



UNIVERSITY OF HELSINKI



<https://helda.helsinki.fi>

Helda

Early Numeracy in 3- to 4-Year-Old Children : The Role of Family Variables, Child's Gender, and Language Skills

Aunio, Pirjo

Routledge, Taylor and Francis Group

2025-10-10

Aunio, P, De Smedt, B, Vessonen, T & Korhonen, J 2025, 'Early Numeracy in 3- to 4-Year-Old Children : The Role of Family Variables, Child's Gender, and Language Skills', *Journal of Research in Childhood Education*.

<https://doi.org/10.1080/02568543.2025.2566965>, <https://doi.org/10.1080/02568543.2025.2566965>

<http://hdl.handle.net/10138/602640>

10.1080/02568543.2025.2566965

cc_by

publishedVersion

Downloaded from Helda, University of Helsinki institutional repository.

This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Please cite the original version.



Early Numeracy in 3- to 4-Year-Old Children: The Role of Family Variables, Child's Gender, and Language Skills

Pirjo Aunio, Bert De Smedt, Terhi Vessonen & Johan Korhonen

To cite this article: Pirjo Aunio, Bert De Smedt, Terhi Vessonen & Johan Korhonen (09 Oct 2025): Early Numeracy in 3- to 4-Year-Old Children: The Role of Family Variables, Child's Gender, and Language Skills, Journal of Research in Childhood Education, DOI: [10.1080/02568543.2025.2566965](https://doi.org/10.1080/02568543.2025.2566965)

To link to this article: <https://doi.org/10.1080/02568543.2025.2566965>



© 2025 The Author(s). Published with license by Taylor & Francis Group, LLC



Published online: 09 Oct 2025.



Submit your article to this journal [↗](#)



Article views: 95



View related articles [↗](#)



View Crossmark data [↗](#)

Early Numeracy in 3- to 4-Year-Old Children: The Role of Family Variables, Child's Gender, and Language Skills

Pirjo Aunio ^a, Bert De Smedt ^b, Terhi Vessonen ^a, and Johan Korhonen ^c

^aUniversity of Helsinki, Helsinki, Finland; ^bKU Leuven, Leuven, Belgium; ^cÅbo Akademi University, Vaasa, Finland

ABSTRACT

Research on early numeracy has largely focused on 5- and 6-year-olds and studies in younger children, often collapsed samples across different age groups. We collected data from 3-year-olds ($n = 147$) and 4-year-olds ($n = 173$). First, we ensured the reliability and validity of the Early Numeracy Test (ENT) in 3- and 4-year-old children. Second, we investigated the role of family variables (i.e., socioeconomic status and number of siblings), gender, and language skills in individual differences in early numeracy. Results showed that the adapted ENT can be used to reliably measure numerical relational and counting skills in 3- and 4-year-olds. Both numerical relational and counting skills were related to their symbolic magnitude processing skills. When analyzing individual differences, we found that in both age groups higher numerical relational skills were related to fewer number of children in the family, higher family income, and higher parental educational level. In the 4-year-olds, higher counting skills were related to having a higher parental educational level. There were no gender differences in early numeracy. When language skills were accounted for, only parental education level predicted numerical relational skills directly and indirectly through language skills, but only in 4-year-old children.



ARTICLE HISTORY

Received 19 December 2023
Accepted 13 August 2025

KEYWORDS

Early numeracy; individual differences; language skills; preschoolers; symbolic number processing

Preschool is a time of extensive mathematics skills development (Litkowski et al., 2020a) and research has shown that early numeracy skills at the ages of 5 and 6 years predict later mathematics learning and that they are an important predictor for success in the labor market (Aunio & Niemivirta, 2010; Duncan et al., 2007; Liu et al., 2025; Ritchie & Bates, 2013; Shapka et al., 2006). Although early numeracy skills have attracted a lot of research attention in the last 15 years (see Clements & Sarama, 2021, for a good summary), the existing body of empirical studies concentrates on 5- and 6-year-olds. In addition, studies with 3- and 4-year-olds have often been collapsed across these young age groups (e.g., Bleses et al., 2023; Dunekacke et al., 2024; Hornburg et al., 2024), which leaves it unknown as to how different types of numerical skills evolve in this quite “critical” two-year period (Litkowski et al., 2020a; Purpura & Lonigan, 2015). Children are rapidly developing in many areas between 3 and 4 years (Best & Miller, 2010), during which early numeracy development has been found to be related to individual factors, such as language development (Duncan et al., 2007; Purpura & Reid, 2016) and contextual factors, such as parental educational background (Muñez et al., 2021; Thomas et al., 2021). The existing evidence is mainly limited to data from English-speaking children (for a review, see Ernst et al., 2024; Hornburg et al., 2024; Polignano & Hojniski, 2012; Purpura & Lonigan, 2015), and only a few studies have been published outside the English-speaking context (Dunekacke et al., 2024; Sjoe et al., 2019; ten Braak & Størksen, 2021; Thomas et al., 2023).

