury & Plomin, 2013). The present dissertation specifically focuses on the factors that exist in the home environment. It is important to stress, however, that despite what their names suggest, measures assessing the home learning environment never provide the objective reflection of the environment and should not be considered purely environmental measures. Indeed, through gene–environment interaction and correlation, environmental factors always include a genetic component. The gene–environment interaction can be briefly explained as the heritable sensitivity to certain environmental factors. In other words, an individual might be genetically predisposed to developing a certain characteristic or health condition, but this genetic predisposition might not ever manifest itself without the presence of certain environmental factors. Gene–environment correlation, on the other hand, refers to the relationship between the genes and the environments, and there are three main processes driving this relationship: 1) passive gene–environment correlation (occurs due to the genetic resemblance between parents and their offspring and because parents tend to offer the environment that strengthens the initial resemblance even further), 2) active gene–environment correlation (occurs when an individual gravitates towards a certain environment because of their genes), and 3) evocative gene–environment correlation (occurs when a person's heritable behavior elicits certain environmental responses) (Plomin et al., 1977, 1994; Rutter et al., 1997).

Both gene–environment interaction and correlation make it difficult, if not impossible, to measure purely environmental effects. Plomin and Bergeman (1991) importantly highlighted significant genetic influences on most environmental measures employed in modern behavioral sciences (e.g., measures related to parental behavior, the home environment, peer groups, social support, etc.) and further demonstrated that this methodological challenge can be addressed by controlling for genetic confounding (though the possible degree of what can be controlled for might vary depending on the study design). Unfortunately, in the present dissertation, it was impossible to directly test gene–environment interaction and correlation. Instead, family risk (information about having close relatives with reading and/or mathematical difficulties) was used as a proxy for children's genetic predisposition for reading and/or mathematical difficulties (the familiar control method).

1.7 Aims of the Present Research

A large body of research focusing on reading and mathematical development already exists; however, there are still clear knowledge gaps, as demonstrated in this dissertation's introduction. Even when some aspects related to reading and mathematical development appear to have been thoroughly investigated, the use of different methods across studies often precludes meaningful comparisons and meta-analyses. Moreover, there is an obvious lack of long-term longitudinal studies that include proper control for confounding influences. Furthermore, the home learning environment, encompassing various aspects of parental involvement in children's learning, is a complex and contentious topic of research, characterized by numerous knowledge gaps. Taking this into account, the present dissertation studies sought to 1) examine how reading and arithmetic skills develop from childhood into adolescence and 2) identify parental factors that are significantly associated with skill development. More specifically, the studies aimed to gain new insights into how family risk and different environmental factors coming from home shape developmental trajectories over an extended period of time.

Study I examined the association between two research methods that are most commonly used to identify children at family risk for reading difficulties (parental self-reports and direct skill assessments) and evaluated the extent of each method's unique value in predicting children's reading fluency and accuracy. Study I employed two different samples collected in Finland (the first one was a prospective family risk sample in which half of the children were at family risk for reading difficulties; in the second sample, children, and their parents were unselected for their skills) and carried out a series of regressions. Evaluating the predictive power of each family risk identification method carries great value both for facilitating better screening for children in need of early support and for designing better research in the future. The findings from this study also have important implications for how we should interpret the results of the other two studies included in the present dissertation (all used different family risk measures). Study I laid the groundwork for the rest of the dissertation by highlighting why family risk was an important construct in psychological and educational research and how it could be most accurately and effectively measured.

Study II investigated whether family risk for reading and mathematical difficulties directly predicted children's academic skills (reading fluency, reading comprehension, and arithmetic fluency). Study II also tested if parental difficulties were predictive of the home learning environment and examined whether the associations between parental skills and children's skills were mediated by the home learning environment (HLE and HNE). To achieve these objectives, a longitudinal path model was constructed that included children's skills from Grades 1, 2, 3, 4, 7, and 9. Moreover, by including both reading- and mathematics-related information, this study examined the underpinnings of reading and mathematical comorbidity. The findings have important practical implications as they enhance our understanding of which specific learning activities organized at home have long-term effects on skill development and whether parents with learning difficulties might be in need of external support to be able to provide the best possible learning environment for their pre-school children.

Study III focused on identifying different developmental patterns (starting in Grade 1) that led to single or co-occurring difficulties in reading and/or arithmetic fluency in adolescence (in Grade 9). The identification was performed using latent profile analysis. In addition, various family-related factors (family risk, the home learning environment, and parental academic support provided in Grades 1–9) were tested as predictors of the identified developmental patterns. Study III extended the work completed in Study II by focusing specifically on learners who demonstrated difficulties at the end of comprehensive school (Grade 9). The overall group-level analysis performed in Study II provided the big picture of the factors predictive of reading and arithmetic skills. This approach to analysis assumes that all participants follow similar developmental patterns. The focus on low-performing learners in Study III, however, enabled us to further investigate whether different groups of learners follow heterogeneous developmental trajectories. In addition, Study III included parental academic support from different grades as predictors with the aim of better understanding whether parental academic support is associated with the developmental trajectories of children with difficulties.

2 METHOD

2.1 Participants

The studies included in this dissertation utilized data from three longitudinal research projects conducted in Finland: 1) the Jyväskylä Longitudinal Study of Dyslexia (JLD), 2) the Study of Interaction, Development and Learning (VUOKKO), and 3) the First Steps Study. Each sample had its own advantages and limitations, and the combination of the three samples provided unique and complementary insights into our understanding of academic skill development.

The first sample, the JLD, followed approximately 200 families (children and their parents), and half of the children were at a family risk of reading difficulties. For this reason, the lower end of reading skill distribution was well represented in the sample, providing a large variation and ensuring higher statistical power. A total of 9,368 families residing in Central Finland were considered for this study. Families were contacted when mothers were expecting babies, and all participating children were born from April 1993 to July 1996. Recruitment was based on the following three-step selection procedure: 1) a short parental questionnaire with three questions regarding their own and their relatives' reading and spelling skills, 2) a longer parental questionnaire with questions on demographic characteristics and more questions about reading skills and reading history, and 3) a clinical interview and a comprehensive assessment of reading, writing, and cognitive skills (for more detailed information on recruitment, see Leinonen et al., 2001). The recruitment process ensured that the control and family risk groups were matched on parental education and intelligence quotient scores (all scored above 80). This sample had a very long follow-up period (children were followed from birth till age 23) and high retention rates.

The second sample, the VUOKKO, was a recently collected population-based sample that included over 300 families. All children recruited for this study were born in 2013 and came from one middle-sized city in central Finland. Most participating families came from the same ethnic and cultural background. Highly educated parents were slightly overrepresented. The study began in 2015 and has had a relatively short follow-up (until Grade 1) so far. The data used in our dissertation studies were collected at one time point: Grade 1.

The third sample, the First Steps Study, was also a population-based sample that included approximately 2,000 families from four municipalities in central, western, and eastern parts of Finland. The large sample had a balanced representation of both urban and rural areas. The sample was highly ethnically homogeneous and representative of the country's population. The socio-economic characteristics of the sample were close to the national distribution (Statistics Finland, 2007). The study began in 2006 (N = 1,880) when the children were 6 years old (one year before school entry), and the follow-up continued until Grade 9 (the end of comprehensive school in Finland). At the first time point, the children's cognitive skills were assessed and information about various parental characteristics/factors was collected. The children's reading fluency, reading comprehension, and arithmetic fluency were assessed in Grades 1, 2, 3, 4, 6, 7, and 9.

2.2 Research Ethics

The three longitudinal samples included in the present dissertation received ethical approval. More specifically, the Ethical Committee of the University of Jyväskylä reviewed and approved the JLD, VUOKKO, and First Steps Study. Additionally, the Central Finland Hospital District Ethics Committee reviewed and approved the JLD (this was necessary at that time because newborns had electroencephalographic assessments at the maternity ward). Throughout the three studies, research was conducted in accordance with the ethical guidelines set for research with human subjects.

Overall, the same ethical principles were followed across the studies. Participation was strictly voluntary, and written informed consent was provided by the participants' legal guardian/next of kin. All assessment procedures were safe, and special attention was paid to ensure participants' well-being and manage risks. Once the data were collected, they were stored securely to protect the participants' privacy. After signing a data usage contract, the author of the present dissertation worked with pseudonymized data files, which allowed the identities of the participants to remain unknown. The data files were handled with utmost care at all stages of the research.

2.3 Statement on Data Findability, Accessibility, Interoperability, and Reusability (FAIR)

The JLD data set and the First Steps data set were created before best practices in open data were formulated and the FAIR data principles were published. While these datasets may not strictly adhere to the FAIR principles, the raw data supporting the findings of the three dissertation articles can be provided upon request to any qualified researcher. The metadata for the latest dataset, VUOKKO, is currently being prepared, with the aim of aligning this data set with the FAIR criteria as much as possible.

2.4 Measures

Each of the three dissertation studies had a longitudinal design. Specific measures were selected in accordance with the studies' research goals. Information on the measures used in each study is given in Table 1 (for full details, see the original articles).

Table 1 Summary of the Participants, Measures, and Data Analyses

Study	Participants	Child measures	Parental measures	Data analyses
I	- JLD sample: Grade 1 (*N* = 182) Grade 2 (*N* = 169) Grade 3 (*N* = 191) Age 23 (*N* = 129). - VUOKKO sample: Grade 1 only (*N* = 318)	In Grade 1 the assessment battery included: - The word reading subtest of the nationally standardized reading test ALLU (Lindeman, 1998) (both the JLD and VUOKKO had this measure). - The test of silent reading efficiency and comprehension (TOSREC) (Wagner et al., 2010) (only the VUOKKO had this measure). In Grades 2, 3, 8, and at age 23 the assessment battery included (only for the JLD): - The word list reading subtest of the nationally standardized reading test, Lukilasse (Häyrinen et al., 1999). - Text reading (three age-appropriate texts varying in length from 124 to 204 words) - Pseudoword text reading (one short text containing made-up words resembling the Finnish language; 19 words in Grade 2 and 29 words at all other time points)	- Questionnaire of 12 items that were identical or almost identical to the items in the adult reading history questionnaire developed by Lefly and Pennington (2000) (Items: 2, 5, 6, 9, 11, 13, 16, 17, 19, 20, 22, and 23). - Text reading accuracy and fluency assessment (Tunturilappi: Leinonen et al., 2001). - Pseudoword reading accuracy and fluency assessment (in JLD - Leinonen et al., 2001; in VUOKKKO - Nevala et al., 2006).	- Simple linear regression - Hierarchical linear regression - Longitudinal path analysis
II	- First Steps sample: Grade 1 (*N* = 2,052) Grade 2 (*N* = 2,006), Grade 3 (*N* = 1,995), Grade 4	- At all time points, reading fluency assessments included the word reading subtest of the ALLU (Lindeman, 2000) and the word chain test (Nevala & Lyytinen, 2000). Additionally, reading fluency was assessed with the TOSREC sentence reading test in Grades 1–4 (Wagner et al., 2010) and with YKÄ in Grades 7 and 9 (Lerkkanen et al., 2018). - Reading comprehension was measured with multiple-choice tests: ALLU in Grades 1–4	- Self-report measure of academic difficulties (one item for reading difficulties and one item for mathematical difficulties). - Home learning environment questionnaire that included questions about shared reading and formal teaching of reading and math skills (completed when children were in kindergarten).	- Longitudinal path analysis - ANOVA

Study	Participants	Child measures	Parental measures	Data analyses
	(*N* = 1,954), Grade 7 (*N* = 1,770), Grade 9 (*N* = 1,721)	(Lindeman, 2000) and YKÄ in Grades 7 and 9 (Lerkkanen et al., 2018). - At all time points, arithmetic fluency was measured with the arithmetic test consisting of addition and subtraction tasks (Räsänen & Aunola, 2007).		
III	- First Steps sample (only low performers selected from the full sample): Grade 1 (*N* = 276), Grade 2 (*N* = 280), Grade 3 (*N* = 287), Grade 4 (*N* = 286), Grade 6 (*N* = 365), Grade 7 (*N* = 369), Grade 9 (*N* = 391)	The same as in Study II	- Self-report measure of academic difficulties (one item for reading difficulties and one item for mathematical difficulties). - Home learning environment questionnaire that included questions about shared reading and formal teaching of reading and math skills (completed when children were in kindergarten). - Parental homework support questionnaire (distributed once in each grade).	- Latent profile analysis (with the use of the three-step approach) - ANOVA - Chi-square tests

3 OVERVIEW OF THE ORIGINAL STUDIES

3.1 Study I: Intergenerational Transmission of Dyslexia: How Do Different Identification Methods of Parental Difficulties Influence the Conclusions Regarding Children's Risk for Dyslexia?

The goal of this study was twofold: 1) to examine the association between the two most common methods for identifying family risk for dyslexia (self-reported parental reading difficulties and directly assessed parental reading skills) and 2) to establish how predictive each method was of children's skills. Previous research has clearly demonstrated that the process of identifying adult reading difficulties can be significantly influenced by the selected methods (e.g., Deacon et al., 2012; Tamboer et al., 2014). However, to the best of our knowledge, no previous study has examined how different identification methods offered to parents affect the prediction of children's skills and how this, in turn, influences our understanding of the intergenerational transmission of reading ability. In view of this objective, Study I has important implications for both future research and educational practice. Future researchers will benefit from understanding how the research methods they select can influence the conclusions they draw about their findings. Moreover, establishing that parental assessments are not superior to parental self-reports for the purpose of predicting children's skills can facilitate more data collection in the future (considering that self-reports are a more cost- and time-effective measure than assessments). The practical value stems from the fact that self-reports can be more easily and widely used for screening children at risk for reading difficulties and in need of early support. Thus, evaluating the predictive power of self-reports can help make more educated decisions about planning screenings and allocating support. Moreover, it is known that inevitable measurement errors reduce the reliability of skill assessments currently used for identifying children with difficulties. However, the use of multiple measures that provide different sources of information for estimating the risk for learning difficulties can improve the reliability of the identification process; thus, finding a sufficiently reliable family risk measure could provide a valuable addition to the identification methods that are currently employed by clinicians and practitioners (Joyner & Wagner, 2020).

The extent to which the two parental methods can explain the common variance in children's reading ability is unknown. There are three possible ways in which these methods can contribute to the prediction of children's skills: 1) the two methods identify the same parents as carrying risk and explain the same variance in children's skills and thus can be used interchangeably, 2) one of the methods is significantly more accurate and for this reason the other method can be discarded from future studies, and 3) the methods complement each other and therefore need to be used in combination to ensure the most accurate prediction of children's skills. Figure 2 provides a visual hypothesis for Study I. It is a given that neither method can identify all parents carrying risk (this population is represented by the biggest circle in Figure 2), but estimating how big the areas and overlaps should be in Figure 2 is possible and valuable.

The main reason behind the imperfect accuracy of reading assessments is that some individuals with dyslexia demonstrate clear reading difficulties only in childhood, and then they gradually improve and reach the reading levels of typical readers (approximately 30% of Finnish children with early dyslexia follow a resolving trajectory in their reading development [Torppa et al., 2015]). This means that despite carrying the genetic risk, such adults (those who improved their reading skills gradually) cannot be identified with standard reading assessments for adults. The accuracy of self-reports has also been called into question after some research has reported that the way people self-assess their reading can be significantly affected by their age, gender, and socio-economic status (Snowling et al., 2012). Overall, Study I aimed to better understand the limitations of existing identification methods when they are applied for predicting children's reading skills in the Finnish context.

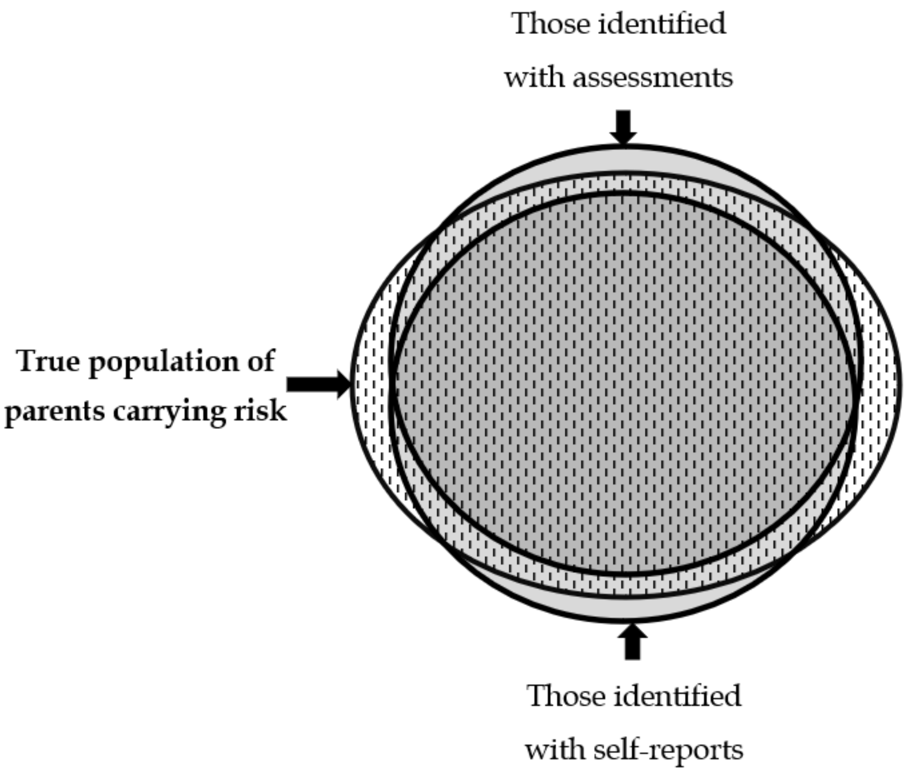

Figure 2 The Visual Hypothesis for Study I

This study used two separate data sets: the JLD (a prospective family risk sample) and the VUOKKO (a general population sample). The JLD included parental data (collected before children were born) and children's data (collected when children were in Grade 1 (age 7), Grade 2 (age 8), Grade 3 (age 9), Grade 8 (age 14), and at age 23). Parental data consisted of a 12-item self-report measure (similar to the adult reading history questionnaire developed by Lefly and Pennington, 2000) and direct reading assessments (text reading accuracy and fluency and pseudoword reading accuracy and fluency).

In the control group, both parents of each child participated in reading assessments. This was done to ensure that the children in this group were not at risk of reading difficulties. In the family risk group, however, only the parents who had previously self-reported difficulties were then tested with reading assessments for confirmation purposes. For this reason, a composite score of both parents' scores was calculated only for the control participants. Most at-risk families had an assessment score of the one parent carrying the risk, and this individual score was used in the analysis. To ensure consistency, the same approach was employed when calculating the sum scores of self-reports. Cronbach's alphas for all items were .81 and .77 for mothers and fathers, respectively.

The results of Study I indicated that the two family risk identification methods (reading assessments and self-reports) correlated strongly in the JLD (.60) and moderately in the VUOKKO (.42). The stronger correlation found in the

JLD can be most likely attributed to the fact that it had a wider representation of lower reading skills, which provided this sample with more variability. Moreover, in the JLD, it was found that the two family risk identification methods were nearly equally predictive of children's reading performance at almost all time points. Each parental method, when added as the sole predictor of children's skills in simple linear regressions, explained on average 6%–7% of variance. In the VUOKKO, however, a significant difference in their predictive power was found between the two family risk identification methods. Parental self-reports turned out to be a strong predictor that explained 7% of the variance in children's reading while parental skill assessments were not found to be significantly predictive. The likely reason behind these results lies in the fact that parents with lower reading skills were more inclined to opt out of assessments than parents with typical skills (our missing value analysis revealed this systematic missingness). At the same time, all parents were equally active in completing self-reports (i.e., their willingness to participate was not related to their skills). This led to parents with lower skills being underrepresented in the data collected with reading assessments but not with self-reports.

Study I extended the previous literature in several ways. First, simple linear regressions constructed separately for each time point showed that both family risk measures retained similar predictive effects on children's reading not only in childhood and adolescence but also in adulthood when children turned 23. To the best of our knowledge, no previous family risk study included children's skills from adult time points. Second, a longitudinal path model that included all time points revealed that both family risk measures represented the highest value at the earliest time points when children's own reading skills could not yet be directly measured. Once children's reading skills were developed enough for direct assessment and could be added as autoregressors, both family risk identification methods stopped being predictive of later skills beyond the early time points. Third, in research, special attention needs to be paid to ensuring that people with lower skills are adequately represented because the failure to recruit enough people with lower skills can have a dramatic effect on findings and conclusions. The inclusion of two different samples in this study, one with missingness and one without, highlighted the true scale of this effect. Missing value analysis revealed that parents with lower reading skills were more avoidant of reading tests than of self-reporting. Thus, self-reports proved to be a valid alternative to skill testing because they were found to be just as predictive as short assessments, and people with lower skills found them a less daunting prospect compared with assessments.

3.2 Study II: Longitudinal Effects of the Home Learning Environment and Parental Difficulties on Reading and Math Development across Grades 1–9

Study II aimed to examine possible associations between parental reading and mathematical difficulties, HLE, and HNE at age 5 and children's academic skills (reading fluency, reading comprehension, and arithmetic fluency) in Grades 1–9. These associations were examined by constructing longitudinal path models that tested whether parental skills directly predicted children's skills and/or if there was an indirect link between them going through the home learning environment.

It is known that both reading and mathematical skills are largely heritable (de Zeeuw et al., 2015; Kovas et al., 2013; Little et al., 2017), but their development might also be influenced by the home learning environment (Daucourt et al., 2021; Dong et al., 2020; Dunst et al., 2017; Flack et al., 2018; Niklas et al., 2016). However, studies with long follow-ups that test for potential long-term effects of the home environment and control for possible genetic confounding are rare (Torppa et al., 2022). Also, it is unclear whether parents with and without academic difficulties provide differential home environments for their children. Moreover, it is not known whether the home environment can act as a protective factor that mediates the adverse effects of parental difficulties on children's academic skills (Esmaeeli et al., 2019). Finding this to be the case would have important implications for the development of parental recommendations. If it is additionally found that parents with difficulties avoid organizing specific learning activities at home, and by doing so, they put children at an additional disadvantage, then this would imply the need for developing specific support for children at family risk for difficulties and/or for their parents.

Furthermore, it has been repeatedly found that reading and mathematical difficulties often co-occur (Joyner & Wagner, 2020), and there is emerging evidence that some at-home learning activities might have not only domain-specific but also cross-domain associations with children's skills. For example, book exposure and literacy-related activities organized by parents have been reported to predict children's mathematical skills (Lehrl et al., 2020; Manolitsis et al., 2013). However, most existing research follows a domain-specific approach when examining the role of the home learning environment, and there is a clear lack of studies that not only test cross-domain associations but also control for family risk/parental academic skills. Finding further evidence that points to cross-domain associations would suggest that different skills develop as part of one complex developmental process and that this entire process can be influenced through specific home activities. This would mean that better support can be constructed by developing a comprehensive support system that integrates both reading- and mathematics-related components. Study II was designed to address multiple gaps in the literature listed above. To the best of our knowledge, no previous study has examined the effects of parental reading and mathematical difficulties together with the effects of various home learning activities on children's long-term development of reading and mathematical skills (in Grades 1–9).

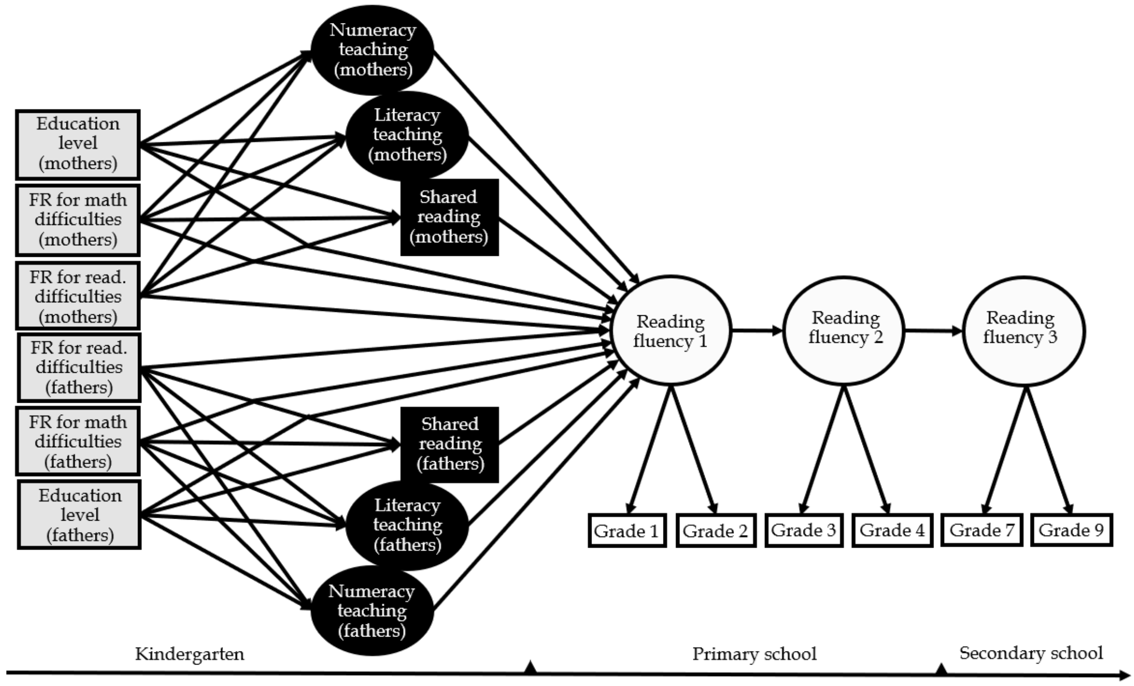

Figure 3 Hypothesized Model for Reading Fluency in Study II

Study II employed data from the First Steps Study, which followed approximately 2,000 children from kindergarten to Grade 9. Parental characteristics (parental learning difficulties, parental education, and the home learning environment) were measured with a questionnaire that was offered to both mothers and fathers when the children were in kindergarten (at age 5). The items assessing the home learning environment included questions about 1) shared reading/informal literacy activities, 2) literacy teaching/formal literacy activities, and 3) numeracy teaching/formal numeracy activities. Children's reading fluency, reading comprehension, and arithmetic fluency were measured in Grades 1, 2, 3, 4, 7, and 9.

To analyze the data, three longitudinal path models were constructed and estimated using MPlus Version 7.4: reading fluency, reading comprehension, and arithmetic fluency. Each model was based on the same hypothesized model (see Figure 3). As shown in the hypothesized model, the items about literacy and numeracy teaching were initially supposed to form separate latent variables; however, it turned out that these variables correlated with each other very highly and separating them into different constructs negatively affected the fit of the models. For this reason, it was decided to merge numeracy and literacy teaching into one teaching variable for each parent. Once it was done, all models fitted the data well.

The results of Study II revealed that parental difficulties directly predicted children's skills. More specifically, parental reading difficulties were predictive of reading fluency in children while parental mathematical difficulties predicted not only children's arithmetic fluency but also their reading comprehension. Furthermore, no indirect associations between parental difficulties and children's skills going through the home environment were found. Importantly, parents with and without difficulties did not differ in the home learning activities they organized for their children. At the same time, parental education was significantly predictive of the home environment: higher levels of parental education were associated with more shared reading (with both mothers and fathers) and less teaching/formal learning (with mothers specifically). Finally, teaching activities did not predict any of the children's skills. However, shared reading with fathers positively predicted reading comprehension in Grades 1–2, and shared reading with mothers positively predicted faster development of reading comprehension achieved by Grades 3 and 4. Figure 4 offers a visual summary of these results by showing all paths found to be statistically significant as arrows (see the published version of this study for all path estimates and standard errors for all regression paths tested in the three models included in the analysis).

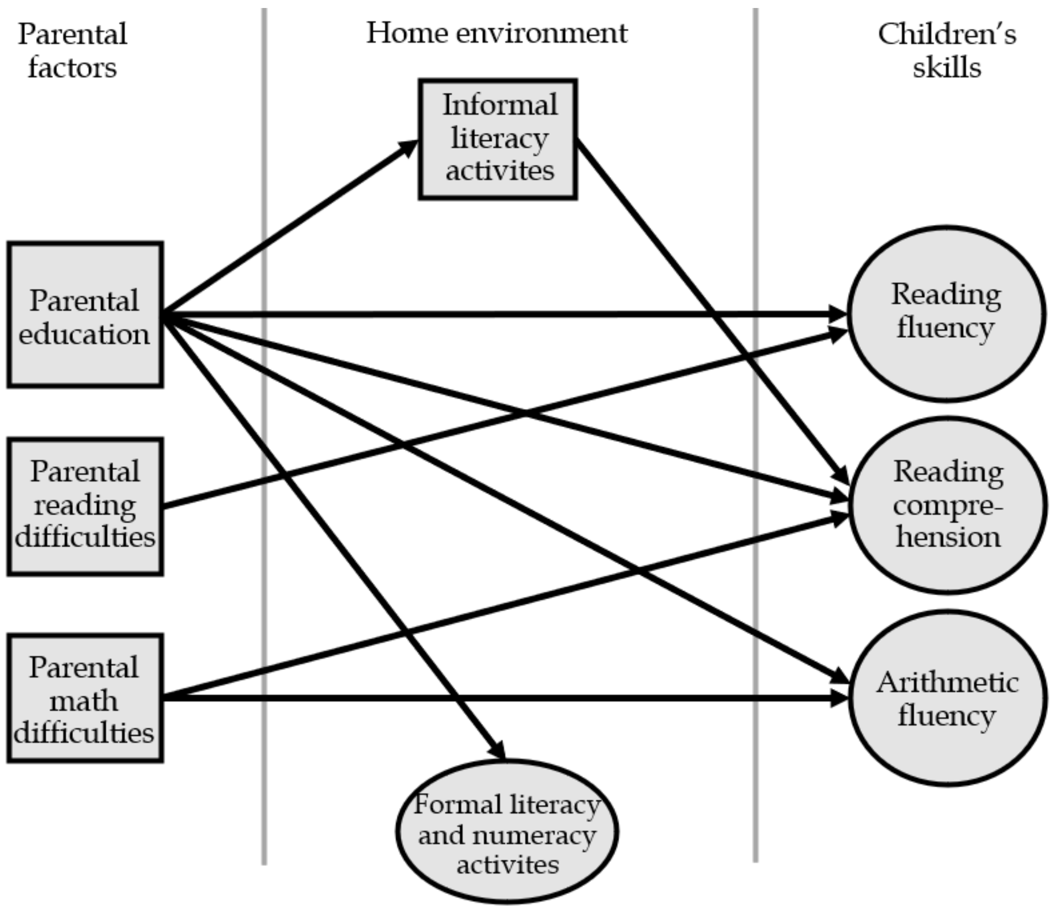

Figure 4 Visual Summary: All Significant Paths Found in Study II Are Shown as Arrows

The findings that emerged from Study II provided supportive evidence for Pennington's multiple deficit model, which posits that children's learning difficulties arise from a complex interaction of various risk factors. In addition, Study II extended the previous literature in several ways. Children whose parents have mathematical difficulties, lower levels of education, and a lower interest in organizing shared reading at home appeared to be at the highest risk for reading comprehension difficulties. Parental mathematical difficulties and lower levels of education were also predictive of lower arithmetic fluency in children. These findings have important implications for early identification, intervention, and support. Children who are at family risk for mathematical difficulties could potentially benefit from learning activities aimed at developing both their mathematical skills and reading comprehension skills, and the identification of these children could be done through parental self-reports even before the children's school entry. Moreover, recommendations given to parents should emphasize the value of early shared reading, as it appears to have long-term effects on children's development of reading comprehension.

3.3 Study III: Parental Influences on the Development of Single and Co-occurring Difficulties in Reading and Arithmetic Fluency

The main goal of Study III was to examine how single and co-occurring difficulties in reading and arithmetic fluency developed from Grade 1 to Grade 9 in a large cohort of Finnish children. A secondary goal of this study was to test several parental variables as potential predictors of children's developmental paths. First, latent profile analysis (LPA) was carried out to determine whether children with diverse types of difficulties (identified in Grade 9) followed distinct developmental paths in their academic development. Second, several profile predictors were included in the LPA model: parental reading and mathematical difficulties, parental education, the home literacy and numeracy environment provided when children were in kindergarten, and parental assistance with school homework when children were in Grades 1–9.

This study builds on the work completed in the previous study. In Study II, level group analyses with a general population sample were conducted that provided valuable insights but assumed that all the participants had followed similar developmental patterns. To extend that work, Study III was designed to specifically focus on groups of children with different academic difficulties that are identifiable at the end of compulsory schooling (i.e., Grade 9) and to trace their long-term developmental pathways that are possibly heterogenous. With this approach, it was possible to focus on individuals with single and comorbid difficulties as well as on individuals with late-emerging and persistent difficulties. A specific focus on these groups of learners can help identify and better understand specific risk factors that lead to underachievement at an important age (in adolescence) when many far-reaching decisions about the future are made. An additional novel aspect of Study III is the inclusion of new predictors. Study II focused on the role of family risk and the early home learning environment measured when children were 5 years old. Study III, however, additionally tested parental academic assistance in Grades 1–9 as predictors.

Previous research has demonstrated that reading and arithmetic difficulties are often comorbid (Moll et al., 2019). However, most previous research that looked at this type of comorbidity was either cross-sectional or longitudinal but only with short follow-ups. Thus, long-term developmental patterns leading to different types of difficulties remain to be traced and examined. Furthermore, earlier studies often investigated cognitive factors as possible predictors of the co-variance of reading and mathematical skills, but there has been a lack of research looking at any environmental factors. Therefore, it is still unclear if environmental factors could be predictive of divergent academic outcomes in adolescence.

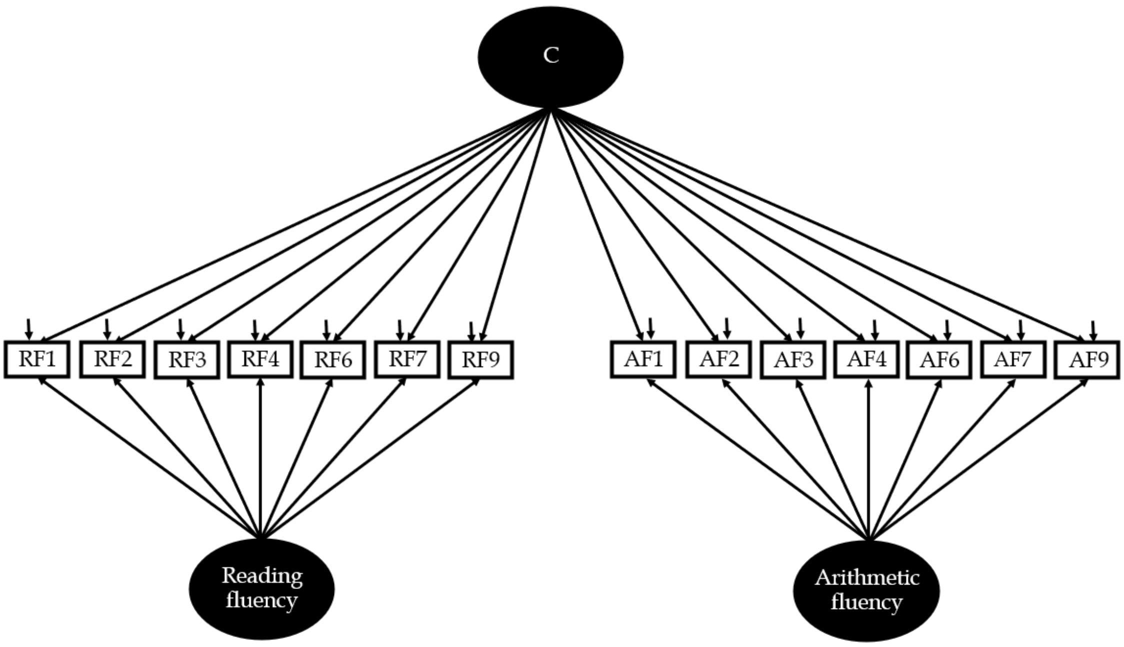

Figure 5 The Visual Representation of the LPA Model in Study III

Note. C represents the latent profiles. Reading fluency and Arithmetic fluency represent the initial levels of these skills. RF and AF with numbers indicate the grades when these skills were assessed.

Study III utilized data from the First Steps Study, which was the same data set that was used in Study II. First, children's reading fluency and arithmetic fluency measured in Grades 1, 2, 3, 4, 6, 7, and 9 were included in the LPA (see Figure 5 for more details about the LPA model), a common statistical procedure that retrieves homogenous groups from a heterogeneous population. Second, all predictors previously used in Study II were included in the analysis, as well as a few additional predictors. Namely, predictors that reflected parental academic assistance in Grades 1–9 were added. Importantly, for this type of analysis, it was decided not to use the entire sample (over 2,000 children) that was previously utilized in Study II. General population samples have large variability in skills, and if an LPA is run without the sample being restricted to a specific group of interest (without reducing variability), then the groups with low skills are likely to be consolidated into the same group (see Huijsmans et al., 2020 for an example of such a problem occurring in an LPA). In view of this, in this study, the LPA was run only with those participants who scored at least one standard deviation below the mean (calculated for the entire sample) in either reading or arithmetic fluency (or both) measured in Grade 9. In this way, 391 low-performing adolescents were identified for an additional LPA that was carried out with MPlus version 7.3.

The results of Study III showed that within the group of all low-performing students, there were three distinct profiles: Reading Difficulties (RD profile, n = 121), Mathematical Difficulties (MD profile, n= 94), and Comorbid Difficulties (RD&MD profile, n = 176). These findings indicate an extremely high rate of RD&MD comorbidity: 59% of all participants with insufficient reading fluency in Grade 9 additionally demonstrated poor arithmetic fluency, and 65% of all participants with poor arithmetic fluency also showed insufficient reading fluency. The long-term trajectories of these groups (visually represented in Figure 6) diverged over time. Skill gaps between the low-performing and typically-performing students were significant already in early grades but grew consistently larger over time.

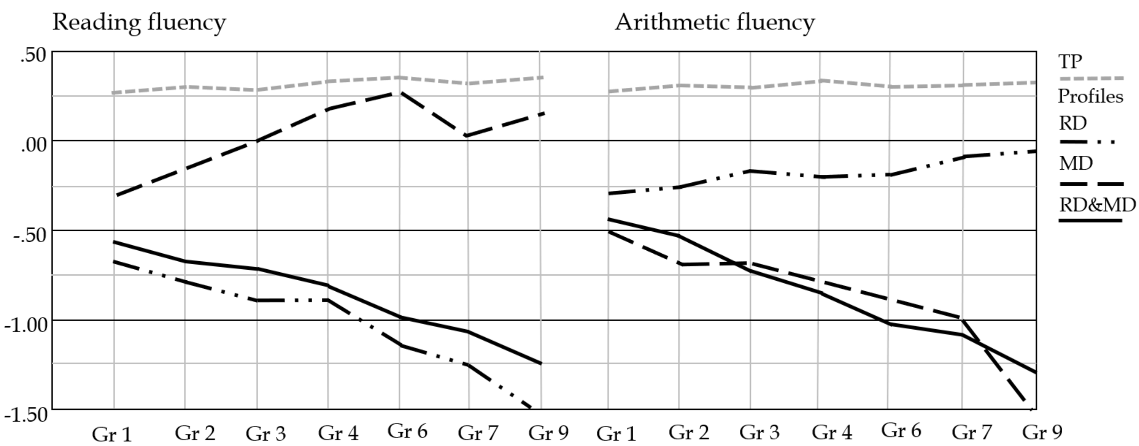

Figure 6 Longitudinal Pathways (Based on Z-Scores) of Different Profiles

Note. RD = Profile of Reading Difficulties, MD = Profile of Mathematical Difficulties, RD&MD = Profile of Comorbid Difficulties, TP = typical performers (added here for comparison but not identified in the LPA).

Subsequent analysis with family-related predictors included repeated measures analysis of variance (ANOVA) and the “three-step approach” (Asparouhov & Muthén, 2014). Both statistical methods showed consistent results, but ANOVAs also provided comparisons between the low-performing profiles and typically performing students. The findings suggest that students with learning difficulties (regardless of the difficulty type) were consistently receiving significantly more academic assistance from their parents than their typically developing counterparts, and this support was domain-specific (MD and RD&MD received more math-related support, while RD and RD&MD received more reading-related support compared with other groups of learners). However, the amount of parental support declined over time, reaching the level of "rarely" by Grade 9 across all low-performing profiles (this finding is visually represented in Figure 7).

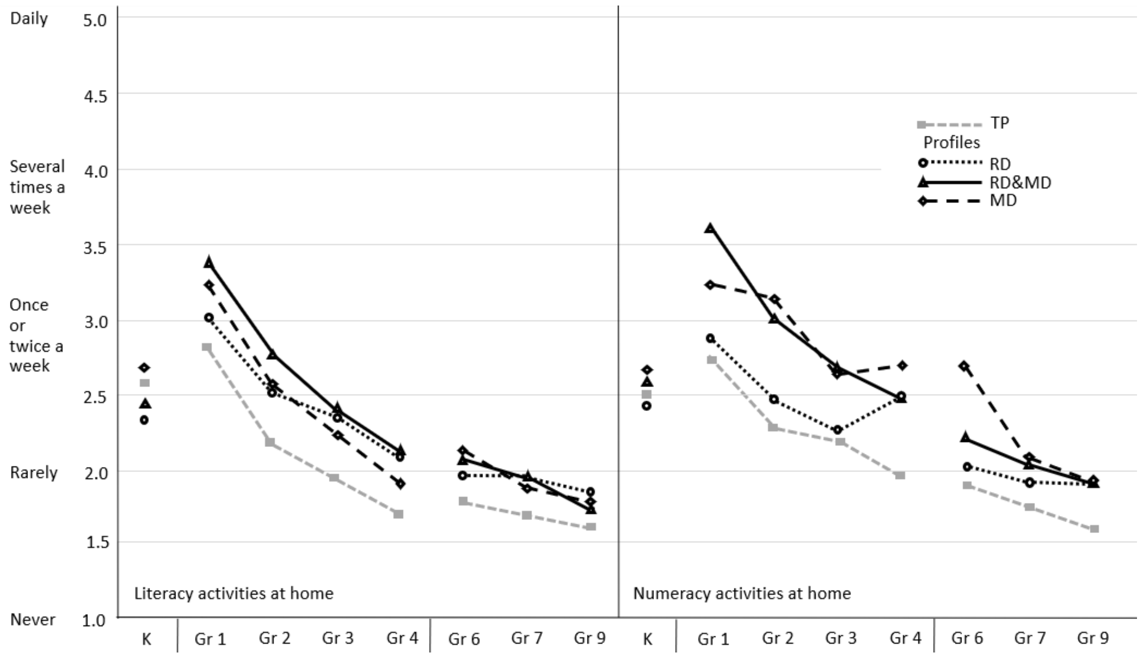

Figure 7 Literacy and Numeracy Activities Organized at Home across Eight Time Points for Different Profiles of Children

Note. RD = Profile of Reading Difficulties, MD = Profile of Mathematical Difficulties, RD&MD = Profile of Comorbid Difficulties, TP = typical performers (added here for comparison but not identified in the LPA), K = Kindergarten. Lines representing the frequency of learning activities have disconnections in Kindergarten and Grade 4 to indicate that the items of the parental questionnaires were adapted to ensure their age appropriateness.

The findings of Study III extended the previous literature on learning difficulties in several ways. No previous study traced the development of reading, arithmetic, and comorbid difficulties over such an extensive period (throughout the duration of compulsory schooling). The identified developmental patterns indicated that both reading and arithmetic difficulties are less common than comorbid difficulties and that children with single RD and MD tend to underperform in the other domain (at least in the early grades). Furthermore, even though parents demonstrated being aware of their children's specific types of difficulties and provided significantly more domain-specific academic support than parents whose children did not have these specific difficulties, it is important to highlight that this support decreased over time and by Grade 9 was provided only rarely despite children's continuously growing need for support. These findings from Study III have important implications for the Finnish education system. First, in early grades, children with learning difficulties (regardless of type) would benefit from a more comprehensive support system that promotes both reading and mathematical development. Second, in later grades, when the non-affected skills have already significantly improved, support should become more deficit-specific to compensate for rare parental support.

4 DISCUSSION

Strong reading and mathematical skills undoubtedly contribute to a higher quality of life. These skills are indispensable for navigating the complexities of modern life, pursuing educational and professional aspirations, and fostering growth at both the individual and societal levels. Research on reading and mathematical development holds the key to more informed educational policies, rational funding allocations, and effective reform initiatives. All of this, in turn, ensures better education for all, including those with difficulties. The present dissertation aims to improve our understanding of reading and mathematical development from childhood to adolescence among different groups of learners and which family-related factors are associated with this development.

Numerous studies have consistently demonstrated a hereditary component of learning difficulties (de Zeeuw et al., 2015; Kovas et al., 2013; Little et al., 2017). Importantly, having a parent with reading difficulties increases the chances of children displaying the same type of difficulties by up to 66%, which makes family risk for reading difficulties (i.e., lower parental reading skills) stand out as one of the strongest early predictors of children's later skills (Snowling & Melby-Lervåg, 2016; Thompson et al., 2015). Encouragingly, intervention research has indicated that children at risk for reading difficulties can benefit significantly from early preventative efforts (Dion et al., 2010; Lovett et al., 2017). Furthermore, studies utilizing prospective family risk samples, where participants with difficulties are intentionally oversampled, have larger statistical power compared with studies with general population samples, due to a broad representation of skill levels at the lower end of the distribution.

For these reasons, the precise identification of family risk holds substantial value in educational, clinical, and research contexts. It facilitates large-scale screenings, enables more targeted early interventions and support, and enhances the methodological rigor of family risk studies and studies examining the role of the home learning environment in child development. Nevertheless, prior to the research conducted as part of this dissertation, different family risk identification methods had not been systematically examined or compared. Study I addressed this research gap by demonstrating that the two most commonly used family risk identification methods yielded nearly equivalent levels of reliability. This suggests that the more cost- and time-efficient method, parental self-reports, can be effectively employed on a broader scale.

What is more, parents provide their children not only with genes but also with the home environment. Research looking at the learning activities organized at home has often shown significant correlations with children's skills (Dong et al., 2020; Mutaf-Yıldız et al., 2020). This, however, does not necessarily mean that the home environment affects children's skills. In fact, when family risk is controlled for, such significant correlations often disappear (Puglisi et al., 2017; van Bergen et al., 2017), revealing the presence of genetic confounding and thus suggesting that the tested environmental factors have much less influence on skill development. Even though identifying influential environmental factors is only possible when environmental influences are examined alongside genetic influences (Asbury & Plomin, 2013), research that includes proper controls and follows children for an extended period is rare. As a result, it remains unclear if academic difficulties can be significantly remediated through consistent learning at home and if this remediation would have a lasting influence. Study II included in the present dissertation followed children from Grade 1 to Grade 9 and revealed that out of different home learning activities, only shared reading had long-term effects on children's development (on reading comprehension specifically), and these effects remained significant even with family risk being controlled for.

Lastly, even though it is well established that reading and mathematical difficulties co-occur at a high rate (Joyner & Wagner, 2020), most scientific studies on reading and mathematical development include only one type of skill in their research focus, and the etiology of the comorbidity between reading and mathematical difficulties remains poorly understood. This is another important research gap that the present dissertation aims to address. Notably, Study II demonstrated that family risk for mathematical difficulties predicted reading comprehension, suggesting that mathematical and reading comprehension difficulties have some common familial underpinnings (Carvalho & Haase, 2019; Landerl & Moll, 2010). Study III revealed that distinct developmental profiles existed, but comorbid learning difficulties were the most common type of difficulty. The results further showed that even when the learners had only single difficulties, they still underperformed in the other domain, at least in early grades, suggesting that the boundaries between different types of difficulties are not so clear-cut and are permeable. Furthermore, while most current research only focuses on either reading or mathematics, the findings discussed in the present dissertation highlight the need for future research to include both reading- and mathematics-related aspects in the same analysis to ensure deeper understanding of skill development.

This thesis adds to an already large body of research that has previously explored a variety of topics related to reading and mathematical development. However, longitudinal studies with proper controls that include reading and mathematical skills together have been rare, and this dissertation aims to fill several important gaps in research by utilizing multiple longitudinal data sets with unique features and extensive follow-ups and by combining the use of person-oriented and variable-oriented methods of statistical analysis.

4.1 Family Risk for Reading and Mathematical Difficulties

It is well known that children develop under the influence of both genetic and environmental factors, but disentangling these influences often represents a challenge. In the studies included in this dissertation, the familial control method was employed to gain a better understanding of what family-related factors play an important role in children's academic development and if they are acting through the genetic and/or environmental pathways. To begin with, in line with a host of previous research on reading development (Elbro et al., 1998; Esmaeeli et al., 2019; Hulme et al., 2015; Torppa et al., 2011, 2015; van Bergen, van der Leij, et al., 2014), Studies I and II showed that parental reading skills significantly predicted children's reading skills, pointing to a familial basis for academic performance. However, analogous research on mathematical development is much less common (Shalev & Gross-Tsur, 2001; Soares et al., 2018), and the present dissertation aimed to address this knowledge gap. Both Studies II and III found that family risk for mathematical difficulties was significantly predictive of children's mathematical skills.

Moreover, Studies I, II, and III extended previous literature by showing that family risk for reading and mathematical difficulties can significantly predict corresponding skills in children not only in early grades but in adolescence and even in adulthood at age 23 (at least in the case of reading skills, as shown by Study I). Notably, previous research reported that family risk for reading difficulties can predict children's reading skills in early grades, even over and above their own pre-reading cognitive skills before school entry (Puolakanaho et al., 2007). Study I expanded upon this research by showing that family risk becomes a redundant predictor once children's own reading skills from earlier time points after school entry are added as autoregressors. This means that family risk identification measures provide uniquely valuable information about children's academic prospects prior to or at the early stages of formal reading instruction but not beyond. Such information can be particularly useful for organizing early interventions with pre-school children (Zijlstra et al., 2021) and for conducting more methodologically rigorous research, including studies on the home learning environment.

It is important to note here, however, that Studies I and II noticeably differed in how much variance family risk could explain in children's skills. In Study I, family risk was much more predictive (explaining 5%–9% of variance) compared with Study II (where around 1% of variance was explained). The key difference between the studies lies in how family risk was measured. In Study I, it was measured with self-reports using 1) a comprehensive questionnaire (with 12 items assessing a variety of issues related to reading) and 2) reading assessments using both a regular text and a list of pseudowords. In Study II, however, the family risk measure consisted of only one self-report item asking parents whether they thought they had reading difficulties. Based on this, it can be concluded that parental self-reports can be a valid alternative to reading assessments, but only when they include a diverse set of items. In addition, Study I revealed that the two identification methods were almost equally predictive and that parents with lower skills were much more willing to complete a self-report than to participate in a skill assessment. This finding should be considered when designing future family risk studies. For example, the use of parental self-reports is likely to ensure a more representative sample, while the use of direct parental assessments is likely to lead to systematic missingness. This, however, could be addressed by oversampling those with difficulties.

Finally, since Study I only focused on reading, a similar study is needed to critically evaluate and compare different methods used for identifying family risk for mathematical difficulties. It is also important to note that none of the family risk identification methods used in the studies included in the present dissertation explained more than 15% of the variance in children's skills at any given time point. This is a rather small amount of variance compared with what is usually reported by studies with genetically sensitive designs. For example, a meta-analysis focusing on twin design studies by de Zeeuw et al. (2015) estimated the genetic effects to be 73% and 57% for reading and mathematical skills, respectively. This suggests that current family risk identification methods can be further improved. Collecting information from both parents for each child appears to be an obvious area for improvement. The present dissertation has sometimes included information from both parents, but sometimes it was available only for one parent. The use of self-reports can potentially help to collect data from both parents. Future methodological research will suggest further areas for improvement. Ultimately, striving for ongoing methodological improvements in family risk research is a worthwhile objective, especially given that family risk studies are less time- and cost-intensive when compared with studies with genetically sensitive designs.

4.2 The Home Learning Environment

The home learning environment is another key topic in this dissertation. Measures assessing the HLE and HNE included formal and informal learning activities. The formal at-home learning activities were divided into 1) reading- and 2) math-related at-home teaching offered to pre-school children and 3) literacy- and 4) numeracy-related parental homework support offered to school-age children. The only informal at-home learning measure that was included in the dissertation studies was shared reading organized with pre-school children. Other informal learning activities should be explored in future research.

Findings from Studies I–III demonstrated that knowledge about family risk can improve research investigating environmental influences in the home. In

Study I specifically, it was found that a comprehensive parental self-report of difficulties is as good as parental skill assessments for identifying children at family risk for learning difficulties, and it can be easily added to the list of items offered to parents reporting the learning activities they organize at home. This can be done by looking at both reading and mathematical development. However, a more acute shortage of studies using the familiar control method exists in the field of mathematics. Indeed, there has been a recent surge of correlational studies suggesting a link between the HNE and children's early mathematical skills (Del Río et al., 2017; Mutaf Yıldız et al., 2018; Susperreguy, Douglas et al., 2020), but very few of these studies controlled for family risk. Thus, it remains unclear which numeracy learning activities are most beneficial for children, and the present dissertation aims to address this knowledge gap. Based on the results of the present dissertation studies, it can be recommended that future studies explore the role of other types of at-home math-related activities, including informal learning activities. These studies need to be longitudinal and control for genetic confounding.

Interestingly, neither Study II nor Study III found any evidence indicative of parental at-home numeracy-related activities contributing positively to children's mathematical skills (in line with findings from De Keyser et al., 2020; Missall et al., 2015; Zippert & Rittle-Johnson, 2020). This, however, does not necessarily mean that these activities are not helpful for children. The lack of significant findings here could be ascribed to various reasons, but there are two that seem to be most plausible. The first relates to the fact that the measures assessing the home numeracy environment and parental academic support contained an insufficient number of questions that were unable to capture the full picture of what parents did at home to support their children's mathematical development. Notably, it has been recently suggested that the same learning activities might contribute differently to children's mathematical skills at different ages, and thus it is important to adjust measures according to children's age. Current research, however, often utilizes measures that are not aligned with age-based practices, and this likely contributes to non-significant and contradictory findings (Mutaf-Yıldız et al., 2020; Thompson et al., 2017). In a collaborative study with Salminen et al. (2021), we used a more extensive list of HLE and HNE items at different time points starting from toddlerhood. This approach allowed us to evaluate the performance of the same items at different time points. As our data collection is ongoing, we are planning new studies utilizing data from preschool and school-age participants. One of our upcoming goals is to better understand how current methodological tools can be adjusted for different age groups.

A second reason no positive associations between the HNE and children's skills were found in the present dissertation studies could be explained by the fact that some parents might have recognized emerging difficulties in their children and provided more learning activities as a response. This speculation is supported by previous findings suggesting that noticing difficulties in children prompts parents to organize more at-home learning (Ciping et al., 2015). In addition to the formal HNE measured before children's school entry, Study III included in the present dissertation has also examined the role of parental academic support (the formal HNE organized during school age). In line with previous studies (Hill & Tyson, 2009; Silinskas et al., 2013), Study III found that more academic support was predictive of worse skills in children, which may suggest that parents were aware of their children's difficulties and were providing support accordingly to facilitate compensation, but unfortunately these efforts did not lead to a substantial enough remediation of difficulties. It appears children's developmental outcomes consistently elicited parental responses, which can be translated into an evocative gene–environment correlation (Plomin, 1994; Plomin et al., 1977; Rutter et al., 1997). Importantly, it is likely that after children started school, their difficulties became more apparent, leading more parents to provide more support. Indeed, the gap between low-performing and typically performing children kept steadily growing over time, suggesting that in pre-school and Grade 1, children's difficulties were less noticeable than in later grades (in some cases difficulties might not yet have emerged at all). This would explain why there was no significant association found before school entry and a negative association at school age.

Another important finding from Study III that deserves a highlight is that even though parents whose children had difficulties were consistently providing significantly more academic support compared with parents whose children did not have difficulties, the amount of this support was steadily declining, and by the time children reached adolescence, this support was on average organized only rarely. Concurrently, the skill gap between typical and low-performing learners only kept growing. While the exact mechanisms behind this gradual decline in support warrant further investigation, it is reasonable to speculate that some children and/or their parents might have felt increasingly frustrated with tasks that continuously increased in difficulty. This frustration could have led them to the conclusion that their efforts at home did not result in improved academic performance. Other potential reasons for the decline in parental support could be related to teachers intentionally reducing the volume of homework they assign to older students or/and children becoming more independent from their parents while potentially becoming more resistant to parental support. Indeed, children are not mere recipients of the home environment – they actively contribute to it (Salminen et al., 2021).