CONTACT Pirjo Aunio  pirjo.aunio@helsinki.fi  Faculty of Educational Sciences, University of Helsinki, Siltavuorenpenger 5A, P.O. Box 9, Helsinki 00014, Finland

© 2025 The Author(s). Published with license by Taylor & Francis Group, LLC

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

In this study, we aimed to investigate young children's early numeracy learning in a non-English-speaking country. First, we aimed to ensure the validity and reliability of a Finnish Early Numeracy Test in 3-year-olds and 4-year-olds. Second, we investigated the effect of family variables and gender on early numeracy skills and additionally verified if language skills mediated this relationship. This study will contribute to our scientific knowledge related to measuring early numeracy in young age groups and early numeracy development among young children.

Early numeracy skills in 3- to 4-year-olds

Children's understanding of the numerical relations among objects (e.g., whether there are more or less objects in different collections) and ability to count (including cardinal value of number symbols and enumeration) constitute the core of early numeracy and provide foundational support for mathematical learning later at school (Bugden & Ansari, 2011; Chu et al., 2015; B. L. Devlin et al., 2022; Geary & vanMarle, 2018). The *understanding of numerical relations* refers to knowledge of how two or more items (entities, numbers) are connected to each other. Numerical relational skills include, for instance, understanding the connections between sets of quantities (more vs. less), comparing non-symbolic and symbolic quantities, and understanding the order relations between quantities and Arabic numerals (Purpura & Lonigan, 2013). These skills develop fast in preschool (Chan et al., 2022; Krajcsi, 2021; Le Corre & Carey, 2007; Wynn, 1990, 1992). Numerical relational skills and learning to count have been found to be developmentally related (Aubrey et al., 2006). Learning counting skills starts during the early stages of a child's development, first by reciting a number of word sequences without any reference to quantities around 2 and 3 years of age ("one, two, three . . ."; Fuson, 1988; Gelman & Gallistel, 1978). Afterward, around 4 and 5 years of age, linking number words and quantities becomes more frequent and efficient by practicing, along with increasing understanding that number words present the number of items in a set (Clements & Sarama, 2021; Spelke, 2017; Wynn, 1992). Counting (i.e., numbering) skills include, for instance, verbal counting, counting forward and backward from numbers other than one, identifying counting errors, cardinal number knowledge, subitizing, estimation, and enumeration (Purpura & Lonigan, 2013). We focus on counting and number relational skills because these early numeracy skills are the most rapidly developing at the age of 3–4 years (D. Devlin et al., 2022; Dunekacke et al., 2024; Jordan et al., 2022; Litkowski et al., 2020a).

Factors related to individual differences in early numeracy

There are large individual differences in early numeracy development, which have been explained for instance by contextual factors (such as family socioeconomic status or SES) and individual-level factors (such as gender, language skills; Elliott et al., 2023; Hornburg et al., 2024; Muñoz et al., 2021; Purpura & Reid, 2016; Thomas et al., 2023). Our current research follows the premises aligned in the multilevel supply-use model (Brühwiler & Blatchford, 2011), which promotes understanding of learning in a holistic context with various levels of factors affecting learning. In the model, learning outcomes can be affected by use-level factors – such as learning environments (e.g., family socioeconomic status, home language, home environment), individual learning preconditions (e.g., cognition, motivation), and individual learning processes (e.g., learning strategies, attention) – and by supply-level factors, such as teacher characteristics (professional experience, beliefs), classroom context (e.g., class size), context of school and subject, and characteristics of education systems. In the current study, the focus is on early numeracy performance (i.e., learning outcome) and learning environment factors (use-level factors), such as parental education and income level, in addition for the number of children in the family. Language skills are used as individual learning preconditions (use-level factors).