It is important to note here, however, that even though all concepts related to the home environment were assessed using very brief measures, Study II revealed that shared reading specifically was a significant positive predictor of reading comprehension measured at school age. This finding is consistent with a number of studies (Hamilton et al., 2016; Manolitsis et al., 2013; Martini & Sénéchal, 2012; Puglisi et al., 2017; Sénéchal, 2006, 2015; Torppa et al., 2007). Ultimately, these findings lend support to the home literacy model (Sénéchal & Lefevre, 2002), which posits that the informal HLE facilitates the development of reading comprehension specifically. In view of this, it could be the case that formal reading- and math-related teaching organized by parents before the school entry indeed did not have much long-term impact (Manolitsis et al., 2013; Silinskas et al., 2020). It was previously argued that the influence of formal reading-related at-home teaching in the context of consistent orthographies could be rather minor, easily fading away once formal instruction at school begins (Manolitsis et al., 2013; Silinskas et al., 2020). It is also important to highlight that the Finnish education system is known for its effectiveness, high teacher quality, and equal opportunities (Kupiainen et al., 2009; Reinikainen, 2012). Against this background, it is conceivable that the effects of formal at-home math-related teaching also fade away shortly after school entry.

Furthermore, Study II did not find any evidence suggesting that parents' own difficulties were predictive of the home environment. This is in line with some studies (Elbro et al., 1998; Laakso et al., 1999; Torppa et al., 2007) but in contrast with others (Dilnot et al., 2017; Hamilton et al., 2016). Consequently, Study II did not find the home environment to mediate the association between parental difficulties and children's skills, and this finding is consistent with Esmaeeli et al. (2019). There has hardly been any research testing the home environment as a mediator between parental and children's skills, but the need for such research has been acknowledged (Esmaeeli et al., 2019). It is certainly possible that the home learning environment can either act as a protective factor, curbing the negative genetic influences coming from parental difficulties (Torppa et al., 2022) or represent an additional risk factor, such as in those cases where parents with difficulties provide a more disadvantageous environment compared with parents without difficulties (Hamilton et al., 2016). The present dissertation studies, however, did not reveal these indirect links. One of the reasons for this could be attributed to the fact that there are potentially different subgroups of parents with difficulties that first need to be identified before any environmental effects can be observed (for example, some of the parents with difficulties could be placing an emphasis on preventing learning difficulties in their children through a lot of home learning, while others could be avoiding learning activities altogether). This is something that is important to investigate in the future.

4.3 Typical Learners and Learners with Single and Co-occurring Difficulties

While it is generally known that foundational academic skills develop in a highly stable, predictable manner (Aunola et al., 2004; Foorman et al., 1997; Hulslander et al., 2010; Landerl & Wimmer, 2008; Watts et al., 2014), it is important to acknowledge that not everyone's developmental trajectory can be predicted from earlier assessments of their skills. Some individuals exhibit remarkable improvements in their skills, while others experience unexpected declines in the rate of their skill development (Eklund, 2017; Hulslander et al., 2010; Torppa, 2015). In line with earlier research, Studies I, II, and III found that both reading and arithmetic skills were highly stable in the rank ordering of individuals; however, differentiation in how skills developed was also shown to be possible as different developmental patterns emerged over time. Despite the high stability in skill development that makes children's own earlier skills strongly predictive of their later skills, large degrees of variance in adolescent and adult outcomes remain unexplained in research. This implies that, even though most learners follow predictable developmental pathways, less predictable trajectories are also possible.

Study III employed latent profile analysis focusing specifically on those who ended up with the lowest foundational academic skills in adolescence and found three distinct groups of low-performing learners: a group with single reading difficulties, a group with single arithmetic difficulties, and a group with comorbid difficulties. Further analysis included typically performing learners as a reference group. This revealed that divergent developmental patterns became increasingly pronounced over time. All groups of low-performing children started off at similar skill levels in Grade 1 (both in reading and arithmetic fluency), and the skill gaps between low- and typically performing children were at their smallest size. Over time, however, the skill gaps between low- and typically-performing learners kept steadily widening. This finding is consistent with earlier research that followed children in the early grades (Aunola et al., 2004). The present dissertation provides novel insight by showing that the same developmental pattern, the growing divergence between different groups of learners, remains present at least until adolescence.

Importantly, foundational academic skills demonstrate not only developmental stability but also a close interrelation with one another (Koponen et al., 2020; Korpipää, 2020), and findings from Studies II and III further corroborate this knowledge. In Study II, it was found that family risk for mathematical difficulties was significantly predictive of not only arithmetic fluency, but also of reading comprehension. This parent–child cross-domain link provides evidence in support of Pennington's multiple deficit model (2006) that posits an intergenerational transmission of multiple deficits, some of which can lead to reading difficulties and others to mathematical difficulties (Carvalho & Haase, 2019; Landerl & Moll, 2010). Furthermore, Study III revealed that comorbid difficulties were more common than single difficulties, and even those who were allocated to the profiles with single difficulties were, in fact, often underperforming in the other skill, at least in the early grades. These learners, however, gradually followed a resolving trajectory only in the non-affected domain, slightly narrowing down the initial gap with typical learners. All these findings together lend support to the RDoC framework (Cuthbert, 2014), MDM (Pennington, 2006), and the generalist gene hypothesis (Plomin & Kovas, 2005). Indeed, the boundaries between various types of difficulties are challenging to discern, and it is likely that underlying both reading and mathematical difficulties are shared cognitive deficits stemming from the same genetic factors.

4.4 Limitations and Future Directions

The previous sections have already outlined the main methodological shortcomings of the present dissertation, but some of them are still worthy of reiteration and further reflection. One of the main limitations of the present study stems from missingness in paternal self-reports. Even though during data collection for Studies II and III both mothers and fathers were invited to report information on home learning activities, only maternal data were used in the analysis due to extensive missingness in paternal data. The value of collecting information from multiple informants when studying family-related topics has been widely recognized, but unfortunately, the process of recruiting and retaining not only mothers but also fathers in longitudinal research is often fraught with difficulties (Costigan & Cox, 2001; Mitchell et al., 2007). Considering that both parents contribute to both the genetic makeup and the home environment of their children, future studies need to pay special attention to recruiting not only mothers but also fathers. Moreover, since parents with reading difficulties were less likely to participate in reading assessments in Study I compared to those with typical reading skills, it can be further speculated that other types of difficulties can also affect research participation. For example, less functional families and families dealing with serious socio-economic and/or health-related challenges might be less likely to submit their reports of the home environment, thus affecting the estimates in the statistical models and reducing the generalizability of the findings. Addressing this limitation in future studies will represent a serious challenge, but more qualitative participant-led research (i.e., studies where researchers take steps to be less intimidating) specifically with hard-to-reach communities might find some novel ways of recruiting them in large-scale quantitative studies.

Another important limitation of these dissertation studies is the use of self-reports, which are known to be subject to social desirability bias across many different research fields (Bornstein et al., 2015; Fleming, 2012). At the same time, Study I demonstrated that the use of comprehensive self-reports that measure various facets of the same concept can greatly improve the reliability of the measure. Simple and short self-reports can be easily used to generate large data sets, but the inevitable trade-off is that this data often does not reveal the full picture and must be interpreted with utmost caution. More methodological research that evaluates the quality of research measures can help researchers find measures that balance practical utility with the quality of evidence they produce. Pondering the question of what makes a parental self-report of reading difficulties comprehensive enough and what items are the most important to include led me to design an additional study the findings of which are not included in this dissertation, but interested readers might want to acquaint themselves with it separately (Khanolainen et al., in press). Similar studies investigating the role of different self-report items are still lacking in the field of mathematics, but the promising findings coming from the present dissertation should encourage further research that would make use of methods assessing family risk for mathematical difficulties. A critical examination of these research methods will ensure that both identification accuracy and practical applicability are maximized.

Moreover, to facilitate a large-scale data collection involving around 2,000 children, rather brief classroom-based yearly skill assessments were used in Studies II and III. The only math measure included in the present dissertation was arithmetic fluency, while reading assessments incorporated fluency and comprehension tasks. Future research should consider how assessment batteries can be strengthened, and more assessments for different subskills can be included. Simply including more tasks increases the likelihood of participant fatigue. One way to deal with this issue is through implementing planned missingness (i.e., purposefully introduced missingness that can be appropriately handled with specialized statistical techniques) (Zhang & Yu, 2022). With this approach, assessment batteries can be expanded while individual respondent burden and assessment time are reduced. Another effective way to optimize the volume of assessment batteries is by utilizing item response theory. This statistical technique facilitates the identification of the best (most discriminating) items/tasks, allowing researchers to construct brief versions of assessment instruments with retained psychometric properties (Edelen & Reeve, 2007).

Finally, the analysis for both Studies II and III was based on quantitative indicators of the home learning environment and parental academic support (see Dumont et al., 2014 who highlighted why this is not ideal). In future studies, however, it is important to collect additional information on the quality of at-home activities, though this will represent a serious methodological challenge due to the multitude of potentially influential quality-related factors. One such factor could be parental academic anxiety. A limited number of previous studies (Maloney et al., 2015; Oh et al., 2022) have explored the possibility that parents' mathematical anxiety affects the quality of academic support they provide. The argument that has been put forward is that support organized by a math anxious parent could even be detrimental to children's mathematical development. So far, there has been no solid evidence to substantiate this claim because none of the studies conducted so far have controlled for parental mathematical difficulties. This is an important knowledge gap that I have identified during my doctoral research, and I intend to address it in my future studies.

4.5 Practical Implications and Concluding Remarks

The present dissertation unveiled a multitude of novel insights into the development of foundational academic skills. These insights both illuminate important avenues for future research that were outlined in the discussion above and point to three main practical implications for the education system and its support mechanisms. The first practical implication comes from Study I. Though this study was designed to be methodological (i.e., it primarily aimed to improve future research), it also revealed that self-reports can be used on a broader scale in educational practice. Their wider use can facilitate the large-scale screenings necessary for the identification of at-risk children who would benefit from early interventions (see Zijlstra et al., 2021 for an example of such an early intervention for children at family risk for lower reading skills).

The second practical implication relates to the finding from Study II that shared reading organized before school entry was the only component of the early home learning environment that was associated with faster reading comprehension development at school age. This study also found that less-educated parents were less inclined to organize shared reading with their children, favoring teaching activities instead. In view of this, all parents need to be made aware of the long-term benefits shared reading offers. Parents might also find it helpful to receive guidance on how to engage in shared reading effectively. This can be achieved through various initiatives (e.g., parental education programs, community outreach, and awareness campaigns) that stress the importance of organizing interactive reading and discussions during these activities.

The third practical implication relates to the high rate of co-occurring difficulties found in Study III. This finding suggests that most children with learning difficulties would benefit from a comprehensive support system targeting more than just one specific skill deficit. In fact, a comprehensive support system is likely to be beneficial even for those with single difficulties, at least in early grades – the time when they underperform in both foundational academic skills. Study III also indicated that parents of low-performing children tried to offer relevant support throughout the whole time of compulsory schooling, but the amount of it gradually declined. At the same time, the gaps in skills between low-performing and typically performing children not only persisted but widened over time. While the exact reasons why parental support is reduced are yet to be explored, the findings outlined in this dissertation suggest that parents recognize the difficulties in their children, but they struggle to offer adequate support. Thus, it is important to design and revise schools' support mechanisms and intervention programs in a way that would emphasize not only children's skill development itself but also the need to develop the motivation and positive outlook of both children and parents. This approach can help families stay consistent by recognizing the value of their ongoing efforts toward improvement. Doing so can facilitate an effective alliance between children, parents, teachers, and researchers that is needed to achieve better outcomes for all children.

YHTEENVETO

Perheen roolia lukemisen ja matematiikan kehityksessä on tutkittu paljon, mutta tutkimus on yleensä rajautunut vanhempien koulutustasoon sekä kirjojen lukemiseen, peleihin, ja leikkeihin kotona. Kun tutkitaan perheen roolia taitojen kehityksessä, olisi kuitenkin tärkeää huomioida myös vanhempien lukemisen ja matematiikan taidot, koska niiden tiedetään liittyvän sekä kotiympäristöön, että lapsen taitojen kehitykseen. Aiempi tutkimus ei ole myöskään usein tarkastellut lukemisen ja matemaattisten taitojen kehitystä yhdessä. Tämä väitöstutkimus pyrki lisäämään tietoa tällä alueella hyödyntämällä useita pitkittäis-tutkimusaineistoja.

Väitöstutkimuksen tulokset osoittivat, että vanhempien lukutaito ennakoi lasten lukutaitoa. Tutkimuksissa on kaksi yleisintä tapaa tunnistaa vanhempien lukemisvaikeudet; taitotestit ja itsearvioinnit. Niiden avulla mitattujen vanhempien lukemisen vaikeuksien havaittiin ennustavan lasten lukivaikeuksia lähes yhtä hyvin. Tämä viittaa siihen, että vanhempien itsearvioinnit voivat tarjota aikaa ja resursseja säästävän tavan arvioida lasten lukivaikeuden riskiä. Jotta itsearvioinnit olivat yhtä ennustavia kuin lyhyet lukemistestit, tuli niiden olla kattavia ja sisältää monipuolisesti erilaisia osa-alueita.

Lukutaidon lisäksi vanhempien matemaattisten vaikeuksien havaittiin ennustavan lasten matemaattisia vaikeuksia. Lukemisen ja matematiikan taitojen havaittiin myös liittyvän vahvasti yhteen ja vanhempien matemaattiset taidot ennustivatkin lasten matemaattisten taitojen lisäksi lukemisen ymmärtämistä. Samanaikaiset lukemisen ja matemaattisten taitojen vaikeudet olivat jopa yleisempiä kuin yksittäiset vaikeudet näillä alueilla. Nämä havainnot viittaavat siihen, että useimmat oppilaat, joilla on oppimisvaikeutta, tarvitsevat tukea, joka kohdistuu useaan taitoon.

Vanhempien taitojen lisäksi kotiympäristöllä oli merkittävä rooli lasten oppimisessa. Esikouluikäisten lasten kanssa yhdessä lukeminen ennusti positiivisesti taitojen kehitystä. Opettaminen sen sijaan oli negatiivisesti yhteydessä taitoihin. Tulosten valossa on tärkeää tehdä kaikki vanhemmat tietoisiksi yhdessä lukemisen pitkäaikaisista eduista. Opettamisen negatiivinen yhteys taitoihin saattaa johtua siitä, että kun lapsella havaittiin luku- tai matematiikan taidon kehityksessä vaikeuksia vanhemmat pyrkivät tukemaan lasta opettamalla. Tarjotun tuen määrä väheni vähitellen. Taitojen erot heikosti suoriutuvien ja tyypillisesti suoriutuvien lasten välillä eivät kuitenkaan vain säilyneet, vaan ne laajenivat ajan myötä. Vaikka tarkat syyt vanhempien tuen vähenemiseen ovat vielä selvittämättä, tässä väitöskirjassa esitetyt havainnot viittaavat siihen, että vanhemmat tunnistavat lastensa vaikeudet, mutta heillä on vaikeuksia tarjota riittävää tukea läpi peruskoulun.

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ORIGINAL PAPERS

I

INTERGENERATIONAL TRANSMISSION OF DYSLEXIA: HOW DO DIFFERENT IDENTIFICATION METHODS OF PARENTAL DIFFICULTIES INFLUENCE THE CONCLUSIONS REGARDING CHILDREN'S RISK FOR DYSLEXIA?

by

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Intergenerational Transmission of Dyslexia: How do Different Identification Methods of Parental Difficulties Influence the Conclusions Regarding Children's Risk for Dyslexia?

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ABSTRACT

By investigating children whose parents have dyslexia, family risk (FR) studies are expanding our understanding of the intergenerational transmission of dyslexia. These studies, however, vary in their identification of FR, and how the use of different identification methods influences research findings and conclusions is yet to be systematically investigated. This study aims to evaluate the association between two FR identification methods—parental self-reports and direct skill assessments—and their unique contributions in the prediction of children's reading. The study employed two datasets: a prospective FR sample (half of the parents in the sample had dyslexia and the remaining half did not) and an unselected sample. Parental self-reports and direct skill assessments correlated strongly (.60) in the prospective FR sample and moderately (.42) in the unselected sample. Moreover, both FR identification methods were almost equally predictive of children's reading (explaining 5%-9% of the variance at different time points) in the prospective FR sample only. In the prediction of the children's skills, the two methods complemented each other only for some of the measures. At the same time, in the unselected sample, parental skills were not predictive of children's reading, whereas self-reports were. The two FR identification methods seem to have equally high predictive power when the variability in parental data is high. However, they lose their predictive power when either the lower or higher end of the parental reading distribution is underrepresented.

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Dyslexia is a neurodevelopmental disorder that affects the acquisition of reading skills and usually involves difficulties with reading fluency, accuracy, and spelling (American Psychiatric Association, 2011). Like other neurodevelopmental disorders, dyslexia is subject to intergenerational transmission. A recent meta-analysis of family risk (FR) studies (Snowling & Melby-Lervåg, 2016) estimated that if a child has a parent with dyslexia, their probability of having dyslexia is on average 45%. This makes parental reading difficulties an important risk marker for the early identification of children who are prone to later dyslexia and who are likely to benefit from early support.

Although estimations of the probability of dyslexia vary across studies, FR is a significant predictor of reading skills: children with FR are 4–10 times more likely to have reading difficulties than their peers without such family history (e.g., in Finnish, Torppa et al., 2011; in Norwegian, Esmaeeli et al., 2019; in Dutch, van Bergen et al., 2014; in English, Hulme et al., 2015; in Chinese, McBride-Chang et al., 2011). The predictive magnitude of FR varies across studies likely owing to their use of different methodologies to identify parental reading difficulties. The two main identification methods are parental self-reports of reading difficulties and direct skill assessments. Importantly, previous studies indicate that the accuracy of adult dyslexia identification can be significantly affected by the employed methodology (e.g., Deacon et al., 2012; Tamboer et al., 2014). However, how exactly these identification methods influence research findings and conclusions remains to be systematically investigated.

The next logical step to extend existing research is to investigate how different identification methods influence the prediction of children's reading skills. The extent to which parental self-reports and direct skill assessments explain common variance in children's reading skills remains unclear. There are three ways that parental self-reports and direct assessments may be considered: (1) the two methods can be used interchangeably because they provide risk estimations that fully correspond to each other and neither method is superior to the other; (2) one of the methods has a clear predictive advantage, so the other one can be completely abandoned; and (3) the two methods complement each other (e.g., in cases where parents have dyslexia that resolved over time), calling for both methods to be used together for better prediction accuracy. Establishing what FR identification method provides the best prediction accuracy is of empirical and theoretical interest for our current understanding of reading development and for future research. It is also of practical importance—compared with parental skill assessments, a short parental questionnaire can be more easily and widely used to screen for at-risk children. However, is this method sufficiently accurate when used alone? In this study, we set out to address this question. Overall, this study investigated the association between self-reported and directly assessed parental dyslexia, evaluated the unique contribution of each parental dyslexia identification method to predict children's skills, and evaluated the necessity of employing parental assessments for risk estimation after self-reports were already used.

FR Identification with Self-Reports

Self-reports are often regarded as a reliable measure to detect FR (Esmaeeli et al., 2018; Leavett et al., 2014; Snowling et al., 2012). Self-reports have repeatedly been noted as a time-saving and cost-effective tool, especially in large-scale studies for which demand is growing (Esmaeeli et al., 2018; McGonnell et al., 2007; Snowling et al., 2012). Currently, multiple self-report measures that employ various sets of questions are in use. Nevertheless, research investigating how these different measures and their specific items contribute to the accurate identification of children with FR is limited. Moreover, the accuracy of these measures cannot be compared across publications owing to various research design differences.

The main problem with all self-reports stems from researchers' inability to estimate how close the participants' perceptions of themselves are to an objective reality, as social desirability bias is likely to occur and participants' understandings of what constitutes reading difficulties likely vary. Snowling et al. (2012) found that factors such as age, gender, and socioeconomic status significantly influenced parents' likelihood of self-reporting reading difficulties. Deacon et al. (2012) reasonably argued that people can only fill in self-reports based on their individual perceptions of their skills. However, these perceptions can be easily distorted if, for example, a person compares themselves with a gifted sibling or was taught to read by someone who provided ill-suited feedback (either overly positive or negative).

The simplest self-reports rely on a direct self-identification of difficulties. For example, two recent large-scale FR studies (Esmaeeli et al., 2018, 2019; Khanolainen et al., 2020) used a self-report measure that consisted of only one question about having reading and/or writing difficulties. Such measures essentially capture a person's self-concept of ability that is based on a person's perception of oneself formed through experience with and interpretation of one's environment (Shavelson et al., 1976). Although such a simple yes-or-no self-report enabled the collection of large samples, its predictive power was low—FR only explained about 1% (Khanolainen et al., 2020) and 3% (Esmaeeli et al., 2018, 2019) of the variance in children's reading skills. Reducing the reliance on subjective self-perceptions in self-reports, however, is theoretically possible through tapping into different domains of participants' abilities by employing a combination of different types of questions.

A more comprehensive self-report measure was developed and tested by Snowling et al. (2012). Their 15-item questionnaire (the adult reading questionnaire) included not only self-concept questions (e.g., "Do you think you are a good reader?"), but also questions describing specific situations (e.g., "Do you have problems with organization or time management?" and "Do you find it difficult to find the right word to say?") and a direct question about diagnosis (e.g., "Have you ever had a diagnosis of dyslexia?"). Snowling et al. (2012) tested the validity of their measure by asking participants to complete both direct reading assessments and the adult reading questionnaire. Although the self-report measure was found to be valid in the sense that it correlated well with the tested skills, the researchers identified specific groups that were more likely to report difficulties. For example, fathers, older parents, and parents with higher levels of education were more likely to self-report dyslexia. Establishing what explains these findings is difficult, but the researchers speculated that men and people with higher education might feel more comfortable with admitting their reading difficulties. Leavett et al. (2014) used the same dataset as Snowling et al. (2012) and found that adults with a higher socioeconomic status and mild difficulties were more likely to self-report dyslexia than adults with a lower socioeconomic status and more pronounced difficulties. They thus argued that people's self-perception of skills depends on their immediate circle of peers—people compare themselves to those with whom they socialize, and adults with a higher socioeconomic status are often surrounded with people having higher qualifications and more intellectually demanding jobs. However, the extent to which the adult reading questionnaire predicts children's reading difficulties is not known, as neither Snowling et al. (2012) nor Leavett et al. (2014) included children's skills in their analysis.

Another popular self-report measure to identify adult reading difficulties is the adult reading history questionnaire (ARHQ) developed by Lefly and Pennington (2000). Their 23 items tap into an adult's childhood abilities (e.g., "How much difficulty did you have learning to read in elementary school?"), current reading skills (e.g., "How would you compare your current reading speed to that of others of the same age and educational qualifications?"), and memory (e.g., "Do you have difficulty remembering addresses, phone numbers, or dates?"). Deacon et al. (2012) used ARHQ to test if the measure was sufficient to accurately identify high-functioning adults with dyslexia by comparing the reading skills and phonological awareness of three groups of university students: those with an official diagnosis of dyslexia received in childhood, those who never had a diagnosis but self-reported reading difficulties, and the controls. Because all participants were studying at the university level, authors considered those with either a childhood diagnosis or self-reported difficulties to be high-functioning individuals with dyslexia. The two groups with difficulties (diagnosed in childhood and self-reported) performed remarkably similarly across a variety of measures (word and non-word reading fluency and accuracy, reading comprehension, and phonological awareness). Based on these results, Deacon et al. (2012) argued that ARHQ is sufficiently accurate in identifying high-functioning adults with dyslexia whose difficulties were already mostly resolved. However, in FR research, ARHQ is primarily used in combination with direct assessments (Pennington & Lefly, 2001); therefore, the predictive power of the questionnaire regarding children's reading when used on its own remains unclear. Resolved or partly resolved difficulties in parents might still be an important risk factor for child development. The use of self-reports could be the only way to detect this group of parents, and ARHQ appears to be sensitive in this respect.

Specific items might be more predictive in some contexts than others, so the search for the most reliable and practical identification measures continues in different countries. For example, to detect dyslexia among Spanish adults, Giménez et al. (2017) recently developed a 30-item questionnaire with 30 specific situations (e.g., "You sometimes lose the thread of the conversation" and "You have to read slowly to avoid confusion"). Results showed that parental self-reports were almost as accurate predictors of the child reading achievement in Grade 1 as commonly used children's early cognitive skills—rapid automatized naming (RAN) letters, word accuracy, and phonological processing. The researchers performed receiver operating characteristic (ROC) analysis to assess the predictors' discriminative potential and reported the following results: area under curve (AUC) of self-report = .69, AUC of RAN = .73, AUC of phonological processing = .76, and AUC of word accuracy = .81. Although the findings for self-reports do not suggest strong discriminating power (as AUC was below .70), the researchers argued that because parental skill assessments are out of school scope, self-reports are a good alternative measure to identify preschool children in need of preventative support.

Another comprehensive self-report inventory was recently developed in Dutch by Tamboer and Vorst (2015) and included 56 items. First, participants with dyslexia were identified using 10 tests covering all known symptoms of dyslexia (Dutch dictation, English dictation, pseudowords, sound deletion, spoonerisms, spelling, rhyming words, words with missing letters, words with changed letter order, and working memory). Second, the researchers tested which of the self-report items were most predictive of directly assessed dyslexia. They found that less than 20 items were sufficient to accurately differentiate between adults with and without dyslexia, with estimations of correct positive and negative identifications being 89% and 99%, respectively. Despite its promising results, to date, this identification method has not been used in any FR research to predict children's skills. Overall, only few studies use FR to predict children's skills, and they all use different FR identification methods. Thus, before deciding if large-scale studies should shift away from cumbersome assessment batteries and exclusively rely on the use of concise self-report measures, evaluating how FR identification methods influence the prediction of children's skills is important.

FR Identification with Direct Skill Assessments

FR studies using parental reading assessments have reported varying predictive values of FR on children's skills. For example, Torppa et al. (2011) and van Bergen et al. (2014) estimated that FR identified with direct assessments could explain 8%–16% and 11% of the variance in children's reading fluency (children aged 9 in both samples), respectively. In a later cross-sectional study, van Bergen et al. (2016) reported that 17% of the variance in children's (age range: 7–17 years, M = 10.92 years, SD = 2.21) reading fluency was predicted by parental reading fluency.

The main drawback of adult skill assessments was highlighted by Deacon et al. (2012) and Tamboer et al. (2014)—compared with childhood, difficulties in adulthood usually become less pronounced (especially in people with resolved dyslexia) as skills change through educational and occupational experiences. In a Finnish sample of 48 adults with diagnosed childhood reading difficulties and 37 controls, Eloranta et al. (2019) found that more than half (60.4%) of those with childhood reading difficulties did not meet the criteria for adult reading difficulties. This finding calls for further research to investigate whether using parental self-reports and direct skills assessments together increases FR's predictive power.

Present Study

FR studies considerably vary in their research design (in measures and their cutoffs, in participants' age and language, in their decision to include or exclude those with comorbid difficulties, etc.), and the identification tool that predicts children's skills with the highest accuracy has not yet been identified. Thus, research is required that employs both methods—parental self-reports and direct skills assessments—in conjunction, allowing for their effective comparison. This study aimed to analyze how different FR identification methods influence the results of FR studies in the Finnish context. The study sought to answer the following research questions:

1. What is the relationship between self-reported reading difficulties and reading difficulties identified with direct skill assessments among parents?
2. What is the association between parental difficulties (identified with self-reports or direct assessments) and children's skills?
3. Do additional direct skill assessments improve the prediction of children's skills obtained with only parental self-reports?
4. Do the predictive values of self-reports and direct assessments hold when children's own skills from earlier time points are included into the model (as autoregressors)?