Learning environmental factors on early numeracy

Socio-economic status (SES) of the family has been shown to be related to preschoolers' early numeracy (DeFlorio & Beliakoff, 2015; Hornburg et al., 2018; Muñoz et al., 2021; Thomas et al., 2023). SES has been operationalized mostly by using parental education level and income level, finding both direct and indirect effects (e.g., through parents' beliefs, home numeracy activities) on early numeracy achievement (Bleses et al., 2023; Davis-Kean, 2005; Elliott et al., 2023; Hornburg et al., 2024; Susperreguy et al., 2020). Most of the studies related to family SES originate from the United States and they showed that preschoolers from low-income households typically lag behind in both numbering and numerical relational skills (Elliott et al., 2023; Hornburg et al., 2024; Jordan et al., 2006; Ramani & Siegler, 2011). However, previous studies have focused on children age 4 years and older, with some exceptions (Anders et al., 2012; Hornburg et al., 2018, 2024; Salminen et al., 2021). Hornburg et al. (2024) showed with their U.S. sample that parental educational level was associated with 3- to 5-year-olds' counting skills when age, gender, and language skills were accounted for. With a Danish sample, Bleses et al. (2023) showed that parental education was, albeit only weakly, related with 3- to 5-year-olds' composite early numeracy skills when controlling for age, gender, household income, and other relevant skills (language or executive functions). In their Finnish sample (children age 2.5 years to 5.5 years), Salminen et al. (2021) did not find significant associations between parental education and counting performance of preschoolers after they controlled the parental reading and mathematical learning difficulties.

Family members (i.e., siblings) can provide children with extra resources or competition for the resources, for which reason the effect of siblings can be positive or detrimental to children's development. The effects of siblings have been found to differ based on the content of development (Workman, 2017). Although these effects have been described for children's cognitive development more broadly construed, there is less evidence related to the effects of siblings on children's early numeracy. Muñoz et al. (2022) showed that Singaporean children age 4 years 5 months with siblings had weaker early numeracy skills than those without siblings (see also Downey, 2001). The existing evidence is inconclusive concerning the relationship between family SES and siblings with early numeracy skills, especially among 3- to 4-year-olds, remains limited, and this highlights the need for further investigations.

The role of family SES and siblings may be especially relevant in Finland, where most children under the age of 3 do not participate in early childhood education. All children in Finland under the school age (7 years) and above 9 months have a subjective right to early childhood education and care (ECEC), which is mostly arranged by the municipalities. If a child starts early childhood education early, it happens most often at the age of 1.5–2 years. One parent is entitled to childcare leave from work if they take care of a child under 3 years old at home. It is possible to have approximately 14 months parental leave per child. In Finland, the aim of ECEC is to support children's learning conditions and promote lifelong learning and educational equality in accordance with inclusive principles (Law of Early Childhood Education, 2018). The ECEC core curriculum describes six interrelated domains of broad competences: (1) thinking and learning; (2) cultural competence; (3) interaction and expression; (4) self-care and everyday skills; (5) oral and verbal communication, interaction, social and language skills, social competence, self-control, social life, and self-awareness; and (6) digital literacy and active participation (National core curriculum for ECEC, 2022). It leaves room for local decision-making for organizing ECEC care. In Finland, there are no educational standards set on mathematics learning in early childhood. In ECEC, the importance of play for the child and its pedagogical possibilities in the promotion of wellbeing and learning are highly valued. In 2022, there were 234,300 children participating in early childhood education. Forty percent of under 3 years old and 89% of 3- to 5-year-old children participated in ECEC. The maximum time spent in early childhood education is 10 hours a day (Law of Early Childhood Education, 9 §). Participation in ECEC becomes more common in older

age groups: in 2022, 86% of 3-year-olds, 90% of 4-year-olds, and 91% of 5-year-olds attended ECEC (National Statistics 11.12.2023). Thus, children's home environment is important for their learning, especially in their first years of development; later on, the attendance to ECEC becomes important.