To answer these research questions, the present study employed two different samples collected in Finland. The first was the Jyväskylä longitudinal study of dyslexia (JLD) that used a prospective FR design (half of the children in the sample were at FR for dyslexia identified through parental dyslexia and half were controls); this sample had statistical power because it included many parents with dyslexia and had a long follow-up (from birth to age 23), but it made generalization to a general population sample problematic. The second was the interaction, learning, and development (VUOKKO) study that had a recently collected population-based sample; however, the follow-up was short because the children have recently completed Grade 1. The JLD sample had more parents and children with dyslexia and thus more variability. Therefore, we expected stronger associations between parental variables and children's skills in this prospective FR sample than in the VUOKKO sample. However, the population-based sample VUOKKO allowed to validate the associations found in the JLD sample and decide whether they could be generalized to a general population. Both samples had their own advantages and limitations, and using them in combination helped assess the value of different FR identification methods in the prediction of children's reading skills from pre-school to adulthood. Previous studies have provided only a fragmented picture so far because they used samples with specific populations (university students and at-risk groups of people) and/or had a different research focus owing to which their analysis did not include either children's skills or both parental variables (self-reports or direct skill assessment scores). Answering our research questions using both samples enabled us to systematically evaluate how the application of different FR identification methods in different samples can influence our understanding of dyslexia and its intergenerational transmission.

Method

Sample 1

JLD aimed to identify the early precursors of dyslexia by recruiting 200 families expecting a child between 1993 and 1995 and following them since the children were newborns (Leinonen et al., 2001; Lohvansuu et al., 2021). In the present study, we included JLD data from parents (collected before the children were born) and data from their children (collected at six time points: age 7/Grade 1, age 8/Grade 2, age 9/Grade 3, age 14/Grade 8, and age 23). Half of the children were at FR for dyslexia ($N = 102$), and half were age-matched controls ($N = 89$). To be included in the FR group, children needed to have at least one parent with dyslexia. Parental dyslexia was identified using direct skill assessments, clinical interviews, and questionnaires. In addition to concurrent difficulties, the parent with dyslexia was expected to report childhood reading difficulties and having at least one other relative with dyslexia. To be included in the control group, children's parents were required to achieve a z-score higher than −1 in all literacy-related assessments and to report no reading difficulties in their family. Moreover, the two groups were matched on the basis of intelligence quotient scores (all of them had scores higher than 80) and educational levels (they were close to the average level in Finland; see Table 2 for more details). All families recruited in the study were monolingual and spoke Finnish as their first language.

Parental Measures

In the JLD sample, the parents were included based on an initial screening questionnaire. Next, the parents' skills were tested. Then, based on the testing results, they were divided into control and FR groups. In all control families, both parents were tested to ensure that their child did not have FR for dyslexia. The average reading scores of the parents in the control group were used in this study. However, in the at-risk families, only the parents who self-reported dyslexia in the initial screening questionnaire were tested to ensure that they indeed had dyslexia and that the child had FR for dyslexia. Thus, most at-risk families only had a test score available from one parent with dyslexia, and this individual score was used in all calculations (in 10 at-risk families, however, both parents were tested, and in 3 families, both parents had dyslexia; average reading scores of both parents were obtained in those cases).

Direct Reading Assessments

The cognitive assessment for the parents with self-reported dyslexia included a broader assessment battery than the one used with the controls. Of the assessments, two reading tasks that were available for both groups, controls and parents with dyslexia, are included in this study: (1) text reading accuracy and fluency (Tunturilappi: Leinonen et al., 2001) and (2) pseudoword reading accuracy and fluency (Leinonen et al., 2001).

In the text reading task, parents were asked to read aloud a passage about Lapland as fast and as accurately as they could. The reading time of the passage in seconds was the score for text reading fluency, and the total number of correctly read words was the score for text reading accuracy. In the pseudoword reading task, parents were asked to read aloud 30 pseudowords presented one by one (their length varied from two to four syllables). The mean reaction time was the score for reading fluency, and the number of correctly read pseudowords was the score for reading accuracy. The total score of parental skills was computed as an average of the two fluency and two accuracy z-scores. Cronbach's alphas for the overall composites were .92 for both mothers and fathers.

Self-reports of Reading Difficulties

Parents were asked to complete a self-report measure that included items that were identical or almost identical to the items from the ARHQ (Lefly & Pennington, 2000). The 12 items used in this study corresponded to the ARHQ items 2, 5, 6, 9, 11, 13, 16, 17, 19, 20, 22, and 23. An average of both parental self-reports was obtained in the case of all control families and when data on the at-risk families with two parental assessments were available (10 cases). In the case of most at-risk families, however, an individual score of the parent who participated in the reading assessment was used. Cronbach's alphas for the composites of all self-report items were .81 for mothers and .77 for fathers.

Child Measures

Separate total scores for reading fluency and accuracy were computed for different time points (Grades 2, 3, and 8 as well as age 23) as the composites of the fluency and accuracy scores achieved on the assessments listed below (word list reading, text reading, and pseudoword text reading). Cronbach's alphas for the fluency composites were .90 in Grade 2, .87 in Grades 3 and 8, and .86 at age 23. Cronbach's alphas for the accuracy composites were .65 in Grade 2, .67 in Grade 3, .60 in Grade 8, and .66 at age 23. Grade 1 assessment included only one measure.

Word Reading

A subtest of the nationally standardized reading test battery (ALLU; Lindeman, 1998) was used to assess word-level reading in Grade 1. This test offered 80 items containing a picture with four phonologically similar words next to it. Children were asked to look at pictures and choose a matching word for them within a 2-min time limit. The fluency score used in the analyses was obtained by calculating the sum of correct answers (the maximum value was 80). The accuracy score was calculated as 100 * the sum of correct answers/(the sum of correct answers + the sum of incorrect answers).

Word List Reading

Word list reading was assessed with the nationally standardized reading test Lukilasse (Häyrinen et al., 1999) in Grades 2, 3, and 8 and at age 23. The reading list comprised 90 items in Grade 2 and 105 items in Grades 3–8 and at age 23. Children were asked to read aloud as many words as possible within 2 min in Grade 2 and within 1 min in Grades 3 and 8. The fluency score was calculated as the sum of all correctly read words, whereas the accuracy score corresponded to the percentage of correctly read words out of all attempted items.

Text Reading

Three age-appropriate texts of varying lengths (124–204 words) were used to assess text reading in Grades 2, 3, and 8 and at age 23. The reading time was considered as the fluency score, and the percentage of correctly read words corresponded to the accuracy score.

Pseudoword Text Reading

Children were asked to read aloud a short text comprising 19 pseudowords in Grade 2 and 38 pseudowords in Grades 3 and 8 and at age 23. The sentence structure and made-up words resembled the Finnish language. The reading time was considered as the fluency score. The percentage of correctly read words was considered as the accuracy score.

Sample 2

The VUOKKO study (Lerkkanen & Salminen, 2015–2019; Salminen, Lerkkanen, et al., 2021–2023) is a follow-up study that follows the development of children's emerging literacy and numeracy skills across toddlerhood (age 2–3 years), preschool (age 5–6 years), and primary school (age 7/Grade 1). The VUOKKO study aims to better understand how the characteristics of children's different learning environments (early childcare and learning, primary education, and children's home environment) are associated with children's learning and development across childhood. For the study, children born in 2013 ($N = 265$; 138 males, 127 females), with their parents and early childhood educators, were recruited from one mid-sized city in Central Finland in 2015 when the children were 2 years old. Majority of the families recruited in the study were monolingual and spoke Finnish as their first language (five families spoke a language other than Finnish). In the present study, we used data collected at one time point: at age 7–8/Grade 1 ($N = 318$; 152 girls and 166 boys).

Parental Measures

Direct Reading Assessments

When the children in the sample were in Grade 1, their parents were invited to participate in the assessment of their own reading skills. Of the assessments, two reading tasks are included in this study: (1) text reading accuracy and fluency (Tunturilappi: Leinonen et al., 2001) and (2) pseudoword list reading accuracy and fluency (Nevala et al., 2006).

In the text reading task, parents were asked to read aloud as fast and as accurately as they could the same passage about Lapland used in Sample 1 (JLD). The reading time of the passages in seconds was considered as the score for reading fluency, and the total number of correctly read words was considered as the score for text reading accuracy. In the pseudoword list reading task, parents were asked to read aloud the list of pseudowords as quickly and as accurately as they could. The fluency score was represented by the total reading time, and the accuracy score was the number of correctly read pseudowords. The total parental skill score was computed as the average of the two fluency and two accuracy z-scores. Cronbach's alphas for the parental skill scores (combining text and pseudoword list accuracy and fluency) were .68 and .76 for mothers and fathers, respectively. In cases when the scores of both parents were available, their average was calculated (both parents of 37 children were assessed). However, in the case of most children, only one parent consented to their direct assessment (59 fathers and 88 mothers). Thus, their individual scores were used in all calculations.

Self-reports of Reading Skills and Difficulties

All parents of children in Grade 1 were asked to self-assess their reading skills by completing the full set of items of the ARHQ (Lefly & Pennington, 2000). We then selected the 12 items that were also available in JLD. Cronbach's alphas for the composites of the selected items were .76 and .73 for mothers and fathers, respectively. All available self-reports were used in initial analyses. However, because the parental skill assessment data had considerable missingness, analysis was performed a second time including only those self-reports whose direct assessments were also available (the sum score of both parental self-reports was obtained for families whose both direct assessments were available, and an individual self-report score was used in cases when only one parent participated in the assessments).

Child Measures

Separate total scores were computed for reading fluency and accuracy in Grade 1 by combining the word reading and sentence reading tasks. Cronbach's alphas for the fluency and accuracy composites were .87 and .56, respectively.

Word Reading

A subtest of the nationally standardized reading test battery (ALLU/TL2A; Lindeman, 1998) was used to assess word-level reading fluency and accuracy in Grade 1. In this test, a maximum of 80 items can be attempted within a 2-min time limit. Each item contained a picture with four words next to it. Children were asked to read the four phonologically similar words and draw a line connecting the picture to the word that matched it. The fluency score used in the analyses was obtained by calculating the sum of correct answers (the maximum value was 80). The accuracy score was calculated as 100 * the sum of correct answers/ (the sum of correct answers + the sum of incorrect answers).

Sentences Reading

The test of silent reading efficiency and comprehension (TOSREC; Wagner et al., 2009) was used as a measure of sentence-level reading fluency and accuracy in Grade 1. TOSREC is a group-administered reading test wherein children read and evaluate the truthfulness of sentences based on real-world knowledge. The sentences gradually became more difficult. Children were given 3 min to read and verify the truthfulness of as many sentences as possible. The fluency score was calculated by summarizing the number of correct answers (the maximum value was 60). The accuracy score was calculated in the same way as for the word reading task.

Statistical Analysis

Table 1 lists the descriptive statistics for all variables used in both samples in this study. Because the distributions of many variables were skewed, we used the maximum likelihood estimator with robust standard errors (MLR) for model estimation in Mplus. Reliance on robust standard errors provides more accurate results when data are nonnormal (Maydeu-Olivares, 2017; Savalei, 2010). Before performing the analysis, we checked the two datasets for outliers. Few outliers were detected using z-scores with cutoff values of 3 and −3. We then performed our analysis twice—first with clean datasets in which outliers were moved to the tails and second with original datasets in which outliers were kept intact. The results did not significantly differ. In view of this, the findings reported below were obtained with the original datasets.

As the next step of data preparation, we examined the patterns of missing data. In the JLD sample, the parental self-reports had no missing data and parental skill assessments had only two missing values. Little's test of missing completely at random (MCAR) showed that children's data were missing at random ($\chi^2(18) = 23.853$, $p = .160$) with one exception—skills in Grade 1. This variable, however, contained very few missing values (two values, which is around 1%). In view of this, we proceeded with our analysis without any further action related to missingness.

In contrast, in the VUOKKO sample, 336 parents submitted their self-reports, but only 147 parents' skills were directly assessed. Overall, out of the 318 children assessed in Grade 1, 101 had at least one parent with a direct assessment. Extensive missingness in parental skills prompted us to examine its pattern. We performed Little's MCAR test; results showed that parental skills were not missing at random ($\chi^2(10) = 19.32$, $p = .036$). Further inspection revealed that parents whose children had lower reading scores were less likely to participate in a direct assessment.

Apart from this systematic missingness in parental skill data, we established that the VUOKKO sample had other distinctive features that need to be noted. Although parental reading test and self-report scores were approximately normally distributed, highly educated parents with solid reading skills were overrepresented. Table 2 shows that in the VUOKKO sample, parents were not only more educated than those in the JLD sample, but also more educated than the control parents in the JLD sample. In addition, we specifically examined the results of the text reading task because it was used to assess parents in both samples (Tunturilappi: Leinonen et al., 2001). This analysis revealed that the parents in the VUOKKO sample read faster than the control parents in the JLD sample (the means in the entire VUOKKO sample were 124.54 and 134.86 s for mothers and fathers, respectively, whereas the means in the JLD control group were 137.96 and 147.57 s for mothers and fathers, respectively). The implications of these sample characteristics are discussed later in the article (in the Discussion section).

Our analysis strategy comprised three main steps and was followed for each dataset using SPSS 24 and Mplus Version 7.4 (Muthén & Muthén, 2012). First, we separately used each FR identification method's scores (parental skill assessments and self-reports) to predict children's skills at each time point through a series of simple linear regressions. Second, we conducted hierarchical linear regression analysis to assess whether the inclusion of direct assessment improves children's skill prediction conducted with only parental self-reports. We also added the interaction between parental self-reports and skill assessments as the last block in our hierarchical regressions to determine whether having all the different aspects of FR (a person's broadly but subjectively self-reported history of various experiences related to reading as well as adult difficulties objectively but briefly measured via direct assessments) constitutes a particularly high risk for children's reading development. Third, to further investigate the predictive relations between parental and children's variables, longitudinal path models with observed variables were constructed. Separate path models (that included both self-reported and assessed parental skills as predictors of children's skills at all time points) were fitted to the longitudinal dataset (JLD): one for children's reading fluency and the other for children's reading accuracy. The goodness of fit of these models was assessed using four indicators: chi-square test, comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR). To be considered as a model with a good fit, the four indices below needed to be as follows: non-significant chi-square, CFI greater than 0.95, RMSEA less than 0.06, and SRMR less than 0.08 (Hu & Bentler, 1999).

Results

Pearson correlation coefficients are reported across all measures in Table 3 for JLD and Table 4 for VUOKKO. Most variables were significantly related with one another. As can be seen from these tables, parental self-reported difficulties and parental reading skills assessed with direct assessments were significantly correlated (.60 in JLD and .42 in VUOKKO). These associations provide an answer to our first research question.

To answer the second research question (about the association between parental difficulties and children's

TABLE 1
Descriptive Statistics for All Variables Across Time

	N	Minimum	Maximum	Mean	*SD*	Skewness (std. error)	Kurtosis (std. error)
JLD (the whole sample)							
Reading fluency							
Grade 1	182	8.00	80.00	43.53	19.68	.33 (.18)	−.86 (.36)
Grade 2	169	1.23	10.22	5.16	2.06	.26 (.19)	−.68 (.37)
Grade 3	191	1.55	11.30	5.84	1.86	.38 (.18)	−.13 (.35)
Grade 8	173	2.96	13.85	8.71	2.03	−.11 (.18)	−.09 (.37)
Age 23	129	4.10	17.48	10.21	2.23	.21 (.21)	−.36 (.42)
Reading accuracy							
Grade 1	182	28.13	100.00	95.49	9.41	−4.51 (.18)	23.18 (.36)
Grade 2	169	56.53	100.00	88.29	9.05	−1.23 (.19)	1.09 (.37)
Grade 3	191	63.56	100.00	91.41	7.23	−1.50 (.18)	2.09 (.35)
Grade 8	173	72.46	99.68	94.93	4.94	−2.46 (.18)	6.85 (.37)
Age 23	129	73.91	100.00	97.17	3.53	−3.58 (.21)	17.39 (.42)
Parental formally assessed reading skill							
	189	−1.02	5.21	.00	1.00	2.05 (.18)	5.39 (.35)
Parental self-reported reading skill							
	191	.21	2.27	.97	.43	.64 (.18)	−.14 (.35)
JLD (FR group only)							
Reading fluency							
Grade 1	97	8.00	80.00	38.20	18.22	.60 (.24)	−.40 (.48)
Grade 2	94	1.23	9.33	4.52	1.81	.40 (.25)	−.34 (.49)
Grade 3	102	1.75	11.30	5.42	1.77	.76 (.24)	1.02 (.47)
Grade 8	95	2.96	13.85	8.19	2.10	.16 (.25)	−.26 (.49)
Age 23	69	5.59	16.18	9.70	2.29	.52 (.29)	−.11 (.57)
Reading accuracy							
Grade 1	97	45.28	100.00	94.43	10.17	−3.30 (.24)	11.07 (.48)
Grade 2	94	56.53	99.46	85.86	10.34	−.84 (.25)	−.07 (.49)
Grade 3	102	63.56	100.00	89.48	7.99	−1.01 (.24)	.58 (.47)
Grade 8	95	74.33	92.52	93.85	5.62	−1.87 (.25)	3.28 (.49)
Age 23	69	82.12	100.00	96.75	3.49	−2.27 (.29)	5.95 (.57)
Parental formally assessed reading skill							
	100	−.75	5.21	.59	1.06	1.68 (.24)	3.79 (.48)
Parental self-reported reading skill							
	102	.42	2.27	1.28	.35	.48 (.24)	−.42 (.47)
JLD (controls only)							
Reading fluency							
Grade 1	84	8.00	80.00	49.49	19.69	.06 (.26)	−.99 (.52)
Grade 2	75	1.60	10.22	5.56	2.07	−.05 (.28)	−.81 (.55)

(continued)

TABLE 1
Descriptive Statistics for All Variables Across Time (*continued*)

	N	Minimum	Maximum	Mean	SD	Skewness (std. error)	Kurtosis (std. error)
Grade 3	89	1.55	10.69	6.33	1.86	.01 (.25)	−.51 (.51)
Grade 8	78	3.33	13.85	9.34	1.74	−.25 (.27)	.97 (.54)
Age 23	60	4.10	17.48	10.79	2.03	−.01 (.31)	2.43 (.61)
Reading accuracy							
Grade 1	84	28.13	100.00	96.69	8.40	−6.99 (.26)	55.24 (.52)
Grade 2	75	71.13	100.00	91.34	5.89	−1.30 (.28)	1.86 (.55)
Grade 3	89	65.83	100.00	93.63	5.50	−2.36 (.25)	7.99 (.51)
Grade 8	78	72.46	99.68	96.25	3.57	−4.16 (.27)	25.37 (.54)
Age 23	60	73.91	100.00	97.64	3.56	−5.30 (.31)	34.30 (.61)
Parental formally assessed reading skill							
	89	−1.02	.12	−.66	.18	.81 (.25)	2.67 (.51)
Parental self-reported reading skill							
	89	.21	1.81	.62	.18	.43 (.25)	−.08 (.51)
VUOKKO (the whole sample)							
Reading fluency							
Grade 1	318	−2.14	4.36	.00	.94	.78 (.14)	1.39 (.27)
Reading accuracy							
Grade 1	318	−8.20	.48	.00	.83	−4.97 (.14)	37.14 (.27)
Parental formally assessed reading skill							
	100	−1.35	2.19	−.03	.64	.91 (.24)	1.35 (.48)
Parental self-reported reading skills							
	316	1.17	4.17	2.11	.54	.74 (.14)	.60 (.27)

skills at each time point), a series of simple linear regressions were calculated. The results are presented in Table 5 for the JLD sample and in Table 6 for the VUOKKO sample. Regressions were calculated first with parental self-reports as a single predictor and then with parental test scores as a single predictor of children's skills. Regarding the JLD sample, the regressions were run for the full sample and then separately for the FR and control groups.

In the JLD sample, self-reported parental reading and directly assessed parental reading were both significant predictors of children's reading fluency and accuracy at most ages. The only exceptions were children's accuracy in Grade 1 and at age 23—neither parental measure was significantly predictive at these two time points. The regression coefficients for the self-reports and assessments were similar; they predicted between 5% and 8% of variance in children's fluency and between <1% and 15% in children's reading accuracy. However, parental self-reports and skill assessments were rarely significant predictors when the FR and control groups were separated. Among the controls, parental skills predicted children's reading fluency in Grade 2. Among the FR group, parental skills predicted children's reading accuracy in Grade 3.

In the VUOKKO sample, reading fluency in Grade 1 was significantly predicted by parental self-reports but not by their directly assessed skills. Moreover, as can be seen from Table 6, self-reports were significantly predictive of children's fluency in Grade 1 only when all available self-reports were included. However, self-reports stopped being significantly predictive when the model included only the self-reports from parents who also participated in a direct skill assessment. In addition, neither parental measure predicted children's accuracy in Grade 1, thus replicating the findings of the JLD sample.

Because findings based on p-values alone can be misleading, Tables 5 and 6 present the confidence intervals and coefficients of determination. Moreover, most of the significant values would remain significant ($p < .05$) even if the p-values were adjusted for multiple testing using the Bonferroni correction method (multiplying the raw

TABLE 2
Parental Education Levels in JLD and VUOKKO

Parental education levels	JLD			VUOKKO
	Whole sample	FR group only	Controls only	Whole sample
	N (percent in the sample)			*N* (percent in the sample)
Mothers				
No vocational education or short-term courses only	11 (5.5%)	8 (7.8%)	3 (3.4%)	1 (0.4%)
Vocational school degree	48 (24.0%)	31 (30.4%)	16 (18.0%)	53 (20.1%)
Vocational college degree	53 (26.5%)	22 (21.6%)	30 (33.7%)	10 (3.8%)
University degree (including higher degrees)	88 (44.5%)	41 (40.2%)	40 (44.9%)	200 (75.8%)
Fathers				
No vocational education or short-term courses	14 (7.1%)	6 (5.9%)	8 (9.0%)	4 (3.5%)
Vocational school degree	98 (49.5%)	56 (55.4%)	37 (41.6%)	22 (19.5%)
Vocational college degree	37 (18.7%)	18 (17.8%)	17 (19.1%)	7 (6.2%)
University degree (including higher degrees)	49 (24.7%)	21 (20.8%)	27 (30.3%)	80 (70.8%)

p-values by the number of tests). The use of both this method and multiple effect indicators reveals consistent results, thus increasing our confidence in our findings. The overall pattern is clear: in the JLD sample, the two parental measures were equally significant predictors of both children's fluency and accuracy (with two exceptions—accuracy in Grade 1 and at age 23; these values were predicted by neither method), whereas in the VUOKKO sample, only parental self-reports were predictive of children's fluency in Grade 1 (again, accuracy in Grade 1 was not predicted).

To assess whether the inclusion of both FR identification methods improved the prediction of children's skill (the third research question), or whether the interaction

TABLE 3
Pearson Correlation Coefficients Between all Variables in the JLD Sample

	1	2	3	4	5	6	7	8	9	10	11	12
1. Reading fluency in Grade 1	1											
2. Reading fluency in Grade 2	.77***	1										
3. Reading fluency in Grade 3	.64***	.89***	1									
4. Reading fluency in Grade 8	.51***	.73***	.79***	1								
5. Reading fluency at Age 23	.46***	.71***	.76***	.80***	1							
6. Reading accuracy in Grade 1	.41***	.38***	.32***	.29***	.26**	1						
7. Reading accuracy in Grade 2	.55***	.51***	.51***	.49***	.49***	.39***	1					
8. Reading accuracy in Grade 3	.51***	.59***	.51***	.55***	.58***	.37***	.68***	1				
9. Reading accuracy in Grade 8	.33***	.42***	.43***	.43***	.51***	.30***	.55***	.67***	1			
10. Reading accuracy at Age 23	.32***	.39***	.41***	.45***	.44***	.28***	.52***	.67***	.75***	1		
11. Parental skills assessment	26***	.29***	.23**	.27***	.29**	.05	.31***	.39***	.19*	.23**	1	
12. Parental self-report	.26***	.29***	.24**	.28***	.22*	.12	.25**	.26***	.20**	.16	.60***	1

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

TABLE 4
Pearson Correlation Coefficients Between all Variables in the VUOKKO Sample

	1	2	3	4
1. Reading fluency in Grade 1	1			
2. Reading accuracy in Grade 1	.30***	1		
3. Parental skills assessment	.02	.06	1	
4. Parental self-report	.27***	.09	.42***	1

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

between self-reports and skill assessments predicted children's skills, a series of hierarchical linear regressions was performed (one for each time point). This analysis was performed only with the JLD sample after it was established that in the VUOKKO sample, children's skills were predicted only by parental self-reports (Table 7). Parental self-reports in JLD were added as a predictor for the first block analysis, direct assessments for the second block analysis, and the interaction of self-reports and assessments for the third block analysis (prior to this step in the analysis, independent variables were centered to reduce structural multicollinearity). The results revealed that incorporating direct skill assessments did not significantly improve the prediction of children's fluency over and above the self-report measure. One exception was the reading fluency at age 23, where the prediction was improved by implementing both FR identification methods. Moreover, the prediction of children's accuracy in Grades 2 and 3 and at age 23 was significantly improved by implementing parental skill assessments. None of the interactions was significantly predictive, suggesting that the effects either were tapping the same variance or were additive (for reading fluency at age 23 and reading accuracy in Grades 2 and 3 and at age 23).

To further assess the association between parental difficulties and children's reading skills and to answer the fourth research question (about the addition of

TABLE 5
Standardized Model Estimates in Simple Linear Regressions Conducted Separately for Each Time Point, for Each Predictor and for the Controls and FR Group (JLD Sample)

	Predictor—Parental self-reports						Predictor—Parental skills					
Outcome	Whole sample estimate (s.e.) 95% CI	R^2	FR group estimate (s.e.) 95% CI	R^2	Control group estimate (s.e.) 95% CI	R^2	Whole sample estimate (s.e.) 95% CI	R^2	FR group estimate (s.e.) 95% CI	R^2	Control group Estimate (s.e.) 95% CI	R^2
Reading fluency												
Grade 1	.26*** (.07) [.12, .40]	.07	.07 (.11) [−.15, .30]	.01	.10 (.11) [−.12, .32]	.01	.26*** (.06) [.15, .38]	.07	.13 (.08) [−.02, .28]	.02	.19 (.11) [−.03, .40]	.03
Grade 2	.29*** (.07) [.16, .43]	.09	.04 (.10) [−.16, .25]	.00	.09 (.12) [−.15, .34]	.01	.29*** (.06) [.19, .38]	.08	.08 (.09) [−.06, .22]	.01	.28* (.11) [.10, .47]	.08
Grade 3	.24*** (.06) [.12, .37]	.06	.11 (.09) [−.07, .29]	.01	.09 (.12) [−.14, .32]	.01	.23*** (.06) [.12, .34]	.05	.12 (.08) [−.03, .28]	.01	.11 (.10) [−.08, .31]	.01
Grade 8	.28*** (.07) [.14, .41]	.08	.10 (.10) [−.09, .29]	.01	.12 (.12) [−.12, .36]	.01	.27*** (.06) [.15, .39]	.07	.13 (.08) [−.03, .30]	.02	.13 (.12) [−.10, .37]	.02
Age 23	.22** (.08) [.07, .37]	.05	.06 (.10) [−.15, .26]	.00	.05 (.15) [−.25, .36]	.00	.29*** (.08) [.13, .43]	.08	.22* (.09) [.03, .40]	.05	.18 (.11) [−.03, .39]	.03
Reading accuracy												
Grade 1	.12 (.09) [−.05, .30]	.01	.05 (.12) [−.18, .28]	.00	.05 (.11) [−.17, .27]	.00	.05 (.06) [−.07, .17]	.00	.06 (.09) [−.23, .11]	.00	.12 (.08) [−.04, .28]	.01
Grade 2	.25** (.08) [.10, .40]	.06	.03 (.11) [−.19, .25]	.00	.09 (.13) [−.17, .35]	.01	.31*** (.08) [.15, .46]	.09	.18 (.11) [−.03, .39]	.03	.02 (.11) [−.20, .23]	.00
Grade 3	.26*** (.07) [.12, .40]	.07	.06 (.10) [−.14, .26]	.00	.10 (.13) [−.17, .36]	.01	.39*** (.07) [.24, .53]	.15	.34** (.10) [.15, .54]	.12	.01 (.09) [−.17, .19]	.00
Grade 8	.20** (.07) [.07, .32]	.04	.02 (.11) [−.23, .19]	.00	.17 (.16) [−.14, .48]	.03	.19* (.09) [.00, .38]	.04	.06 (.13) [−.19, .31]	.00	.02 (.07) [−.16, .13]	.00
Age 23	.16 (.09) [−.02, .34]	.03	.10 (.14) [−.17, .36]	.01	.14 (.20) [−.24, .52]	.02	.23 (.15) [−.07, .54]	.05	.33 (.20) [−.07, .73]	.11	.05 (.05) [−.15, .06]	.00

Note. *$p < .05$, **$p < .01$, ***$p < .001$. All models were saturated.

TABLE 6
Standardized Model Estimates in Simple Linear Regressions Conducted Separately for Each Time Point and for Each Predictor (VUOKKO Sample)

	Predictor—Parental self-reports			Predictor—Parental skills		
Child outcomes	Estimate (s.e.)	95% CI	R^2	Estimate (s.e.)	95% CI	R^2
Regressions with all self-reports included (N = 336)						
Reading fluency, Grade 1	.27*** (0.05)	[.17, .37]	.07	.02 (0.09)	[−.16, .21]	.00
Reading accuracy, Grade 1	.09 (0.05)	[−.01, .19]	.01	.09 (0.09)	[−.07, .24]	.01
Regressions with self-reports from parents who also participated in assessments (N = 103)						
Reading fluency, Grade 1	.12 (0.10)	[−.08, .31]	.01	.02 (0.09)	[−.16, .21]	.00
Reading accuracy, Grade 1	.11 (0.08)	[−.27, .04]	.01	.09 (0.09)	[−.07, .24]	.01

Note. * $p < .05$, ** $p < .01$, *** $p < .001$. The models were saturated.

autoregressors), two longitudinal path models were constructed with the JLD total sample (one for fluency and the other for accuracy, as presented in Figures 1 and 2, respectively). The accuracy model fitted the data well: χ2(6) = 11.50, p = .07, RMSEA = .06, CFI = .98, and SRMR = .06. However, because the same type of model for fluency did not fit the data well, we inspected the modification indices provided by Mplus. A theoretically relevant path with modification index above 10.00 was added to the fluency model to improve its fit: children's reading fluency at age 23 was regressed on reading fluency in Grade 3 (standardized estimates of this path are presented in Figure 1). After the new path was added, the fluency model fitted the data well: $\chi^2(5) = 5.92$, p = .31, RMSEA = .03, CFI = .99, and SRMR = .01.In comparison to the previous models (simple linear regressions), these two longitudinal models included children's skills as autoregressors; therefore, both parental skill assessment scores and self-reports stopped being predictive of children's reading fluency. For the accuracy model, however, parental skill assessment scores were still significantly predictive of children's reading accuracy in Grade 2. Overall, children's fluency scores demonstrated higher stability over time than their accuracy scores.

Discussion

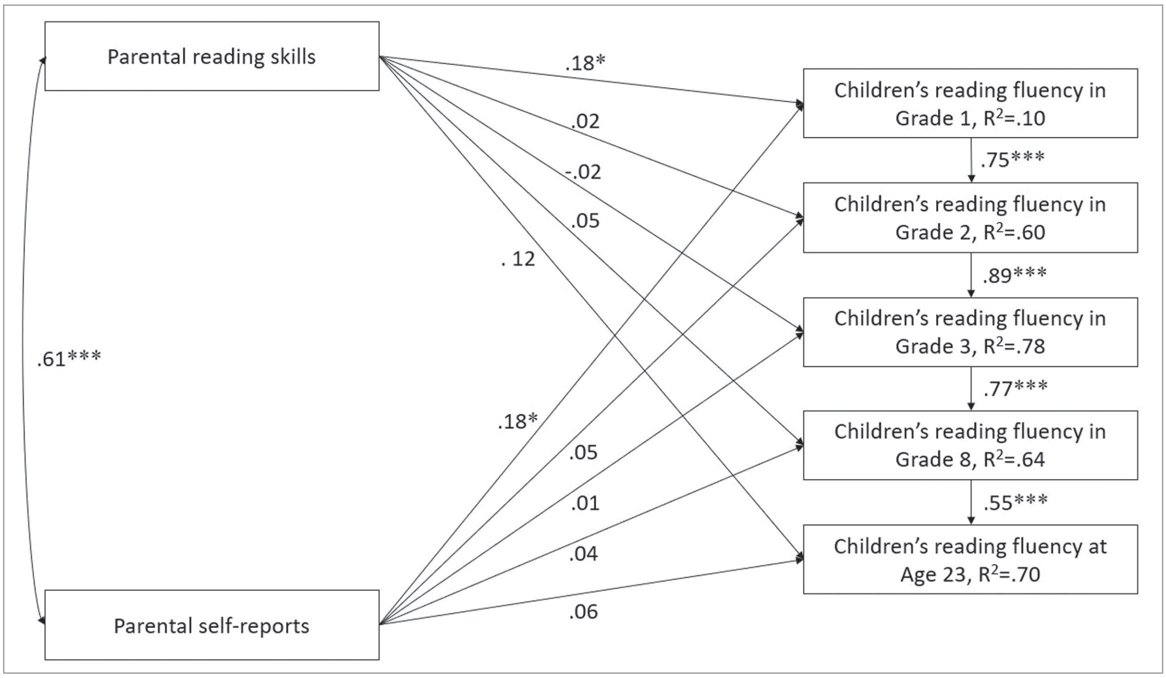
FR for dyslexia can be defined as children's predisposition for developmental dyslexia stemming from one or both of their parents having dyslexia. In this study, we investigated how different FR identification methods influence the associations between FR and children's reading skills. Our study employed two different samples collected in Finland.

TABLE 7
Hierarchical Regressions for Fluency and Accuracy Outcomes in JLD (the Whole Sample), Each with Three Steps: 1) Self-reports, 2) Formal Assessments, 3) Interaction Between Self-reports and Formal Assessments

	Parental self-report (step 1)		Parental formal tests (step 2)		Interaction (step 3)	
Child outcomes	ΔR^2	F change	ΔR^2	F change	ΔR^2	F change
1. Gr 1 fluency	.07	13.41***	.02	3.52	.00	.58
2. Gr 2 fluency	.09	15.58***	.02	3.72	.01	1.23
3. Gr 3 fluency	.06	12.36**	.01	1.97	.00	.02
4. Gr 8 fluency	.08	13.81***	.02	3.14	.01	1.05
5. Age 23 fluency	.04	5.61*	.04	5.33*	.00	.26
6. Grade 1 accuracy	.02	2.90	.00	.17	.01	1.45
7. Grade 2 accuracy	.05	9.58**	.04	8.06**	.00	.43
8. Grade 3 accuracy	.06	11.85**	.09	19.83***	.00	.29
9. Grade 8 accuracy	.03	5.75*	.01	1.89	.01	1.34
10. Age 23 accuracy	.01	1.96	.04	5.24*	.01	1.19

Note. Changes in F: *$p < .05$, **$p < .01$, ***$p < .001$.

FIGURE 1
Regression Paths and Residual Correlations in the Full Fluency Model (JLD)



Note. *$p < .05$, **$p < .01$, ***$p < .001$. Additionally, to improve the model fit fluency scores at age 23 were regressed on fluency in Grade 3 (.31***).

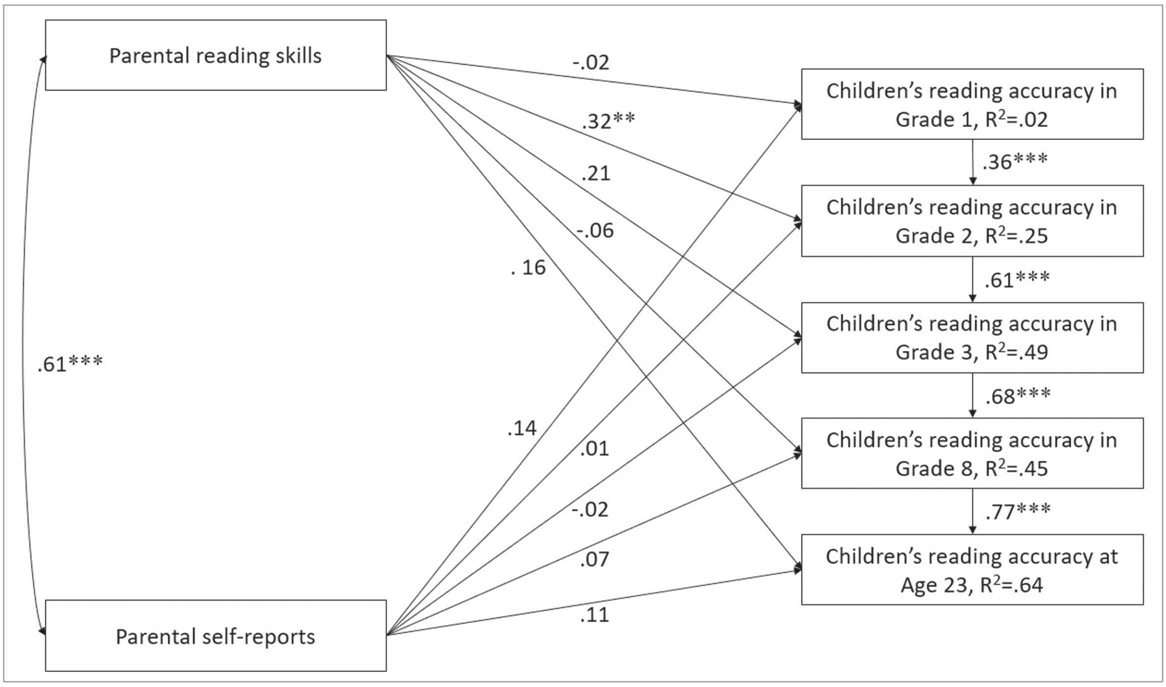
The first dataset, JLD, was a prospective FR sample that included families with and without parental dyslexia. This sample had two main advantages: a wide representation of lower reading skills (owing to approximately half of the families having one parent with dyslexia) and long-term follow-up until age 23. Because the sample included many parents with dyslexia, it had a large variation from the lower end of skill distribution, which is often lacking in general population samples. However, because the sample was pre-selected, replicating the findings in other samples is important. To this end, we used the second sample, VUOKKO, where parents were unselected for their skills and the children were in Grade 1. The inclusion of the two samples contributed to a better understanding of the associations between skill assessments and self-reports as well as of the usability of different FR identification methods to predict children's reading skills.

Parental reading measured with self-reports and direct assessments correlated strongly in JLD (.60) and moderately in VUOKKO (.42). Both these associations were weaker, however, than the correlation previously found in a Dutch prospective FR study (.84–.85) by van Bergen et al. (2014). Moreover, our associations were close to what was previously reported by Snowling et al. (2012), who found that the composite score combing five self-report questions (focusing particularly on reading) moderately correlated with directly assessed non-word reading (.66), spelling (.60), and word reading (.51). The finding that these associations are far from 1 is only to be expected. Although the two methods are designed to measure the same concept (reading skills), they inadvertently capture additional aspects that create a dissociation between the results of the two methods. For example, direct skill assessments provide a snapshot of a person's reading skill or even subskill on that specific day, whereas self-reports reflect a person's history of various experiences with reading in general (including childhood, educational, and professional experiences). Indeed, previous research has confirmed that people's perceptions of their own reading abilities are likely to be affected by their interactions with teachers, relatives, friends, and professional colleagues (Deacon et al., 2012; Leavett et al., 2014; Snowling et al., 2012).

Sample 1

Both parental self-reports and their directly assessed skills predicted children's reading skills in our study. However, specific sample characteristics considerably contributed to the differential results in the two samples. In the prospective FR sample (JLD), parental self-reports and skill assessment scores were almost equally predictive of children's

FIGURE 2
Regression Paths and Residual Correlations in the Full Accuracy Model (JLD)



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

reading skills at most time points. In particular, our analysis revealed that when added as the only predictor, both methods were significant for predicting reading fluency from Grade 1 to age 23, explaining on average 6%–7% of variance at each time point. The situation with reading accuracy, however, was slightly different. FR identified with either method predicted between 4% and 15% of the variance in accuracy at most time points except for the first and the last ones (Grade 1 and age 23). The lack of prediction of the accuracy in Grade 1 means that children's FR status was not related to their likeliness to make mistakes at this time point. To some extent, this finding might be explained by the fact that most Grade 1 children are still in the early phases of reading development and can make mistakes, whether or not they have familial risk for dyslexia. However, it is also important to note that the accuracy measure for Grade 1 was based on a simple word reading task which ultimately had a strong ceiling effect in both samples. In this task, children were given a fixed time to go through as many word reading items as possible. The ceiling effect in such a task is understandable because children could spend as much time as they needed to correctly respond and were also able to stop if they felt that the items were too difficult. Therefore, different approaches (e.g., slow and careful with only few items completed vs. quick and skillful with a lot of items completed) might have resulted in similar reading accuracy scores despite reflecting different competences. At later time points, more demanding tasks (including a pseudoword reading task) were used, and they yielded more mistakes, particularly among children with FR. At age 23, similar to Grade 1, participants were all equally likely to make few mistakes, which explains the lack of prediction of accuracy at this time point. However, such skewness toward being very accurate should be expected in adult Finnish samples regardless of the measures selected, as most Finns manage to achieve similarly high levels of reading accuracy during early school years (Seymour et al., 2003; Soodla et al., 2015). At the same time, children with FR tend to have a slightly lower level of accuracy during early school years, but this improves with age and the performance gap eventually closes (Eklund et al., 2015). Indeed, Finnish studies indicate that early reading difficulties often resolve over time (Eloranta et al., 2019; Torppa et al., 2015).

Importantly, when we split the participants into the at-risk and control groups and separately performed the same analysis for each group, both self-reports and skill assessments stopped being predictive of children's skills at almost all time points. This likely indicates that both FR identification methods effectively identified parents at the lowest and highest ends of distributions. However, when we only considered the opposite ends of the parental skill distribution, either high-risk or low-risk participants, variation was insufficient, which made the previously found associations non-significant. What is also important is that dividing the JLD sample into the FR group and controls made each subsample rather small. This could be another reason why both parental measures lose their predictive power when used within the subsamples.

An investigation of whether skills could predict over and above self-reports showed that directly assessed parental skills did not offer a clear predictive advantage over self-reports. Additive predictive effects of parental skills and self-reports were observed for children's accuracy and fluency at age 23 as well as for accuracy in Grades 2 and 3, suggesting that the inclusion of both self-reports and direct assessments better predicts children's reading skills (compared with the inclusion of only self-reports).

Sample 2

In the VUOKKO sample, where participating families were unselected for their skills, parental skills were not predictive of children's reading skills but parental self-reports were (explaining 7% of children's reading fluency in Grade 1). As previously noted, highly educated parents with solid reading skills were overrepresented in this sample. Moreover, parents with lower skills were more likely to withdraw from assessments while being just as likely to submit a self-report compared with parents with higher skills. This is most likely why self-reports were significantly predictive of children's reading fluency, whereas the same association between parental and children's skills observed in the entire JLD sample could not be found in the VUOKKO sample—a large number of parents from the lowest end of distribution did not participate in the skill assessments. This is a common characteristic of unselected samples of adults that may lead to the underestimation of associations between parental measures and children's measures. In view of this, systematic missingness may possibly be reduced using parental self-reports rather than assessments.

Our skill assessments in the JLD sample were almost as predictive of children's reading as what was previously reported in the Dutch context by van Bergen et al. (2014), who found that direct skill assessments explain 11% of variance in children's reading fluency at age 9. Their study design was very similar to JLD, with approximately half of the parents having dyslexia. Later, van Bergen et al. (2016) additionally collected an unselected sample in which parents with higher education and skill levels were somewhat overrepresented, similar to VUOKKO. At the same time, in the Dutch study, parental skills were still significantly predictive (explaining 17% of variance in children's reading), which is different from the results we obtained with the VUOKKO data. Notably, however, the Dutch sample (van Bergen et al., 2016) had hardly any missing values in the parental skill assessment scores (they were available for both parents in each family), and this is likely the key difference between their sample and VUOKKO that led to the differential results.

Is There a Need to Expand Assessment Batteries?

A more comprehensive assessment battery would have probably provided a much bigger predictive advantage (Grigorenko et al., 2020). A relevant problem with short reading assessments for adults is that they fail to identify those with resolved difficulties (Deacon et al., 2012; Tamboer et al., 2014). This can lead to an inaccurate estimation of FR because parental difficulties experienced in childhood may be just as important predictors of children's reading difficulties as parental reading difficulties experienced in adulthood. As was previously found in the Finnish context, only 40% of those identified as poor readers in childhood confirm their status as adults (Eloranta et al., 2019). In view of this, greater predictive power of parental skill assessments may be achieved by adding cognitive tasks that reveal the cognitive deficits underlying resolved reading difficulties. For example, Eloranta et al. (2019) reported that adults with resolved reading difficulties still underperformed on processing speed, phonological skills, and verbal comprehension in comparison to controls. Importantly, Grigorenko et al. (2020) argued that skill assessments need to be broad and comprehensive; otherwise, identifications of difficulties are not sufficiently reliable regardless of the specific skill assessment employed.

However, testing, especially with extensive assessment batteries, is often not feasible. Therefore, self-reports are an important measure that requires more systematic evaluation. Our results suggest that a multi-item comprehensive self-report can be approximately as predictive of children's reading skills as brief testing. Indeed, the 12 self-report items we used tapped for the most part the same variance as the selected skill assessments. Our prediction based on a more comprehensive self-report was notably better than that reported in studies employing only one yes-or-no self-concept of ability question (Esmaeeli et al., 2018, 2019; Khanolainen et al., 2020; Salminen, Khanolainen, et al., 2021), as these studies explained only around 1%–3% of variance in children's reading. Relying on a single self-concept of ability question is problematic because adults inevitably evaluate their reading level by comparing their skills with those of their reference group, which may drastically differ from one adult to another. A person who has average skills and a reference group with high skills is likely to evaluate their own reading to be poorer than it really is. In contrast, having a reference group with poor skills may lead a person to evaluate their reading as better than it is. Among children and adolescents, this big-fish-little-pond effect has been well documented both in international research (Chiu et al., 2017; Marsh et al., 2007,

2018) and in Finland, which has an unselective school system (Vasalampi et al., 2020).

We recommend future research to avoid single items and to opt for the use of questionnaires with multiple items presenting a variety of dyslexia-related struggles. Moreover, we deem it particularly important to not only focus on current difficulties, but also include multiple questions about childhood, especially when expanding assessment batteries with cognitive tests is not possible. As the correlation table in Appendix A shows, the self-report items related to parental childhood difficulties were those that most strongly correlated with children's early reading skills (in both samples). These childhood-related questions seem to be particularly useful for identifying children whose parents have resolved difficulties, but further research on this topic is needed.

Implications for Research and Practice

In the literature, FR is an important indicator that contributes to a better understanding of the mechanisms of intergenerational transmission as well as the home literacy environment. In practice, FR identification could facilitate early support. Previous studies using the JLD sample have shown that parental reading difficulties are predictive of children's cognitive development (e.g., Torppa et al., 2006) and that parental dyslexia predicts children's reading skills in Grade 2 even over and above the assessment of their early cognitive skills (Puolakanaho et al., 2007). Extending these findings, we found that FR retains a similar predictive effect on children's fluency during school age and beyond (at age 23).

However, overall, FR was not very useful in the prediction of reading fluency beyond the very beginning of elementary school—that is, once the autoregressors were added into the models—indicating the high stability of children's reading fluency. At the same time, the accuracy model showed that children's relative positions in accuracy were not as stable as in fluency and that in Grade 2, parental assessment scores were significantly predictive of children's accuracy despite the addition of autoregressors, suggesting a higher predictive power of direct assessments than self-reports. Therefore, it is worth highlighting that FR information represented the most value in the JLD sample before children's reading could be directly assessed (i.e., in Grade 1). Indeed, when children's skill are assessed, FR information becomes largely unnecessary, as the most accurate prediction of later performance can be achieved with information about earlier performance rather than with any parental information. Thus, FR identification methods are particularly useful when screening for those at FR for reading difficulties at an early age because this facilitates the development of a system in which at-risk children's reading development can be closely monitored and timely support can be provided.

Finally, our findings have important implications for future research. Our findings clearly demonstrate how sample characteristics can significantly affect study results and therefore its conclusions. In general population samples, special attention needs to be paid toward recruiting more people with difficulties to ensure their adequate representation. Although they may be hesitant to volunteer for assessments, their representation could be improved via oversampling. Moreover, because parental self-reports proved to be no less predictive than direct assessments, they can be considered a valid methodological alternative for research purposes that is less likely to intimidate participants with lower levels of reading skills. However, self-reports must include multiple items and some of them must ask about childhood difficulties. Furthermore, for some of the child outcomes, there was an added effect from parental skill assessments which suggests that the combination of self-reports and skill assessments seems to provide the most accurate FR estimate.

Limitations

Unfortunately, the methods in the two studies were not identical, thus limiting the comparisons between them. Moreover, in the JLD sample, in Grade 1, we used only one reading assessment task for children, as this was the only task that was also available in the VUOKKO sample. However, the association between parental variables and children's fluency found for this time point was similar to those found for other time points when more comprehensive assessments were employed. We also performed additional analyses with other reading tasks used in the JLD Grade 1 assessment battery and obtained similar results (Appendix B).

Conclusion

In conclusion, we highlight that although our findings must be interpreted with caution owing to the specific characteristics of our samples, our results have important implications both for future research and for practice. Importantly, both self-reports and parental skill assessments showed similar predictive power for children's reading; the two methods only slightly complemented each other and thus could be used interchangeably. Moreover, self-reports with multiple items provided a notably better FR estimation in our study than self-reports with a single item employed in previous studies (Esmaeeli et al., 2018, 2019; Khanolainen et al., 2020; Salminen, Khanolainen, et al., 2021). FR estimations may be further improved by adding tests for cognitive skills or more self-report items. This suggestion, however, should be investigated in future studies. Considering the strong autoregressive relations between skills at different time points, both FR identification methods provide valuable information only when children are at the pre-reading stage; thereafter, children's own skills are the best predictors of their further development.

Conflict of Interest

The authors declare that they have no conflict of interest to disclose.

NOTE

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APPENDIX A

TABLE A1
Pearson Correlation Coefficients Between Self-report Items and Children's Skills

Sum scores	Fluency	Fluency	Fluency	Fluency	Fluency	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy
	Grade 1 (*N*)	Grade 2 (*N*)	Grade 3 (*N*)	Grade 8 (*N*)	Age 23 (*N*)	Grade 1 (*N*)	Grade 2 (*N*)	Grade 3 (*N*)	Grade 18 (*N*)	Age 23 (*N*)
1. Childhood-related items in JLD	−.353*** (188)	−.371*** (167)	−.264*** (189)	−.272*** (171)	−.282** (127)	−.237** (188)	−.297*** (167)	−.320*** (189)	−.244** (171)	−.087 (127)

TABLE A1
Pearson Correlation Coefficients Between Self-report Items and Children's Skills (*continued*)

Sum scores	Fluency Grade 1 (*N*)	Fluency Grade 2 (*N*)	Fluency Grade 3 (*N*)	Fluency Grade 8 (*N*)	Fluency Age 23 (*N*)	Accuracy Grade 1 (*N*)	Accuracy Grade 2 (*N*)	Accuracy Grade 3 (*N*)	Accuracy Grade 18 (*N*)	Accuracy Age 23 (*N*)
2. Adulthood-related items in JLD	−.155* (187)	−.193* (167)	−.190** (189)	−.229** (171)	−.211* (129)	−.181* (187)	−.191* (167)	−.231** (189)	−.120 (171)	−.107 (129)
1. Childhood-related items in VUOKKO	−.291*** (318)					−.184** (318)				
2. Adulthood-related items in VUOKKO	−.197** (316)					−.007 (316)				

APPENDIX B

Analysis with additional measures available for Grade 1

Child measures in Grade 1

Additional Grade 1 assessments included text reading, word list reading, and pseudoword list reading. The Cronbach's alpha for the fluency composite in Grade 1 was .90. Text reading task used in Grade 1 was the same as the one used in Grade 2 (see the main text of the article for details). Oral word list reading and pseudoword list reading were assessed with the use of 45 items (18 words and 27 pseudowords, each including one to three syllables).

TABLE B1
Descriptive Statistics for All Variables Across Time

	N	Minimum	Maximum	Mean	SD	Skewness (std. error)	Kurtosis (std. error)
JLD sample							
Reading fluency (z-scores)							
Grade 1	189	−6.53	1.50	−.57	1.36	−1.43 (.18)	2.62 (.35)
Reading accuracy (z-scores)							
Grade 1	189	5.60	100.00	92.15	13.28	−4.33 (.18)	22.04 (.35)
JLD sample (controls only)							
Reading fluency (z-scores)							
Grade 1	88	−3.06	1.50	−.02	.92	−.75 (.26)	.53 (.51)
Reading accuracy (z-scores)							
Grade 1	88	19.60	100.00	94.75	9.39	−6.20 (.26)	47.67 (.51)
JLD sample (FR group only)							
Reading fluency (z-scores)							
Grade 1	101	−6.53	1.46	−.93	1.53	−1.21 (.24)	1.37 (.48)
Reading accuracy (z-scores)							
Grade 1	101	5.60	100.00	89.87	15.60	−3.61 (.24)	15.03 (.48)

TABLE B2

Standardized Model Estimates in Simple Linear Regressions Conducted Separately for Each Predictor and for the Controls and FR Group (JLD sample, Grade 1)

	Predictor – Parental self-reports: Estimate (s.e.)			Predictor – Parental skills: Estimate (s.e.)		
Child outcomes	Whole sample	Only FR group	Only controls	Whole sample	Only FR group	Only controls
Reading fluency						
Grade 1	.22*** (.06)	.11 (.09)	.14 (.18)	.24*** (.06)	.04 (.08)	.13 (.10)
Reading accuracy						
Grade 1	.20** (.07)	.05 (.13)	.28** (.09)	.08 (.05)	.05 (.08)	.04 (.08)

Note. *$p < .05$, **$p < .01$, ***$p < .001$. All models were saturated.

TABLE B3

Hierarchical Regressions for Fluency and Accuracy in Grade 1 in JLD (the Whole Sample), Each with Three Steps: 1) Self-reports, 2) Formal Assessments, 3) Interaction between Self-Reports and Formal Assessments

	Parental self-report (step 1)		Parental formal tests (step 2)		Interaction (step 3)	
Child outcomes	ΔR^2	*F* change	ΔR^2	F change	ΔR^2	F change
Grade 1 fluency	.05	9.67**	.02	3.79	.01	2.97
Grade 1 accuracy	.04	8.44**	.00	.50	.00	.02

Note. Changes in *F*: *$p < .05$, **$p < .01$, ***$p < .001$.

II

LONGITUDINAL EFFECTS OF THE HOME LEARNING ENVIRONMENT AND PARENTAL DIFFCIULTIES ON READING AND MATH DEVELOPMENT ACROSS GRADES 1-9

by

Daria Khanolainen, Maria Psyridou, Gintautas Silinskas, Marja-Kristiina Lerkkanen, Pekka Niemi, Anna-Maija Poikkeus, & Minna Torppa, 2020

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Longitudinal Effects of the Home Learning Environment and Parental Difficulties on Reading and Math Development Across Grades 1–9

Daria Khanolainen[1]*, Maria Psyridou[1], Gintautas Silinskas[2], Marja-Kristiina Lerkkanen[1,3], Pekka Niemi[4], Anna-Maija Poikkeus[1] and Minna Torppa[1]

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This study focuses on parental reading and mathematical difficulties, the home literacy environment, and the home numeracy environment as well as their predictive role in Finnish children's reading and mathematical development through Grades 1–9. We examined if parental reading and mathematical difficulties directly predict children's academic performance and/or if they are mediated by the home learning environment. Mothers (n = 1590) and fathers (n = 1507) reported on their reading and mathematical difficulties as well as on the home environment (shared reading, teaching literacy, and numeracy) when their children were in kindergarten. Tests for reading fluency, reading comprehension, and arithmetic fluency were administered to children in Grades 1, 2, 3, 4, 7, and 9. Parental reading difficulties predicted children's reading fluency, whereas parental mathematical difficulties predicted their reading comprehension and arithmetic fluency. Familial risk was associated with neither formal nor informal home environment factors, whereas maternal education had a significant relationship with both, with higher levels of education among mothers predicting less time spent on teaching activities and more time spent on shared reading. In addition, shared reading was significantly associated with the development of reading comprehension up to Grades 3 and 4, whereas other components of the home learning environment were not associated with any assessed skills. Our study highlights that taken together, familial risk, parental education, and the home learning environment form a complex pattern of associations with children's mathematical and reading skills.

Keywords: reading difficulties, mathematical difficulties, home literacy environment, home numeracy environment, familial risk, skill development, comorbidity

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INTRODUCTION

Literacy and numeracy development are strongly interrelated, and the comorbidity of reading and mathematical difficulties is frequent (e.g., Purpura et al., 2011; Davidse et al., 2014; Purpura and Ganley, 2014; Korpipää, 2020). Of the people with either reading or mathematical difficulties, up to 70% also perform worse than average in the other domain (Landerl and Moll, 2010;

Moll et al., 2019; Joyner and Wagner, 2020). Research has identified multiple shared and unique risk factors for reading and mathematical difficulties at the level of cognitive skills (Geary, 2011; Moll et al., 2016; Child et al., 2019) and brain processes (Raschle et al., 2011; Evans et al., 2015; Norton et al., 2015). At the etiological level, both reading and mathematical difficulties are known to be heritable (Kovas et al., 2013; de Zeeuw et al., 2015; Little et al., 2017). Having a parent with reading difficulties, for example, increases the risk of children developing similar problems by up to 66% (van Bergen et al., 2014a; Hulme et al., 2015; Torppa et al., 2015; Esmaeeli et al., 2019). Significantly less is known about familial risk (FR) for mathematical difficulties (e.g., Soares et al., 2018). FR acts via genes, but environmental factors have been shown to play an important role in the development of both reading (Evans and Shaw, 2008; Mol and Bus, 2011; Manolitsis et al., 2013) and mathematical skills (Dunst et al., 2017; Daucourt, 2019). Studies on the interaction of FR and the home literacy environment (HLE) are emerging (Hamilton et al., 2016; Dilnot et al., 2017; Esmaeeli et al., 2018), but comparable studies on the home numeracy environment (HNE) remain scant (Silinskas et al., 2010). Moreover, until recently, HLE and HNE have been separately studied, whereas their cross-domain and joint roles in children's reading and mathematical development have received very little research attention.

In view of the existing gaps in the literature, this study aims to gain new insights into the etiology of the comorbidity of reading and mathematical difficulties. To this end, the study examines the effects of FR for mathematical and reading difficulties together with the effects of the HLE and HNE on children's (aged 7–16 years) reading and mathematical skills from a long-term developmental perspective. To our knowledge, this is the first study with such an objective.

Familial Risk and the Comorbidity of Reading and Mathematical Difficulties

The multiple deficit model (e.g., Pennington, 2006) explains the emergence of learning difficulties and their comorbidity by the complex interactions between multiple risk factors at different levels (genes, brain, cognition, and environment), which can be either domain-specific (i.e., associated only with difficulties in one domain—either reading or mathematics) or domain-general (i.e., associated with difficulties in multiple domains). It has been established that, for example, a deficit in phonological awareness is specific to reading difficulties (Melby-Lervåg et al., 2012) and a deficit in numerosity processing is specific to mathematical difficulties (Hannula et al., 2010; Anobile et al., 2016), whereas difficulties in working memory, processing speed, and oral language are likely to affect more than one learning domain (Koponen et al., 2007; Moll et al., 2019; Daucourt et al., 2020).

The multiple deficit model (MDM) has gained wide recognition over the years. However, Pennington (2006) importantly noted that compared with single deficit models, testing the MDM would represent a much more serious challenge, calling for the test of multiple hypotheses. In their theoretical article, van Bergen et al. (2014b) stressed the unique role of familial risk studies in testing and specifying the MDM—these studies have already provided important evidence suggesting that parents confer liability to reading difficulties via interconnected genetic and environmental risk factors.

In this study, we aim to add knowledge on the intergenerational transmission of reading and mathematical difficulties as well as their comorbidity. To this end, we include FR for both reading and mathematics and examine the effects of both within-domain and cross-domain FR on reading and mathematical development. Although multiple studies have established that FR for reading difficulties is among the strongest predictors for dyslexia (Scarborough, 1990; Pennington and Lefly, 2001; van Bergen et al., 2014a; Torppa et al., 2015; Esmaeeli et al., 2019), so far, only few studies have suggested that the same is true for dyscalculia (Shalev and Gross-Tsur, 2001; Soares et al., 2018). In addition, unlike most studies, we include the parental reading and mathematical difficulties of both mothers and fathers in our analysis to examine if the effects of having one parent with difficulties are different from the effects of having both parents with difficulties. Based on the MDM, it can be expected that when both parents have learning difficulties, children's liability increases more than when having only one parent with difficulties.

Home Literacy and Numeracy Environment

The effects of FR on children's skill development may act through the genetic pathway; both twin and molecular genetic studies have produced compelling evidence for the strong heritability of both reading and mathematical skills (Docherty et al., 2010; Kovas et al., 2013; de Zeeuw et al., 2015; Little et al., 2017). However, parental reading/mathematical difficulties have also been shown to be transmitted through the environmental pathway (Petrill et al., 2005; de Zeeuw et al., 2015; Hart et al., 2016; van Bergen et al., 2017). Therefore, we examine if parental reading and mathematical difficulties impact the home environment and if they affect children's skills not only directly but also indirectly via the home environment.

The home learning environment is often divided into two main components: HLE and HNE. HLE refers to home-based interactions between parents and their children, parental attitudes, and at-home materials related to literacy. HLE has long been considered an important factor for the development of reading skills (see Bus et al., 1995; Evans and Shaw, 2008; Flack et al., 2018; Grolig et al., 2019). In a seminal study, Sénéchal and Lefevre (2002) formulated the home literacy model and showed that to adequately assess the effects of HLE, it is important to differentiate its activities into two separate categories: "formal" and "informal" activities. In their 5-year longitudinal study, children's skills were followed until the end of Grade 3 and HLE was assessed with parental self-reports. The home literacy model was predicated on analysis that revealed that parental teaching (formal learning) and storybook exposure (informal learning) were uncorrelated, with the former explaining children's emergent literacy and the latter explaining children's receptive language.

Further evidence has supported the home literacy model, showing that formal and informal activities contribute to the development of different skills (Sénéchal and Lefevre, 2002). Code-related, formal parent–child literacy interactions in the form of direct teaching (for example, instructing children on how to divide words into phonemes and showing that graphemes correspond to phonemes) contribute to the development of early word recognition and decoding skills, whereas informal literacy activities (for example, shared reading and discussions over a story) mostly involve meaning-related practices and are associated with the development of vocabulary knowledge, reading comprehension, and broader language skills (e.g., Sénéchal, 2006, 2015; Mol et al., 2008; Sénéchal et al., 2008; Martini and Sénéchal, 2012; Sénéchal and Lefevre, 2014).

However, some studies have reported negligible independent effects of formal and informal HLE activities. For example, Manolitsis et al. (2013) and Silinskas et al. (2020) found that the effects of formal learning (at-home teaching) were significantly smaller in the contexts of transparent orthographies (Greek and Finnish) than those previously demonstrated in the contexts of opaque orthographies (English and French). The authors argued that in the context of transparent orthographies, direct at-home teaching could only provide short-term gains that fade away as soon as children get exposed to schooling because learning to read is relatively easy and most children very quickly learn to read.

Using the home literacy model (Sénéchal and Lefevre, 2002) as a guiding framework, a similar model for HNE was developed and tested by Skwarchuk et al. (2014). In a cross-sectional study with 5- and 6-year-old children, the researchers assessed the formal activities of HNE (using parental self-reports of home teaching of arithmetic skills) and informal activities (using a number game title checklist for parents, which is comparable to the storybook exposure checklist designed for HLE). The study revealed that formal parent–child interactions contributed to children's symbolic number knowledge (number identification, counting, and ordinal numbers), whereas informal game-based numeracy-related activities contributed to children's non-symbolic arithmetic skills (addition, subtraction, and matching tasks with toy animals).

It has to be stressed, however, that research focusing on the role of HNE remains rather scant and much less conclusive in comparison to studies on HLE. Whereas some studies suggest that the HNE is a significant contributor to the development of mathematical skills (Niklas and Schneider, 2014; Skwarchuk et al., 2014; Hart et al., 2016; Napoli and Purpura, 2018), other research finds a non-significant or even negative association between children's mathematical development and HNE (Blevins-Knabe et al., 2000; Silinskas et al., 2010; Missall et al., 2015; Zippert and Rittle-Johnson, 2020).

Importantly, from the perspective of understanding comorbidity, a recent study among parents of children aged 3–5 years (Napoli and Purpura, 2018) established a strong relationship between HLE and HNE after analyzing extensive parental self-reports of at-home literacy practices (printing letters, identifying letters and letter sounds, and reading storybooks) and numeracy practices (counting objects, printing numbers, working with number activity books, comparing quantities, counting down, and learning written numbers and simple sums). Results showed that the parents who were actively promoting the skills of their children in one domain were more likely to do the same in the other domain (Napoli and Purpura, 2018). This strong positive association between HLE and HNE could be one of the reasons why researchers find that HLE predicts both reading and mathematical skills (Melhuish et al., 2008; Baker, 2014). In a longitudinal study with pre-school children aged 3–4 years who were followed for 3 years, Anders et al. (2012) found that HLE was an even better predictor of early mathematical skills than HNE. The researchers argued that verbal literacy is a pre-requisite for acquiring numeracy skills, as has been suggested by von Aster and Shalev (2007) and later reported by Purpura and Ganley (2014). This evidence shows that studying both HLE and HNE together is necessary to understand the impact of the home environment on children's skill development. Noting that previous studies mainly focused on early childhood, the present study aims to add knowledge on how the processes of developing reading and mathematical skills are interconnected by extending research to school-aged children. Furthermore, the inclusion of FR and parental education in our study enables us to investigate if the possible correlation between HLE and HNE can be further explained to help understand why some parents are more likely to support their children's skill development (Napoli and Purpura, 2018).

Familial Risk Studies and Home Learning Environment

To establish whether FR is mediated via the home learning environment, studies have compared the HLE factors in families with and without FR for reading difficulties. Whether such an indirect relationship exists, however, is still unclear owing to the scarcity of research (e.g., Snowling and Melby-Lervåg, 2016) as well as to contradictory findings. Some studies found that FR families provide a more disadvantageous HLE for their children than non-FR families do (Hamilton et al., 2016; Dilnot et al., 2017; Esmaeeli et al., 2018). Other studies reported that there were no significant differences between the at-home learning activities of FR families and non-FR families and that parents with reading difficulties taught their children as much academic skills as the parents without such difficulties did (Elbro et al., 1998; Laakso et al., 1999; Torppa et al., 2007). Comparable studies investigating FR for mathematical skills and HNE are scarce. However, in one longitudinal study, Silinskas et al. (2010) showed that Finnish mothers' mathematical difficulties positively predicted their teaching of mathematics.

Few studies have gone further to investigate if HLE can act as a mediator between parental reading difficulties and children's literacy outcomes. In their large-scale study with 6-year-old children, Esmaeeli et al. (2019) suggested that HLE could play the role of a protective factor mediating the adverse influences of FR on children's reading skills. However, Puglisi et al. (2017)

reported that informal HLE did not predict any children's outcomes when maternal language and phonological skills were controlled for. The researchers then argued that the associations found between children's skills and informal HLE might only be a reflection of intergenerational transmission—parents with stronger language skills involve their children in more informal learning activities but also provide genes that predispose their children to have stronger language skills. To disentangle these familial and environmental influences, more studies are needed.

To summarize the previous research, numeracy and literacy are highly interconnected, complex cognitive skills and parents can pass down both reading and mathematical difficulties to their children through genetic and environmental pathways. The exact mechanism of a child developing either one or both sets of difficulties remains poorly understood, but it appears that this process is shaped by the interaction of multiple deficits (domain-specific and domain-general). Moreover, HLE has been repeatedly shown to be associated with children's language and literacy development, and in some recent studies also with mathematical skill development. Clear effects of different HNE activities on numeracy have been found only in a handful of studies and require more research. There is also a particular need for more studies on FR for mathematical difficulties, cross-domain FR effects, and parental comorbidity effects on the development of reading and mathematical skills. In addition, it remains to be seen if FR and non-FR families provide different HLE and/or HNE, and if the influence of FR on children's skills can be mediated through the home environment.

Present Study

Our analysis of the gaps in research suggests that further exploring how the development of reading and mathematical skills is influenced by parental reading and mathematical difficulties (FR for reading and mathematics, respectively) as well as home environment factors is important. Evidence from previous studies is scant because most of the studies on HLE and HNE were cross-sectional and/or small-scale and focused on early development. In contrast, the present study is a large-scale longitudinal study spanning across the compulsory education until adolescence. Based on theory and previous empirical evidence, we divided environment variables into formal (teaching of literacy and numeracy skills) and informal home inputs (shared reading) (Sénéchal, 2006; Sénéchal and Lefevre, 2014; Hamilton et al., 2016; Puglisi et al., 2017). Because parental education has been shown to be reflected in HLE (e.g., Torppa et al., 2006; Park, 2008; Hamilton et al., 2016; van Bergen et al., 2017), it is included in all our models.

We aim to answer the following research questions:

(1) Does FR for reading and/or mathematical difficulties predict the reading and mathematical development of children from Grade 1 to 9?
(2) Do home environment factors (literacy teaching, numeracy teaching, and shared reading) predict the reading and mathematical development of children from Grades 1–9?
(3) Does FR for reading and mathematical difficulties predict the home learning environment?
(4) Are the effects of FR on children's reading and mathematical development mediated by the home environment factors?

In this study, we estimate three different models: for reading fluency, for reading comprehension, and for arithmetic fluency based on our hypothesized models. In view of the research reviewed above, we constructed our hypothesized models (see **Figure 1** for the model of reading fluency; other models were estimated with the same logic) with the expectation to find the following: (1) paths from parental reading difficulties (Pennington and Lefly, 2001; Torppa et al., 2011; van Bergen et al., 2012; Hulme et al., 2015) and parental mathematical difficulties (Shalev and Gross-Tsur, 2001; Soares et al., 2018) to the respective skills in children; (2) cross-domain paths from parental mathematical difficulties to children's reading skills and from parental reading difficulties to children's mathematical skills (Landerl and Moll, 2010; Moll et al., 2015); (3) paths from HLE and HNE to both respective and cross-domain skills in children (Melhuish et al., 2008; Anders et al., 2012; Kleemans et al., 2012; Baker, 2014; Napoli and Purpura, 2018); (4) paths from parental education to children's skills (Torppa et al., 2006; Hamilton et al., 2016; van Bergen et al., 2017); (5) paths from parental education to HLE and HNE (Hamilton et al., 2016); and (6) paths from FR to the home environment (Scarborough et al., 1991; Bus et al., 1995; Elbro et al., 1998; Snowling, 2000; Hamilton et al., 2016; Esmaeeli et al., 2019), including also the examination of the indirect relationships (FR → home environment → children's skills), as Esmaeeli et al. (2019) argued that these paths need to be tested in future studies. Finally, we expected that the paths to later skill assessments run through the early skill assessments.

MATERIALS AND METHODS

Participants and Procedure

This study is a part of a large-scale longitudinal First Steps Study (Lerkkanen et al., 2006) where children (n = 2525) were followed from kindergarten to Grade 9. The children were born in the year 2000 and came from four municipalities: one in an urban area, one in a rural area, and two in, similarly, semi-rural areas in central, western, and eastern Finland. Of all contacted families, 78–89%, depending on municipality, agreed to participate in the study. Ethnically and culturally, the sample was very homogeneous and representative of the Finnish population. Marital statuses as well as the educational levels of the parents were very close to the national distribution of Finland (Statistics Finland, 2007). The study was reviewed and approved by the Ethical Committee of the University of Jyväskylä in 2006, and all participants (children and their parents) gave their informed consent before participation in the study.

Trained specialists administered both individual and group tests in suitable rooms in each school. Children absent from school on the day of testing were tested immediately after they came back to school. Tests for reading fluency, reading

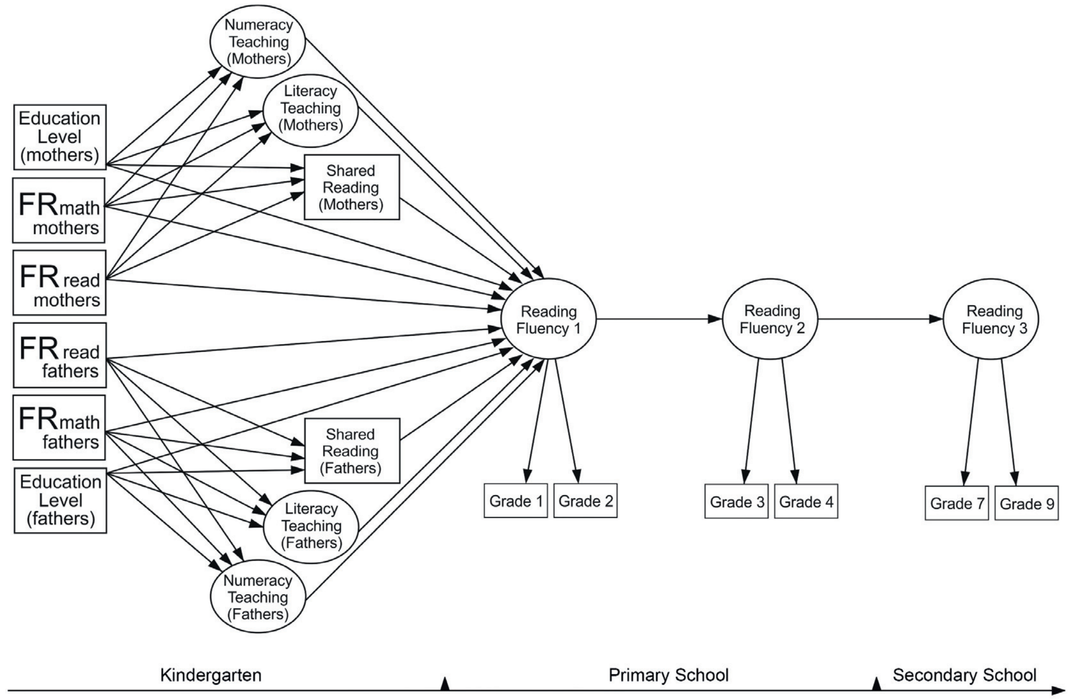

FIGURE 1 | Hypothesized model for reading fluency. Familial risk (FR for reading and mathematical difficulties of mothers and fathers); Reading Fluency 1–Reading Fluency 3, time points of assessments; Grade 1–9, assessments that took place in Grades 1–9. Literacy teaching and numeracy teaching were added in the model as latent variables; they were measured with two questionnaire items each. Shared reading was measured with one questionnaire item making up the observed variables (one for mothers and one for fathers). Other hypothesized models (for reading comprehension and mathematical skills) were constructed with the same logic.

comprehension, and mathematics were administered to children in Grades 1, 2, 3, 4, 7, and 9.

Measures

Reading Fluency

To assess reading fluency, three group-administered tests were administered: a word reading fluency task, a word chain task, and a sentence reading task. The mean of the three standardized reading fluency measures was used as the score. Cronbach's alpha reliability coefficients for the fluency composite were 0.94 in Grade 1, 0.93 in Grade 2, 0.93 in Grade 3, 0.93 in Grade 4, 0.93 in Grade 7, and 0.94 in Grade 9.

The word reading fluency task is an 80-item subtest of the nationally normed reading test battery (ALLU; Lindeman, 2000). Each item comprises a picture and a set of four phonologically similar words. The children were asked to silently read the words and decide which one of them semantically matched the picture. All the words and pictures in the task were simple and frequently used and thus were familiar to young children. The score was calculated as the number of correct answers achieved within 2 min. The score reflects both the word-reading speed and accuracy.

In the word chain task (Nevala and Lyytinen, 2000), children were presented with 10 chains of 4–6 words in a row written without spaces between them. The children were asked to silently read each row and draw a boundary line between each word pair they find. The sum score was based on the number of correct answers given within a set time limit (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).

Sentence reading efficiency in Grades 1–4 was assessed with the Test of Silent Reading Efficiency and Comprehension (TOSREC; Wagner et al., 2010; Finnish version by Lerkkanen and Poikkeus, 2009). The children were asked to read and assess the truthfulness of as many simple sentences as possible (e.g., Strawberries are blue) out of a set of 60 items within 3 min. In Grades 7 and 9, the children were asked to complete a standardized Finnish reading test for lower secondary school sentence reading that had the same instruction as earlier sentence reading measures but slightly different items (YKÄ; Lerkkanen et al., 2018) were used. The sum score was based on the number of correct answers.

Reading Comprehension

To assess reading comprehension in Grades 1–4, a group-administered subtest of a nationally normed reading test battery was used (ALLU; Lindeman, 2000). The children were required to read a short fiction story and answer 11 multiple-choice questions and 1 question in which they had to arrange 5 statements in the correct sequence based on the information gathered from the text. For each correct answer, 1 point was given (max = 12). The children could work at their own pace but for a maximum of 45 min. Then, in Grades 7 and 9, a similar standardized reading comprehension test for lower secondary school (with the same instruction and time limit but different texts and questions) was employed (YKÄ; Lerkkanen et al., 2018). The sum score was based on the number of correct answers. Cronbach's alpha reliability coefficient for the comprehension composite ranged between 0.82 and 0.84 in different grades (0.84 in Grade 1, 0.82 in Grade 2, 0.83 in Grade 3, 0.82 in Grade 4, 0.82 in Grade 7, and 0.83 in Grade 9).

Arithmetic Fluency

Arithmetic fluency was assessed with a group-administered subtest of the arithmetic test (Räsänen and Aunola, 2007) that comprises 14 addition (e.g., 3 + 2 = __, 3 + 6 + 4 = __) and 14 subtraction tasks (e.g., 6 − 1 = __, 20 − 4 − 3 = __). Performance on this test depends on both speed and accuracy, and allows for the assessment of the automatization of basic mathematical computations. The sum score was based on the number of correct answers given within 3 min. Cronbach's alphas varied between 0.91 and 0.92 (0.92 in Grade 1, 0.91 in Grades 2–4, 7, and 9).

Familial Risk for Reading Difficulties

When the children participating in the study were in kindergarten, their mothers and fathers were asked to fill in a questionnaire asking if they themselves and/or the other parent of the child had experienced learning difficulties in reading and/or mathematics. The questionnaire included one question about their own reading difficulties, one about their own mathematical difficulties, and two in regard to their spouse. Each question could be answered on a three-point scale (1 = no difficulties, 2 = some difficulties, 3 = clear difficulties). The children were considered to have FR if they had at least one parent with some or clear difficulties, and the variable for FR was then dichotomized: 0 = no FR (report of no difficulties) and 1 = FR (report of some or clear difficulties). In the descriptive analysis, we also considered if a child has one or two parents with learning difficulties (**Tables 2**, **3**).

Parental Education

Mothers and fathers were asked to indicate their own educational level on 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), 7 = licentiate or doctoral degree (4.4% of mothers and 2.7% of fathers)].

Home Learning Environment (Home Teaching and Shared Reading)

Mothers and fathers were also asked to complete a questionnaire about their at-home learning activities, which was based on the questions developed by Sénéchal et al. (1998) and previously used in the Finnish context (e.g., Silinskas et al., 2012, 2020). The questionnaire included one question regarding shared reading—"How often do you read books to your child or together with your child"? The 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, 5 = more than once a day). There were four items related to home teaching activities: teaching letters, teaching reading, teaching numbers, and teaching arithmetic skills. The answers were given on a five-point scale (1 = never at all/rarely to 5 = very often/daily). We obtained the sum scores by summarizing the individual scores for each activity of mothers and fathers.

Statistical Analysis

When investigating the predictive longitudinal relations between FR, home activities, and children's skills, longitudinal path models were constructed using MPlus Version 7.4. Three separate models (**Figure 1**) were fitted to the data: for reading fluency, for reading comprehension, and for arithmetic fluency. Latent variables were built for reading fluency, reading comprehension, and arithmetic fluency to increase the reliability of the assessment and to minimize measurement error. The skill assessments in Grades 1 and 2 were grouped into Time Point 1, in Grades 3 and 4 into Time Point 2, and in Grades 7 and 9 into Time Point 3.

Latent factors were also built for the home environment measures. The factor structure of the home environment (shared reading and the four teaching items) was validated with confirmatory factor analysis (CFA). We first tested a model with four latent variables grouped as follows: the three literacy items of mothers (including shared reading), the two numeracy items of mothers, the three literacy items of fathers, and the two numeracy items of fathers, as it seemed theoretically plausible. However, this model had a poor fit with the data [χ^2 (29) = 141.19, $p < 0.001$, root-mean-square error of approximation (RMSEA) = 0.05, comparative fit index (CFI) = 0.87, standardized root-mean-square residual (SRMR) = 0.07]. The main reason for the misfit was that the correlations between the literacy teaching and numeracy teaching items were too high to form separate constructs. In view of this, we next constructed a two-factor model wherein all home environment items of mothers were loaded to one factor and all home environment items of fathers were loaded to another factor. This model also did not fit the data well [χ^2(33) = 107.31, $p < 0.001$, RMSEA = 0.04, CFI = 0.91, SRMR = 0.07]. Because the shared reading items had very low factor loadings, we constructed another model with one latent factor for mothers' teaching items, including two items of teaching reading and two items of teaching mathematics, and another latent factor for fathers' teaching items. Shared reading items of mothers and fathers were separately added as observed variables. This model fitted the data well [$\chi^2(31) = 55.81$, $p < 0.01$, RMSEA = 0.02, CFI = 0.97, SRMR = 0.03] and significantly better than the model where the shared reading item was included in the latent factor, as suggested by the Satorra-Bentler corrected chi-square difference test: $\Delta\chi^2(1) = 22.23$, $p < 0.001$. This confirmed our initial hypothesis that the shared reading items should be added in the models as separate variables (informal home environment inputs) from the teaching items (formal home environment inputs).

The measure distributions were close to normal distribution, except for comprehension in early grades that had a slight skew to the left (**Table 1**). Therefore, all models were estimated using Maximum likelihood estimation with robust standard errors. The variables were standardized before fitting the models. A few outliers were present in the distributions of all skills, which were moved to the tails of the distributions before analyses.

To evaluate model fit, chi-square values and a set of fit indexes were used as follows: (a) CFI; (b) RMSEA, and (c) SRMR. Good model fit is indicated by a small, preferably non-significant χ^2, CFI > 0.95, RMSEA < 0.06, and SRMR < 0.08 (Hu and Bentler, 1999). Because the chi-square test is sensitive to a large sample size, the chi-square statistics were not regarded as conclusive.

RESULTS

Descriptive Statistics

Descriptive statistics for children's skill development and HLE measures are reported for all participants in **Table 1**, as a function of FR for reading difficulties in **Table 2**, and as a function of FR for mathematical difficulties in **Table 3**. One-way ANOVAs were conducted to compare the children with no FR (NFR), the children with one parent with difficulties (FR1), and the children with two parents with difficulties (FR2) (**Tables 2**, **3**) and showed significant differences between the NFR group, FR1 group, and FR2 group for all the skills throughout Grades 1–9 except arithmetic skills in Grade 7 as a function of parental reading difficulties. This analysis also demonstrated that parental education was significantly higher in the NFR group than in the FR1 and FR2 groups, whereas there were no group differences in the home environment measures.

Pairwise comparisons of the groups with parental reading difficulties (FR1 and FR2) revealed significant differences in children's reading fluency in Grades 1 and 4 (**Table 2**), whereas comparisons of the groups with parental mathematical difficulties (FR1 and FR2) showed that children significantly differed in their

TABLE 1 | Descriptive statistics for all variables across time.

	N	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
Reading fluency (z-scores)							
Grade 1	2,052	−2.44	4.03	0.00	1.00	0.62	0.44
Grade 2	2,006	−2.89	3.88	0.00	1.00	0.26	0.23
Grade 3	1,995	−4.41	3.18	0.00	1.00	−0.04	0.43
Grade 4	1,954	−4.62	2.76	0.00	1.00	−0.17	−0.30
Grade 7	1,770	−4.19	3.04	0.00	1.00	−0.07	−0.00
Grade 9	1,721	−2.94	2.98	0.00	1.00	−0.09	−0.14
Reading comprehension							
Grade 1	2,035	0.00	12.00	5.50	3.18	−0.00	−0.96
Grade 2	1,974	0.00	12.00	8.51	2.71	−0.73	0.20
Grade 3	1,988	0.00	12.00	9.08	2.16	−1.17	1.73
Grade 4	1,950	0.00	12.00	8.10	2.52	−0.47	−0.21
Grade 7	1,758	0.00	12.00	6.59	2.54	0.05	−0.65
Grade 9	1,702	0.00	12.00	7.01	2.43	−0.15	−0.58
Arithmetic fluency							
Grade 1	2,050	0	28	10.51	4.12	0.33	0.25
Grade 2	2,001	0	28	16.05	4.92	−0.10	−0.45
Grade 3	1,994	0	28	19.61	4.62	−0.65	0.48
Grade 4	1,953	0	27	17.03	4.09	−0.64	0.81
Grade 7	1,749	0	27	13.68	3.81	−0.17	0.34
Grade 9	1,705	1	27	14.89	3.92	−0.13	0.05
Parental education							
Mother	1,563	1	7	4.18	1.52	−0.00	−0.12
Father	1,117	1	7	4.12	1.50	−0.20	−0.15
Home learning environment factors (mean composites)							
Shared reading, mother	1,559	1	7	2.29	1.15	−0.15	−1.01
Shared reading, father	1,104	1	7	2.35	1.15	0.47	−0.89
Teaching, mother	1,115	1	5	2.54	0.75	0.08	−0.11
Teaching, father	1,567	1	5	2.60	0.79	0.02	−0.19

TABLE 2 | ANOVA comparisons among the three risk groups for reading difficulties (RD) for all variables.

	No family risk for RD (NFR)			One parent risk for RD (FR1)			Both parents risk for RD (FR2)					
	N	***M***	***SD***	***N***	***M***	***SD***	***N***	***M***	***SD***	***df* within groups**	**F**	**Pairwise comparisons (Bonferroni)**
Reading fluency (z-scores)												
Grade 1	979	0.18	0.85	377	−0.14	0.82	58	−0.56	0.69	1,411	26.90***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 2	957	0.20	0.83	362	−0.20	0.83	58	−0.52	0.69	1,374	34.23***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 3	941	0.17	0.82	362	−0.11	0.85	57	−0.56	0.63	1,357	19.50***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 4	921	0.19	0.81	356	−0.11	0.87	53	−0.56	0.64	1,327	25.38***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 7	697	0.19	0.83	268	−0.13	0.94	33	−0.26	0.79	995	12.26***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 9	682	0.19	0.84	260	−0.07	0.91	33	−0.26	0.70	972	9.20***	NFR > FR1, FR1 = FR2, NFR > FR2
Reading comprehension												
Grade 1	977	6.06	3.19	373	5.13	3.08	58	4.09	2.87	1,405	20.14***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 2	945	8.98	2.51	358	8.22	2.75	58	7.50	2.93	1,358	17.81***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 3	939	9.43	1.97	361	8.79	2.29	57	8.89	2.12	1,354	13.58***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 4	920	8.58	2.29	356	7.92	2.57	53	7.58	2.54	1,326	12.77***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 7	691	7.02	2.52	268	6.51	2.63	33	5.97	2.36	989	5.88**	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 9	680	7.40	2.41	255	6.96	2.39	32	6.22	1.93	964	6.20**	NFR > FR1, FR1 = FR2, NFR > FR2
Arithmetic fluency												
Grade 1	979	11.10	4.10	376	10.24	4.11	58	9.71	3.97	1,410	8.13***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 2	953	16.81	4.78	362	15.99	4.83	58	14.19	4.97	1,370	10.70***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 3	941	20.23	4.37	362	19.50	4.62	57	18.11	4.94	1,357	8.59***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 4	920	17.59	3.86	356	16.96	4.14	53	16.40	4.22	1,326	4.89**	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 7	690	14.15	3.82	265	13.91	3.66	34	13.29	3.61	986	1.11	NFR = FR1, FR1 = FR2, NFR = FR2
Grade 9	676	15.49	3.74	256	14.70	3.87	34	14.53	3.83	963	4.69**	NFR > FR1, FR1 = FR2, NFR > FR2
Parental education												
Mother	1,009	4.37	1.48	397	4.04	1.48	66	3.38	1.24	1,469	19.20***	NFR > FR1, FR1 > FR2, NFR > FR2
Father	759	4.28	1.49	287	3.82	1.52	48	3.71	1.23	1,091	12.06***	NFR > FR1, FR1 = FR2, NFR > FR2
Home learning environment factors (mean composites)												
Shared reading, mother	1,007	2.96	1.13	397	2.86	1.16	66	2.67	1.17	1,467	2.87	NFR = FR1, FR1 = FR2, NFR = FR2
Shared reading, father	752	2.38	1.16	280	2.30	1.15	47	2.30	1.16	1,076	0.56	NFR = FR1, FR1 = FR2, NFR = FR2
Teaching, mother	1,010	2.60	0.79	399	2.59	0.79	67	2.46	0.84	1,473	0.95	NFR = FR1, FR1 = FR2, NFR = FR2
Teaching, father	756	2.54	0.73	286	2.51	0.80	48	2.64	0.81	1,087	0.62	NFR = FR1, FR1 = FR2, NFR = FR2

**p* < 0.05, ***p* < 0.01, ****p* < 0.001.

TABLE 3 | ANOVA comparisons among the three risk groups for mathematical difficulties (MD) for all variables.

	No family risk for MD (NFR)			One parent risk for MD (FR1)			Both parents risk for MD (FR2)					
	N	***M***	***SD***	***N***	***M***	***SD***	***N***	***M***	***SD***	***df* within groups**	**F**	**Pairwise comparisons (Bonferroni)**
Reading fluency (*z*-scores)												
Grade 1	963	0.17	0.87	383	−0.11	0.78	63	−0.49	0.82	1,406	21.76***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 2	941	0.19	0.85	369	−0.14	0.78	62	−0.48	0.86	1,369	25.19***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 3	927	0.17	0.83	369	−0.09	0.81	60	−0.36	0.82	1,353	17.16***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 4	907	0.20	0.82	360	−0.14	0.81	58	−0.35	0.88	1,322	23.00***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 7	700	0.18	0.86	263	−0.10	0.83	32	−0.21	1.05	992	9.36***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 9	686	0.19	0.86	254	−0.05	0.84	32	−0.26	0.74	969	7.91***	NFR > FR1, FR1 = FR2, NFR > FR2
Reading comprehension												
Grade 1	961	6.06	3.13	379	5.13	3.19	63	4.22	3.31	1,400	19.46***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 2	928	9.03	2.47	367	8.23	2.74	61	6.75	3.13	1,353	31.35***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 3	925	9.42	2.03	368	8.90	2.13	60	8.47	2.48	1,350	12.59***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 4	906	8.64	2.29	360	7.78	2.62	58	7.62	2.25	1,321	19.54***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 7	696	7.06	2.56	263	6.42	2.53	32	5.53	2.24	988	10.27***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 9	681	7.45	2.36	251	6.84	2.45	32	6.09	2.37	961	9.87***	NFR > FR1, FR1 = FR2, NFR > FR2
Arithmetic fluency												
Grade 1	962	11.20	4.11	383	10.17	4.02	63	8.94	3.86	1,405	15.82***	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 2	938	17.08	4.70	368	15.46	4.90	62	13.68	4.55	1,365	26.75***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 3	927	20.42	4.38	369	19.20	4.47	60	17.57	4.73	1,353	19.27***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 4	906	17.84	3.79	360	16.63	4.05	58	14.88	4.36	1,321	25.10***	NFR > FR1, FR1 > FR2, NFR > FR2
Grade 7	692	14.29	3.86	261	13.67	3.52	32	12.38	3.53	982	5.94**	NFR > FR1, FR1 = FR2, NFR > FR2
Grade 9	681	15.57	3.76	249	14.65	3.79	33	13.36	3.69	960	9.62***	NFR > FR1, FR1 = FR2, NFR > FR2
Parental education												
Mother	990	4.48	1.49	403	3.85	1.35	72	4.25	3.95	1,462	50.71***	NFR > FR1, FR1 < FR2, NFR = FR2
Father	749	4.35	1.51	292	3.76	1.40	51	3.20	1.17	1,089	27.52***	NFR > FR1, FR1 > FR2, NFR > FR2
Home learning environment factors (mean composites)												
Shared reading, mother	988	2.94	1.13	401	2.92	1.18	74	2.72	1.05	1,460	1.29	NFR = FR1, FR1 = FR2, NFR = FR2
Shared reading, father	738	2.39	1.15	287	2.30	1.18	52	2.12	1.18	1,074	1.86	NFR = FR1, FR1 = FR2, NFR = FR2
Teaching, mother	991	2.60	0.81	405	2.60	0.94	74	2.60	0.85	1,467	0.09	NFR = FR1, FR1 = FR2, NFR = FR2
Teaching, father	745	2.54	0.75	291	2.60	0.74	52	2.21	0.77	1,085	5.67**	NFR = FR1, FR1 > FR2, NFR > FR2

*p < 0.05, **p < 0.01, ***p < 0.001.

reading comprehension skills in Grades 1 and 2 as well as in arithmetical fluency skills in Grades 2, 3, and 4 (**Table 3**).

Pearson correlation coefficients are reported across all measures in **Table 4**. All skills were significantly related with one another, but the strongest correlations were found in lower grades. The correlations between the reading and mathematical measures and the home teaching environment and shared reading were small, ranging from 0.01 to 0.19.

The Model for Reading Fluency

Figure 2 presents the final model for reading fluency with statistically significant standardized estimates, and **Table 5** reports all the path estimates and residual correlations of the model. The model fitted the data well: $\chi^2(171) = 247.90$, $p < 0.001$, RMSEA = 0.02, CFI = 0.98, SRMR = 0.03. Two significant predictors of reading fluency emerged: children's reading fluency at the first time point was predicted by fathers' reading difficulties and by mothers' educational level. That is, fathers' reading difficulties and lower maternal education predicted poorer performance in reading fluency tasks among their children. However, the effects were small, explaining 2 and 1% of the variance, respectively. There were no significant effects of any of the home environment factors on reading fluency and parental reading, and mathematical difficulties did not predict the home environment factors. However, higher levels of education among mothers predicted less time spent on teaching activities and more time spent on shared reading. In addition, higher levels of education of mothers and fathers were associated with more shared reading with fathers. Again, the amounts of explained variance in the home environment owing to educational level were low, between 1 and 4%. This model did not reveal any significant indirect effects. Reading fluency demonstrated very high stability across time. The first time point explained 85% of the variance in reading fluency at the second

TABLE 4 | Correlations between all variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Grade 1	1													
2. Grade 2	0.80**	1												
3. Grade 3	0.75**	0.82**	1											
4. Grade 4	0.71**	0.79**	0.85**	1										
5. Grade 7	0.61**	0.67**	0.71**	0.75**	1									
6. Grade 9	0.58**	0.64**	0.67**	0.72**	0.81**	1								
7. Grade 1	0.63**	0.60**	0.55**	0.56**	0.47**	0.45**	1							
8. Grade 2	0.48**	0.49**	0.47**	0.47**	0.42**	0.43**	0.53**	1						
9. Grade 3	0.33**	0.35**	0.34**	0.37**	0.33**	0.35**	0.39**	0.48**	1					
10. Grade 4	0.37**	0.39**	0.40**	0.41**	0.41**	0.39**	0.44**	0.55**	0.47**	1				
11. Grade 7	0.26**	0.30**	0.26**	0.30**	0.37**	0.39**	0.36**	0.45**	0.40**	0.51**	1			
12. Grade 9	0.29**	0.32**	0.28**	0.30**	0.35**	0.40**	0.37**	0.43**	0.36**	0.43**	0.51**	1		
Arithmetic Fluency (z-scores)														
13. Grade 1	0.51**	0.48**	0.46**	0.46**	0.33**	0.32**	0.40**	0.29**	0.19**	0.21**	0.14**	0.17**	1	
14. Grade 2	0.47**	0.50**	0.49**	0.49**	0.39**	0.37**	0.39**	0.32**	0.23**	0.27**	0.19**	0.16**	0.69**	1
15. Grade 3	0.46**	0.49**	0.53**	0.53**	0.40**	0.38**	0.40**	0.32**	0.25**	0.27**	0.20**	0.17**	0.64**	0.75**
16. Grade 4	0.44**	0.48**	0.50**	0.53**	0.41**	0.40**	0.40**	0.34**	0.27**	0.33**	0.24**	0.20**	0.61**	0.70**
17. Grade 7	0.36**	0.37**	0.37**	0.37**	0.41**	0.41**	0.33**	0.32**	0.27**	0.31**	0.34**	0.29**	0.51**	0.59**
18. Grade 9	0.37**	0.37**	0.34**	0.36**	0.39**	0.40**	0.35**	0.32**	0.27**	0.29**	0.35**	0.31**	0.54**	0.59**
Parental Reading Difficulties														
19. Mother	−0.13**	−0.16**	−0.12**	−0.14**	−0.10**	−0.08*	−0.12**	−0.12**	−0.10**	−0.13**	−0.02	−0.05	−0.06*	−0.07**
20. Father	−0.16**	−0.18**	−0.14**	−0.15**	−0.13**	−0.12**	−0.13**	−0.12**	−0.10**	−0.08**	−0.12**	−0.10**	−0.09**	−0.10**
21. Mother	−0.12**	−0.13**	−0.11**	−0.13**	−0.09**	−0.07*	−0.10**	−0.15**	−0.11**	−0.14**	−0.10**	−0.09**	−0.10**	−0.15**
22. Father	−0.14**	−0.15**	−0.13**	−0.14**	−0.11**	−0.11**	−0.15**	−0.15**	−0.10**	−0.11**	−0.12**	−0.11**	−0.14**	−0.14**
Parental Education														
23. Mother	0.13**	0.15**	0.12**	0.16**	0.13**	0.17**	0.18**	0.17**	0.17**	0.22**	0.19**	0.19**	0.12**	0.15**
24. Father	0.13**	0.16**	0.12**	0.16**	0.14**	0.13**	0.18**	0.18**	0.19**	0.20**	0.17**	0.18**	0.12**	0.16**
Home Learning Environment														
25. Shared reading, mother	0.02	0.05*	0.04	0.07*	0.07*	0.09**	0.10**	0.14**	0.11**	0.20**	0.19**	0.17**	−0.01	0.01
26. Shared reading, father	0.02	0.04	0.06	0.09**	0.08*	0.08*	0.11**	0.12**	0.16**	0.19**	0.14**	0.15**	0.01	0.05
27. Teaching literacy, mother	0.08**	0.07**	0.10**	0.06*	0.08*	0.09**	0.10**	0.06*	0.03	0.07**	0.03	0.06	0.02	0.03
28. Teaching literacy, father	0.02	−0.02	−0.01	−0.01	0.04	0.03	0.06	0.01	0.02	0.01	0.03	0.06	0.01	−0.01
29. Teaching numeracy, mother	−0.04	−0.05*	−0.01	−0.03	−0.04	−0.02	−0.03	−0.05	−0.05	−0.00	−0.05	−0.03	0.00	0.02
30. Teaching numeracy, father	−0.06	−0.05	−0.04	−0.05	−0.02	−0.00	−0.02	−0.03	−0.01	0.01	0.01	−0.00	0.05	0.04

(Continued)

TABLE 4 | Continued

	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1. Grade 1																
2. Grade 2																
3. Grade 3																
4. Grade 4																
5. Grade 7																
6. Grade 9																
7. Grade 1																
8. Grade 2																
9. Grade 3																
10. Grade 4																
11. Grade 7																
12. Grade 9																
Arithmetic Fluency (z-scores)																
13. Grade 1																
14. Grade 2																
15. Grade 3	1															
16. Grade 4	0.77**	1														
17. Grade 7	0.60**	0.68**	1													
18. Grade 9	0.61**	0.67**	0.75**	1												
Parental Reading Difficulties																
19. Mother	−0.07**	−0.05	−0.02	−0.06	1											
20. Father	−0.09**	−0.10**	−0.09**	−0.08**	−0.04	−0.08*	0.10**	1								
21. Mother	−0.13**	−0.14**	−0.07*	−0.09**	0.30**	0.13**	1									
22. Father	−0.13**	−0.17**	−0.10**	−0.15**	0.16**	0.38**	0.13**	1								
Parental Education																
23. Mother	0.17**	0.18**	0.21**	0.19**	−0.15**	−0.10**	−0.23**	−0.15**	1							
24. Father	0.15**	0.20**	0.16**	0.19**	−0.06*	−0.14**	−0.14**	−0.20**	0.53**	1						
Home Learning Environment																
25. Shared reading, mother	−0.01	0.01	−0.01	0.05	−0.07**	−0.02	−0.05	0.01	0.21**	0.12**	1					
26. Shared reading, father	0.05	0.06	0.05	0.09*	−0.02	−0.03	−0.06	−0.03	0.23**	0.20**	0.48**	1				
27. Teaching literacy, mother	0.03	−0.00	−0.01	−0.04	−0.04	−0.03	−0.04	0.03	−0.06*	−0.05	0.14**	0.04	1			
28. Teaching literacy, father	−0.02	−0.04	0.00	0.05	0.08**	−0.04	0.03	−0.06	0.00	−0.01	0.12**	0.24**	0.26**	1		
29. Teaching numeracy, mother	0.02	0.01	0.00	−0.02	−0.02	0.01	−0.02	0.00	−0.11**	−0.10**	0.12**	0.01	0.68***	0.20**	1	
30. Teaching numeracy, father	0.02	0.01	0.06	0.03	0.01	−0.02	0.00	−0.10**	0.03	0.00	0.07*	0.19**	0.19**	0.67***	0.22**	1

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

time point, which then explained 75% of the variance at the third time point.

The Model for Reading Comprehension

Figure 3 reports the final model for reading comprehension. The model fitted the data well: $\chi^2(170) = 248.42$, $p < 0.001$, RMSEA = 0.02, CFI = 0.97, SRMR = 0.03. The model suggested several statistically significant predictors of reading comprehension. Mothers' and fathers' mathematical difficulties predicted poorer reading comprehension among children, each predicting 1% of the variance. Mothers' and fathers' levels of education were significant positive predictors of children's reading comprehension, each explaining 2% of the variance. Shared reading with fathers was also found to have a direct positive effect on children's reading comprehension (explaining 1% of the variance) at the first time point, whereas shared reading with mothers was predictive of children's comprehension at the second time point (explaining 2% of the variance). In addition, higher levels of education among mothers predicted more time spent on shared reading and less time spent on teaching activities. The higher levels of education of mothers and fathers were associated with more shared reading with fathers. This model did not reveal any significant indirect effects. In addition, reading comprehension demonstrated very high stability across time. The first time point explained 72% of the variance in reading comprehension at the second time point, which then explained 87% of the variance at the third time point.

The Model for Arithmetic Fluency

Figure 4 reports the model for arithmetic fluency. The model fitted the data well: $\chi^2(170) = 255.33$, $p < 0.001$, RMSEA = 0.02, CFI = 0.979, SRMR = 0.03. Similarly to the comprehension model, this model revealed that only mathematical but not reading difficulties of mothers and fathers predicted children's

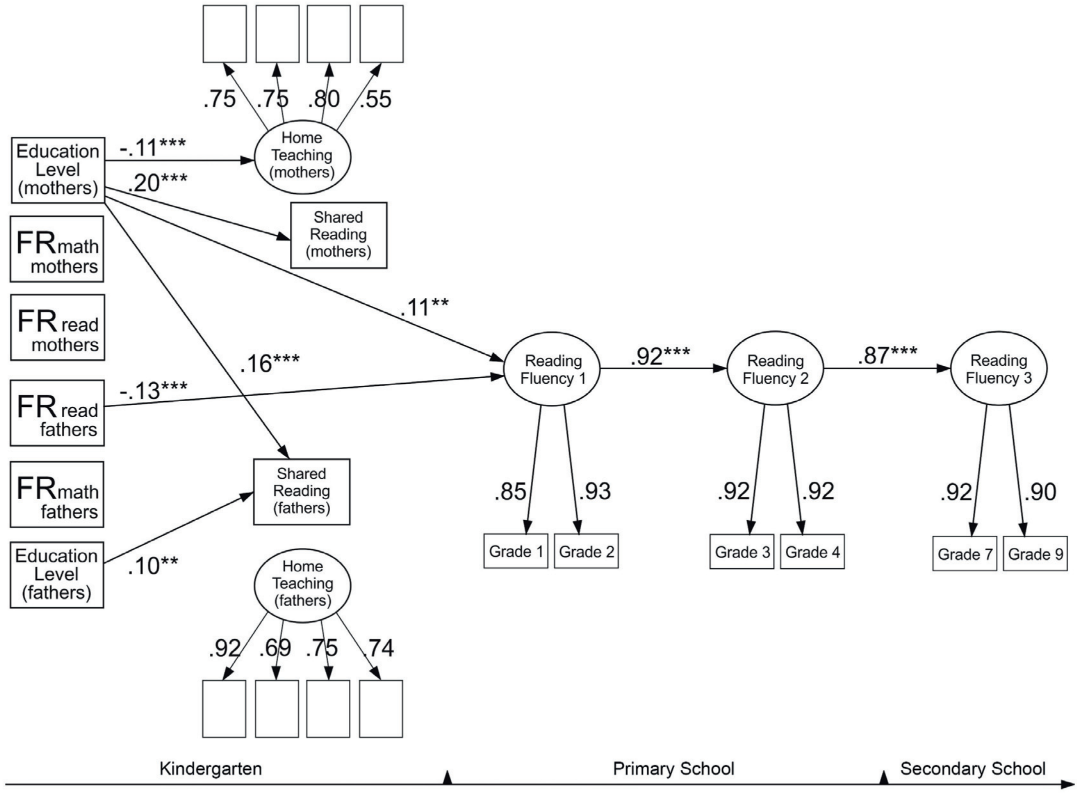

FIGURE 2 | Reading fluency model. The model shows only significant standardized paths. Familial risk (FR for reading and mathematical difficulties of mothers and fathers). $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Two significant residual correlations were included in the model: between the mothers' and fathers' teaching factor (0.27**) and between the mothers' and fathers' shared reading variables (0.47**).

mathematical skills, each explaining 1% of the variance. Mothers' and fathers' levels of education were also significant predictors of children's arithmetic fluency, with fathers' education explaining 1% of the variance at the first time point and mothers' education explaining 1% of the variance at the second time point. No significant effects of any home environment factors for predicting children's arithmetic fluency were observed. Higher levels of education among mothers predicted less time spent on teaching activities and more time spent on shared reading. Higher levels of education among mothers and fathers predicted more shared reading with fathers. This model did not reveal any significant indirect associations. Similarly to reading skills, arithmetic fluency demonstrated very high stability across time. The first time point explained 81% of the variance in mathematics skills at the second time point, which then explained 77% of the variance at the third time point.

DISCUSSION

In this study, our main goal was to gain more understanding of the basis of reading and mathematical comorbidity by examining the transmission of parental reading and mathematical difficulties (FR) onto children's reading and mathematical skills. We examined both direct effects of FR on children's skill development and indirect effects of FR via formal and informal home learning activities. To provide insights into the underpinning processes of the frequently occurring comorbidity of reading and mathematical difficulties, our analysis included mathematical and reading skills, FR for reading and mathematical difficulties coming from both parents, as well as home environment measures for both literacy and numeracy activities. Parental educational level was included as a control measure. Our findings indicated the direct effects of FR on children's skills but no indirect effects via the home environment. Indeed, neither mathematical nor reading difficulties of the parents predicted the frequency of shared reading and parental teaching activities. Higher levels of parental education, on the contrary, predicted more frequent shared reading with both parents and less frequent teaching activities with mothers. In addition, we found that parental mathematical difficulties predicted not only children's mathematical skills but also their reading comprehension, whereas parental reading difficulties predicted only children's reading fluency. This suggests that the mathematical difficulties

TABLE 5 | All regression paths and residual correlations in the three models.

Path estimates	Model for reading fluency: estimate (s.e.)	Model for reading comprehension (s.e.): estimate (s.e.)	Model for arithmetic fluency: estimate (s.e.)
FR for reading, mothers → home teaching, mothers	−0.05 (0.03)	−0.05 (0.03)	−0.05 (0.03)
FR for reading, mothers → shared reading, mothers	−0.04 (0.03)	−0.04 (0.03)	−0.04 (0.03)
FR for math, mothers → home teaching, mothers	−0.06 (0.05)	−0.06 (0.05)	−0.06 (0.05)
FR for math, mothers → shared reading, mothers	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)
FR for reading, mothers→ skills at Time Point 1	−0.05 (0.03)	−0.06 (0.04)	−0.00 (0.03)
FR for math, mothers→ skills at Time Point 1	−0.06 (0.03)	−0.10* (0.04)	−0.11** (0.03)
Education level, mothers → skills at Time Point 1	0.11** (0.04)	0.13** (0.04)	0.06 (0.04)
Education level, mothers → skills at Time Point 2			0.09*** (0.02)
Education level, mothers → home teaching, mothers	−0.11*** (0.03)	−0.11*** (0.03)	−0.11*** (0.03)
Education level, mothers → shared reading, mothers	0.20*** (0.03)	0.20*** (0.03)	0.20*** (0.03)
Shared reading, mothers → skills at Time Point 1	−0.01 (0.04)	0.05 (0.04)	−0.01 (0.04)
Shared reading, mothers → skills at Time Point 2		0.13*** (0.03)	
At-home teaching, mother → skills at Time Point 1	−0.02 (0.04)	0.02 (0.04)	−0.01 (0.04)
FR for reading, fathers → home teaching, fathers	0.01 (0.03)	0.01 (0.03)	0.01 (0.03)
FR for reading, fathers → shared reading, fathers	0.01 (0.03)	0.01 (0.03)	0.01 (0.03)
FR for math, fathers → home teaching, fathers	−0.07 (0.04)	−0.07 (0.04)	−0.07 (0.04)
FR for math, fathers → shared reading, fathers	−0.01 (0.03)	−-0.01 (0.03)	−0.01 (0.03)
FR for reading, fathers → skills at Time Point 1	−0.13*** (0.04)	−0.07 (0.04)	−0.04 (0.04)
FR for math, fathers → skills at Time Point 1	−0.05 (0.04)	−0.10* (0.04)	−0.11** (0.04)
Education level, fathers → skills at Time Point 1	0.06 (0.04)	0.14** (0.04)	0.10** (0.04)
Education level, fathers → home teaching, fathers	−0.01 (0.03)	−0.01 (0.03)	−0.01 (0.03)
Education level, fathers → shared reading, fathers	0.10** (0.03)	0.10** (0.03)	0.10** (0.03)
Shared reading, fathers → skills at Time Point 1	0.02 (0.04)	0.10* (0.04)	0.01 (0.04)
At-home teaching, fathers → skills at Time Point 1	−0.04 (0.04)	−0.02 (0.04)	0.00 (0.03)
Skills at Time Point 1 → Skills at Time Point 2	0.92*** (0.01)	0.85*** (0.03)	0.90*** (0.01)
Skills at Time Point 2 → Skills at Time Point 3	0.87*** (0.02)	0.93*** (0.03)	0.88*** (0.02)
Education level, mothers → Shared reading, fathers	0.16*** (0.03)	0.16*** (0.03)	0.16*** (0.03)
Residual covariances			
Home teaching, mothers with home teaching, fathers	0.25*** (0.04)	0.25*** (0.04)	0.25*** (0.04)
Shared reading, mothers with home teaching, mothers	0.15***(0.03)	0.15*** (0.03)	0.15*** (0.03)
Shared reading, mothers with home teaching, fathers	0.13*** (0.03)	0.13*** (0.03)	0.13*** (0.03)
Shared reading, fathers with home teaching, fathers	0.26*** (0.03)	0.26*** (0.03)	0.26*** (0.03)
Shared reading, fathers with shared reading, mothers	0.44*** (0.03)	0.44*** (0.03)	0.44*** (0.03)

**p < 0.05, **p < 0.01, ***p < 0.001. Some regression and correlation paths were not initially hypothesized but were later added based on the modification indices.*

of parents increase their children's liability for developing not only mathematical difficulties but also reading comprehension difficulties. Finally, of the home environment measures, shared reading predicted reading comprehension in Grades 1 and 2 as well as faster development of comprehension skills from Grades 1 and 2 to Grades 3 and 4, whereas more literacy and numeracy teaching activities did not predict skills. These findings suggest that children's learning difficulties arise from a complex interaction of multiple risk factors (inherited deficits and environmental influences).

Familial Risk as a Predictor of Reading and Mathematical Skills

The results suggested significant within-domain effects of parental skills on children's skills, particularly for parental mathematical difficulties. Both mothers' and fathers' mathematical difficulties predicted poorer performance in arithmetic fluency among their children. Furthermore, fathers' reading difficulties predicted their children's reading fluency. Mothers' reading difficulties, however, were not predictive of any of the children's skills. These findings are consistent with those of previous studies showing significant FR effects for mathematics (Shalev and Gross-Tsur, 2001; Soares et al., 2018) and reading (Elbro et al., 1998; Torppa et al., 2011, 2015; van Bergen et al., 2014a; Hulme et al., 2015; Esmaeeli et al., 2019). However, the effect sizes were modest, with FR (coming from each parent) predicting approximately 1% of children's skills in Grades 1 and 2. Nevertheless, this effect size is comparable to that in earlier studies in which FR was self-reported and not tested. Recently, Esmaeeli et al. (2019) reported that in their study, FR explained 3% of the variance in children's reading skills. However, Torppa et al. (2011) and van Bergen et al. (2014a) estimated that 8–16% and 11% of children's reading skills, respectively, can be predicted by FR when it is identified with parental skill assessments. Undoubtedly, parental testing is

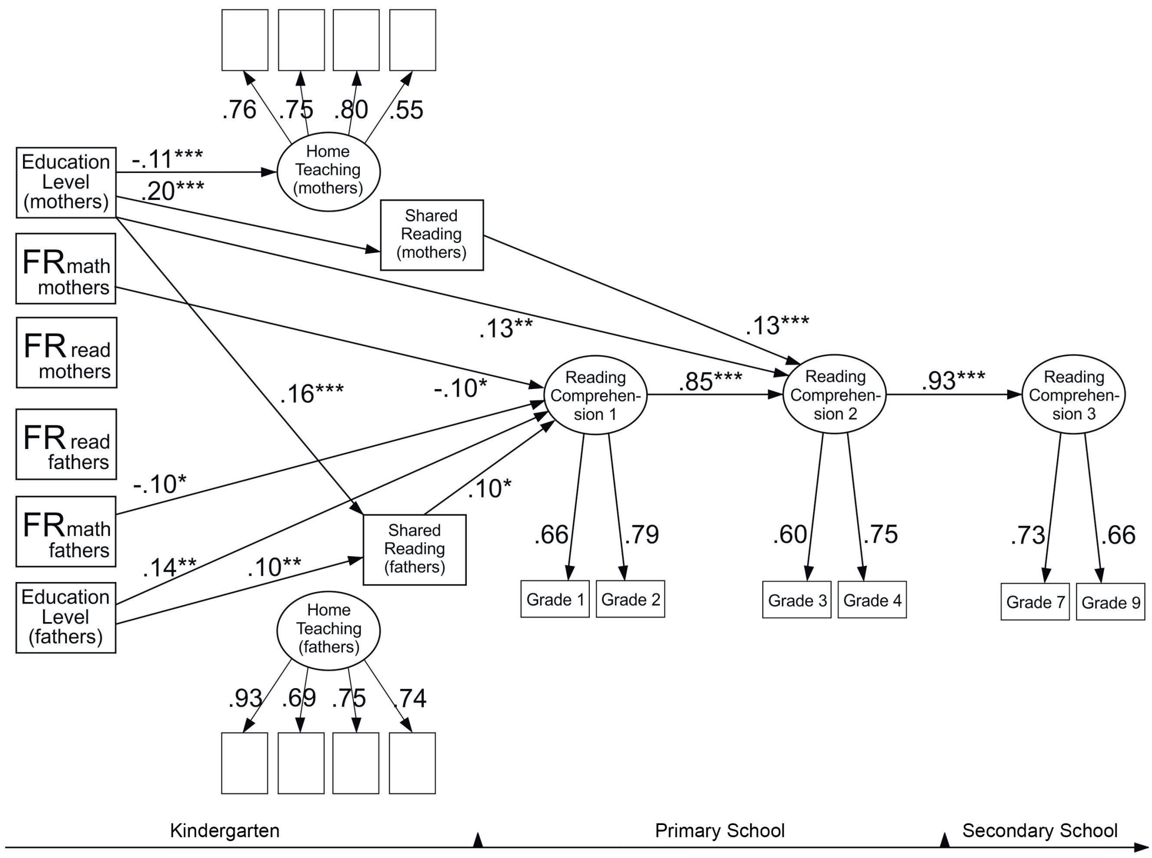

FIGURE 3 | Reading comprehension model. The model shows only significant standardized paths. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Familial risk (FR for reading and mathematical difficulties of mothers and fathers). Two significant residual correlations were included in the model: between the mother's and father's teaching factor (0.27**) and between the shared reading variables (0.47**).

a more reliable measure to detect FR than self-reports, although the correlation between formally tested reading skills and self-reported difficulties has been reported to be as high as 0.80 (van Bergen et al., 2014a).

In line with the previous FR studies, the results of our models revealed significant differences in children's skills between groups with and without FR. For some skill measures, the results further suggested a stepwise pattern wherein the group with one parent FR had stronger skills than the group with FR owing to two parents. This evidence suggests that the dual parent learning difficulty constitutes an aggravated risk for children's skill development. This finding is in line with the MDM and fits with the suggestions of the continuous liability distribution of FR (Snowling et al., 2003; Pennington, 2006; van Bergen et al., 2012). The pattern was present for parental mathematical difficulties in four arithmetic assessments, two reading fluency assessments, and one reading comprehension assessment. However, for parental reading difficulties, the pattern was present only for the reading fluency of children in Grades 1 and 4.

Significant cross-domain effects of FR on children's skills were also identified but only for parental mathematical difficulties. Both mothers' and fathers' mathematical difficulties predicted children's reading comprehension but not reading fluency. Moreover, children's mathematical skills did not appear to be associated with FR for reading difficulties. These paths from FR to mathematical difficulties lend support to the argument that reading and mathematical difficulties have both common and distinct underpinnings (Landerl and Moll, 2010; Carvalho and Haase, 2019) and point to an intergenerational transmission of multiple deficits, as posited by Pennington's MDM. The findings support those of earlier studies indicating that mathematical difficulties more often co-occur with reading difficulties than the other way around (Landerl and Moll, 2010; Carvalho and Haase, 2019). The findings do not, however, explain the comorbidity of reading and mathematical difficulties that is often found using fluency-based assessments (Moll et al., 2019). The processes underlying the specific link between children's reading comprehension and parental mathematical difficulties need to be

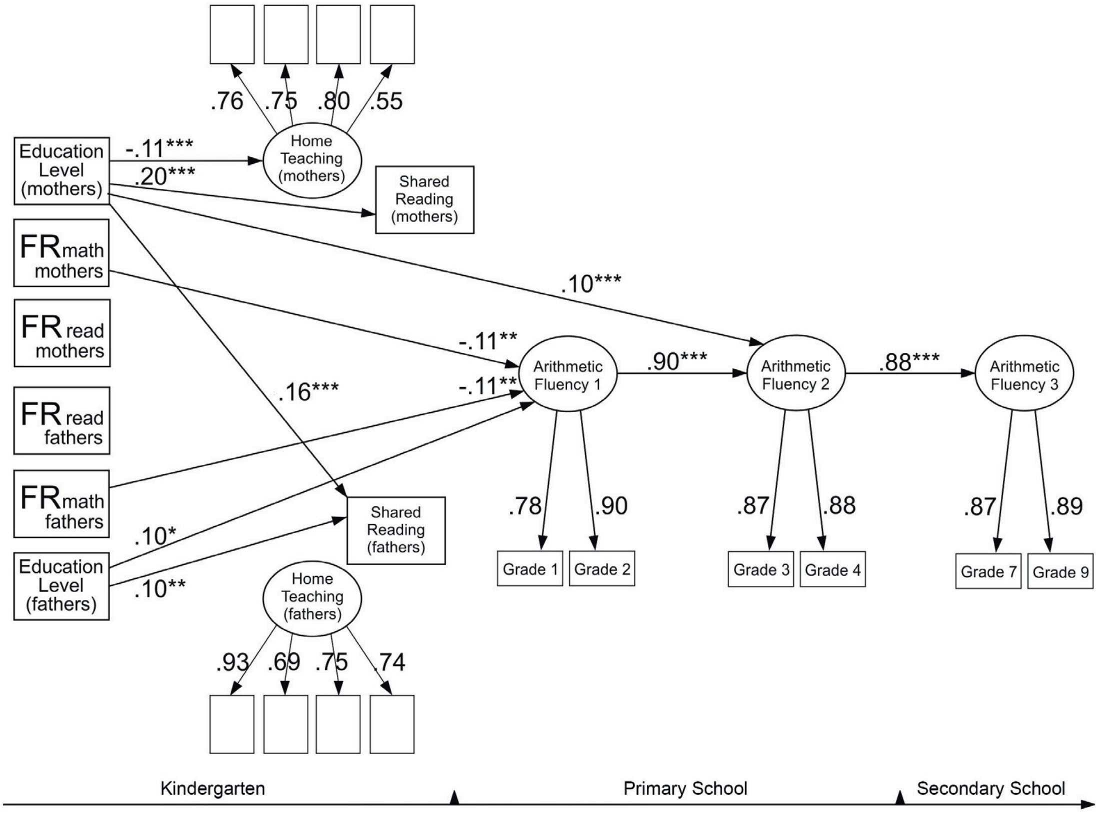

FIGURE 4 | Arithmetic fluency model. The model shows only significant standardized paths. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. FR, familial risk (FR for reading and mathematical difficulties of mothers and fathers). Two significant residual correlations were included in the model: between the mother's and father's teaching factor (0.27**) and between the shared reading variables (0.47**).

examined further. Some research has indicated that the genetic correlations of mathematical skills with reading comprehension are significantly higher than those with decoding (Harlaar et al., 2012). Furthermore, a strong association has been found between children's reading comprehension and mathematical reasoning (Pimperton and Nation, 2010), which may in part explain why we found parental mathematical difficulties predicting children's reading comprehension.

Home Learning Environment as a Predictor of Children's Reading and Arithmetic Skills

At-home teaching activities seemed to have neither direct nor indirect effects on children's skills, which stands in contrast with our hypothesis and earlier research (Martini and Sénéchal, 2012; Sénéchal and Lefevre, 2014; Skwarchuk et al., 2014; Sénéchal, 2015; Puglisi et al., 2017; Napoli and Purpura, 2018). Our findings are in line with some other research (Missall et al., 2015; Zippert and Rittle-Johnson, 2020) and could be viewed as supportive evidence for the argument that gains from formal home activities tend to be negligibly small and short-term in the context of transparent languages and fade away once children enter school (Manolitsis et al., 2013; Silinskas et al., 2020). Indeed, highly regular orthographies speed up the process of reading acquisition allowing children to reach good reading levels with the support of high-quality phonics teaching at school (Aro, 2017), which explains why providing early reading instruction at home does not ensure any long-term advantage. It is also important to stress that Finland has succeeded in promoting educational equality by creating a welfare state, which provides early educational support in schools to every child reducing the need for home teaching and the extent to which a family's socioeconomic background affects their child's development (e.g., Reinikainen, 2012).

At the same time, as expected, shared reading organized by both mothers and fathers had significant direct effects on children's reading comprehension in lower grades, which is in line with earlier findings pointing to the influence of informal literacy inputs on beginners' reading comprehension (Foy and Mann, 2003; Sénéchal, 2006, 2015; Torppa et al., 2007; Martini and Sénéchal, 2012; Manolitsis et al., 2013; Sénéchal and Lefevre, 2014; Hamilton et al., 2016; Puglisi et al., 2017). However, no effects of shared reading were found for arithmetic or reading fluency, which is consistent with the findings of earlier studies that investigated the effects of informal meaning-related home activities on children's decoding skills, symbolic number knowledge, and non-symbolic arithmetic skills (Sénéchal et al., 2008; Martini and Sénéchal, 2012; Sénéchal and Lefevre, 2014; Napoli and Purpura, 2018; Esmaeeli et al., 2019). The reason for reading comprehension being associated with shared reading is typically explained by its impact on oral language (Torppa et al., 2007; Sénéchal et al., 2008; Martini and Sénéchal, 2012; Sénéchal and Lefevre, 2014; Hamilton et al., 2016; Silinskas et al., 2020). Similar to the predictive effects of FR, the effects of shared reading on children's comprehension were rather small—less than 2%. The modest variance explained by informal learning likely stems from the same reasons listed above in regards to the predictive role of formal activities at home. In addition, Puglisi et al. (2017) reported that the relationship between informal literacy learning activities and children's skills is mostly accounted for by parental skills and might reflect a gene-environment correlation. Interestingly, however, this study found that shared reading with mothers was predictive of the reading comprehension of children in Grades 3 and 4 even with the inclusion of FR, as well as over and above the autoregressor, suggesting that the improvement in reading comprehension during the early school years was partially predicted by shared reading.

Familial Risk and the Home Learning Environment

The models indicated that FR for neither reading nor mathematical difficulties predicted at-home teaching or shared reading—parents with difficulties read with their children and taught academic skills in the same way as the parents without difficulties. This is in line with previous research (Elbro et al., 1998; Laakso et al., 1999; Torppa et al., 2007; Hamilton et al., 2016) suggesting that parental reading and mathematical difficulties are not transmitted to their children via the home environment. Intriguingly, higher levels of education among mothers predicted significantly less time spent on teaching activities and more time spent on shared reading. In other words, FR predicted neither formal nor informal home environment activities whereas maternal education predicted both. In the more educated homes, fathers also spent more time reading with their children. It is possible that parents with lower levels of education are more inclined to expect their children's possible school failure or, alternatively, that they increase the volume of home teaching activities when their children display early signs of difficulties (Blevins-Knabe and Musun-Miller, 1996; Silinskas et al., 2010; Sénéchal and Lefevre, 2014).

In addition, and contrary to our hypothesis, we did not find FR having a significant indirect effect on children's skills via the home environment. This negative finding is in line with Esmaeeli et al. (2019), who despite their hypothesis also failed to find significant indirect paths from FR for reading difficulties to children's skill. That said, however, it is important to not completely discard the influence of FR on the home environment. Indeed, Esmaeeli et al. (2018) made a reasonable argument that FR might be negatively affecting the home environment both directly and indirectly through parental education because the FR status is likely to be a contributing factor to lower parental education, as was previously reported both in Finland and in other countries (McLaughlin et al., 2014; Aro et al., 2019). Interestingly, some studies (Scarborough et al., 1991; Bus et al., 1995; Elbro et al., 1998; Snowling, 2000; Leinonen et al., 2001; Torppa et al., 2007)

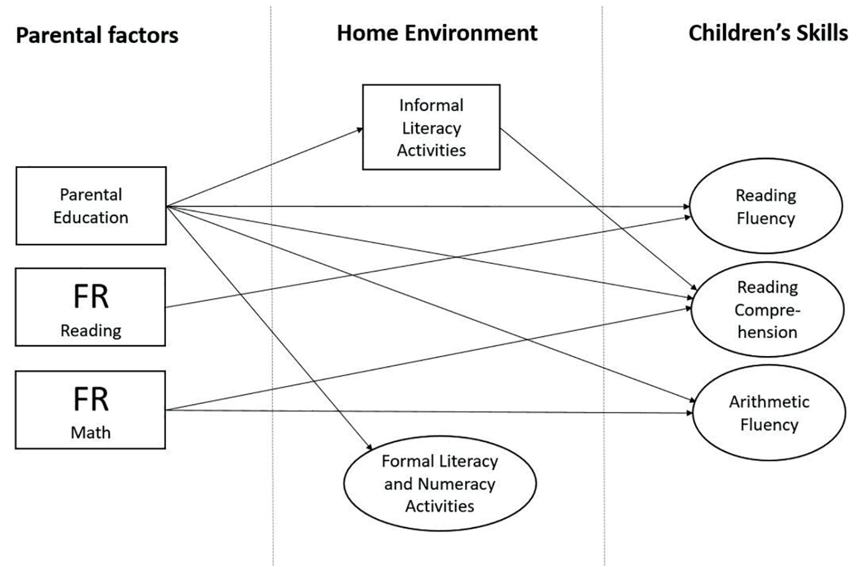

FIGURE 5 | Visual summary. The figure shows all significant paths found in this study.

showed that parents with learning difficulties read less than their control counterparts and thus may provide less positive parental models.

Limitations and Future Research

The present study has limitations in regard to the measures employed. First, similarly to previous investigations (e.g., Silinskas et al., 2010; Esmaeeli et al., 2018, 2019), this study deployed parental self-reports of HLE and HNE, which are liable to social desirability bias. Moreover, the measures mostly focused on assessing the formal activities of the home environment and had only one question assessing informal HLE and no questions tapping into informal HNE. Therefore, an important goal for future research is to incorporate a wider range of assessment measures for HLE and HNE which, in combination with longitudinal study designs, render an essentially more reliable prediction than cross-sectional studies alone. However, even well-founded longitudinal associations are far from being interpreted causally. Thus, randomized controlled trials testing various HLE and HNE interventions are needed to aid in the understanding of causal effects. Second, the quality of at-home learning can vary significantly and could be an additional predictor (Siraj-Blatchford, 2010; Kluczniok et al., 2013). The lack of measures capturing the quality of home teaching could be one of the reasons behind the small amount of variance explained by the home environment activities, and future studies should take this into account. Third, future research would benefit from using a more comprehensive assessment of the FR status. The self-report measure for parents used in the present study was short and simple. Nevertheless, this study revealed significant FR effects on children's reading and mathematical skills that are comparable to those found in previous FR studies (Silinskas et al., 2010; Esmaeeli et al., 2018, 2019).

In this study, we were particularly interested in arithmetic fluency as it starts to develop in early grades and forms the foundation not only for more complex arithmetic skills (Carr and Alexeev, 2011) but also for mathematical reasoning (Powell et al., 2016). The defining feature of specific mathematical difficulty in the primary grades is a poorly developed subtraction and addition fluency (e.g., Jordan et al., 2003). However, a desirable goal is making the mathematical assessment more comprehensive by including, for example, a mathematical reasoning measure. The link between reading comprehension and mathematical reasoning has been previously reported (Pimperton and Nation, 2010) suggesting that the possible intergenerational connection of these skills could to be another avenue for future research. Finally, it is important to assess not only the quantity but also the quality of home learning activities, which represents a serious challenge but could be achieved in future research with the use of qualitative case studies (Siraj-Blatchford, 2010).

CONCLUSION

We have summarized visually the results of this study in **Figure 5**. The key finding is that FR for both reading and mathematical difficulties had direct effects on children's skills—the difference between groups with and without FR became apparent in the early grades and remained stable till the last time point of assessment in Grade 9. More specifically, FR for mathematical difficulties predicted both mathematical and reading comprehension difficulties in children, whereas FR for reading difficulties was predictive of children's reading fluency difficulties only. However, there were no indirect effects of FR via the home environment. Moreover, we failed to detect any effect of the FR status on the home environment. Another important finding is that shared reading was the only component of the home environment that predicted faster development of children's skills: more specifically, the reading comprehension in Grades 3 and 4. At the same time, more educated mothers and fathers spent more time reading with their children, whereas mothers with lower levels of education were more likely to focus on at-home teaching. These findings might appear somewhat counterintuitive and therefore call for more nuanced research of learning milieus at home. In particular, more attention needs to be paid on how to support the home learning activities of academically under-privileged parents who are trying their best to give their children a head start.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of the University of Jyväskylä in 2006. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DK drafted the first version of the current manuscript. MP, MT, and DK contributed to the data analysis. GS, M-KL, PN, A-MP, and MT were responsible for the data collection and commented on the manuscript. All authors contributed to the manuscript drafting, and read and approved the submitted version.

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III

PARENTAL INFLUENCES ON THE DEVELOPMENT OF SINGLE AND CO-OCCURRING DIFFICULTIES IN READING AND ARITHMETIC FLUENCY

by

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

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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

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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 · 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 (χ^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 (χ^2 (165) = 314.477, $p <$ .001) and in math (χ^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

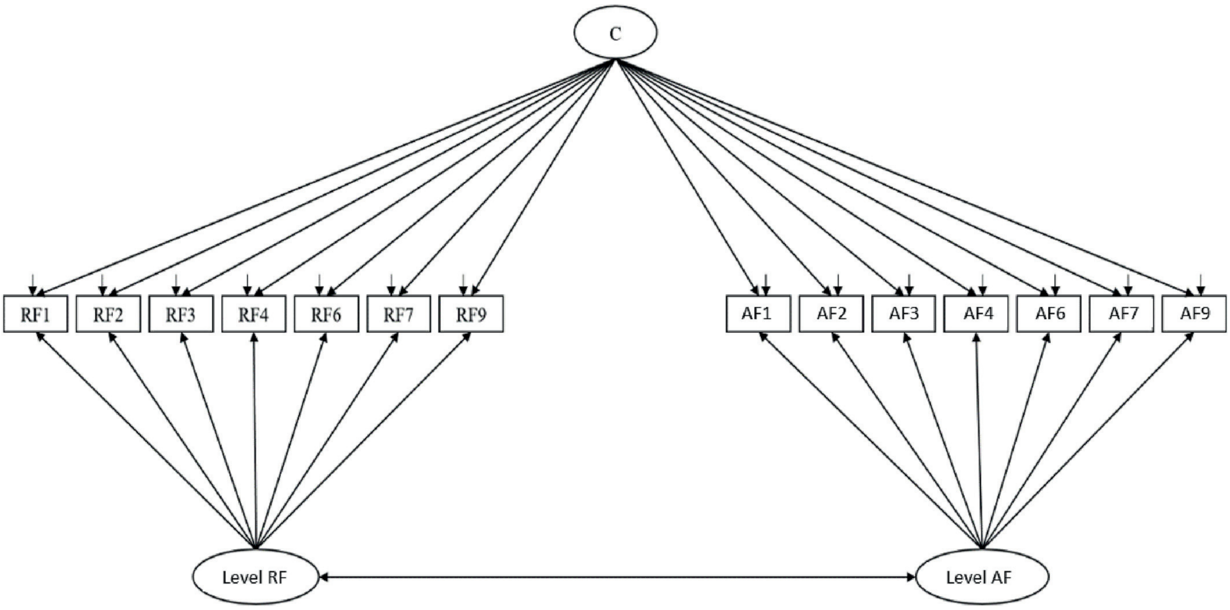

Fig. 1. Latent profile analysis model for the reading and arithmetic fluency measures.
Note. C represents the latent profiles, Level RF and Level AF represent the initial level of reading fluency (RF) and arithmetic fluency (AF). Numbers next to RF and AF indicate the assessment time point (grade).

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.

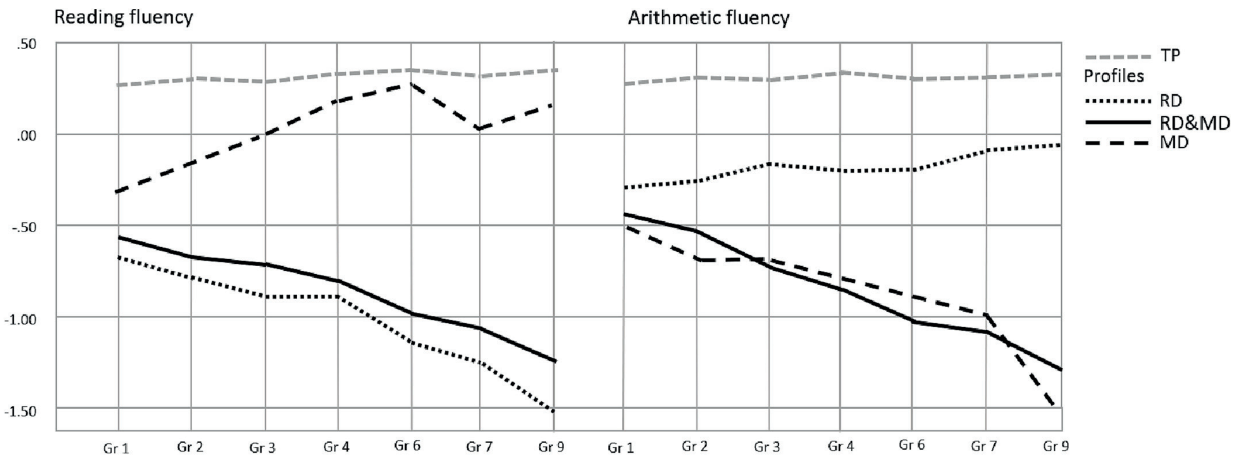

Fig. 2. Reading fluency (z-scores) and arithmetic fluency (z-scores) longitudinal pathways of different profiles across the seven time points.
Note. RD = Reading Difficulty Profile; MD = Mathematical Difficulty Profile; RD&MD = Comorbidity Profile; TP = typical performers (added here for comparison but 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, χ^2 (3, n = 1526) = 5.81, p = .121, whereas family risk for MD was χ^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

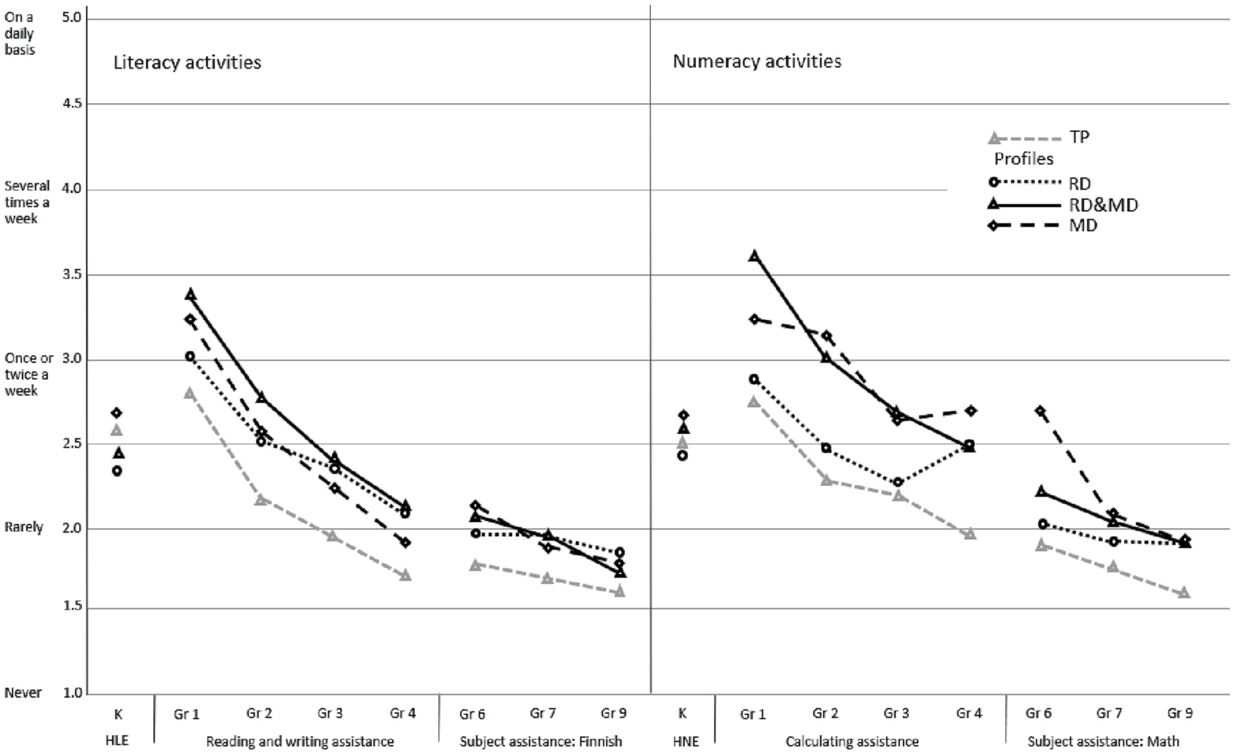

Fig. 3. Literacy and numeracy activities the children of the different profiles received at home across the eight time points.
Note. RD = Reading Difficulty Profile; MD = Mathematical Difficulty Profile; RD&MD = Comorbidity Profile; TP = typical performers; K = Kindergarten; HLE = Home Literacy Environment; 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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