Individual level preconditions for early numeracy

Language skills have been found to be an important individual-level learning preconditions for mathematical performance, and language appears to be a particularly strong predictor before the start of compulsory education (LeFevre et al., 2010; Purpura et al., 2011; Toll & Van Luit, 2014; Zhang et al., 2019; see Peng et al., 2020, for a meta-analysis). Language helps children learn mathematics by supporting the expression of mathematical thinking and comprehension of mathematical concepts (LeFevre et al., 2010). Research has shown that early language skills are related to early numeracy in English-speaking children (Duncan et al., 2007; Hornburg et al., 2024; Purpura & Reid, 2016) and also in Danish (Bleses et al., 2023), French (Thomas et al., 2023), and Finnish children (Kyttälä et al., 2014; Salminen et al., 2021). Well-developed expressive and receptive language skills have been suggested to be an important factor helping preschoolers to understand the meaning of spoken sentences, identify domain-related phrases, engage with numeracy concepts and early numeracy instruction (Hanich et al., 2001; Purpura et al., 2017). Méndez et al. (2019) found a strong association of expressive language and early numeracy skills at the beginning of preschool. Similarly, two more recent studies observed that language skills predict 3- to 5-year-old children's early numeracy skills (i.e., numerical relational and counting skills) when controlling for age, gender, family SES (Bleses et al., 2023; Hornburg et al., 2024). In Finland, preschools have emphasized the learning of language skills and early numeracy skills have been thought to be learned as part of daily activities in preschools, not as deliberately taught skills.

Considering the robust evidence of the association between SES and early numeracy as well as the importance of language skills for early numeracy, it is surprising that only few studies have investigated language skills as a mediator of the association between SES and early numeracy. Such an investigation would provide valuable information to understand the use and outcome-level factors interplay in early numeracy learning as the multilevel supply-use model suggests that learning environment factors are directly related with individual-level preconditions for learning (Brühwiler & Blatchford, 2011). Slusser et al. (2018) showed that language skills (general vocabulary and number word knowledge) fully mediated the relationship between parental educational level and early numeracy in a sample of U.S. 4-year-olds. It remains to be seen whether this can be replicated in other samples.

Related to mathematics learning, **gender** differences have been of interest for a long time and are still relevant as there is a constant shortage of female professionals in the field of STEM (science, technology, engineering, and mathematics; Cheryan et al., 2025). The evidence related to gender differences in early numeracy has been mixed (Kersey et al., 2019). On the one hand, recent studies in Danish 3- to 5-year-olds investigating numerical relational and counting skills as a composite (Bleses et al., 2023), Belgian 4- to 5-year-old (Bakker et al., 2018) and U.S. 3- to 6-year-old preschoolers investigating different numerical relational (e.g., set comparison), counting (e.g., one-to-one correspondence), and arithmetic skills (e.g., addition; Hornburg et al., 2018) suggests that there are no gender differences in early numeracy. On the other hand, some studies have found that Danish girls outperform boys in a composite numerical relational and counting skills measure at aged 3 to 6 years (Sjoe et al., 2019) as do Finnish girls aged 4 to 7 years (Aunio, Hautamäki, et al., 2006) in a composite early numeracy scale, including numerical relational and counting skills. On the contrary, Jordan et al. (2006) found boys in the United States outperformed girls (Mean age 5.8 years) on an early numeracy composite, including numerical relational, counting, and arithmetic skills. Similarly, French boys aged 4 to 6 years outperformed girls in numerical relational and counting skills tasks (Thomas et al., 2023). Due to these discrepancies in previous research, we tested the possible gender effects as in preschoolers' early numeracy.

Present study

Although considerable advances have been made in the study of early numeracy in recent years, there are still several open questions concerning 3- to 4-year-olds. A first question relates to the availability of valid and reliable methods to assess early numeracy skills in young children in non-English-speaking countries. Early numeracy assessment methods have been mainly developed and used in the U.S. context (Assel et al., 2020; Cheng et al., 2017; Clements et al., 2008; Dong et al., 2021; Floyd et al., 2006; Laracy et al., 2016; Lei et al., 2009; Methe et al., 2008; Norwalk et al., 2014; Polignano & Hojnoski, 2012; Purpura & Lonigan, 2015; Purpura et al., 2011; VanDerheyden et al., 2004, 2006). Though some of these measures (e.g., TEMA-3; TEAM) may have been adopted to other contexts (e.g., France, Thomas et al., 2023; Denmark; Sjoe et al., 2019), shortages still exist in investigating the validity and reliability of early numeracy measures, especially for 3- to 4-year-olds. In Finland, the Early Numeracy Test (ENT) originally published in Dutch (van de Rijt et al., 1999; Van Luit et al., 2006) has been standardized only with children age 4 years 6 months to 7 years 6 months. The ENT measures numerical relational skills such as comparison, classification, making correspondence, and seriation (Aunio, Hautamäki, et al., 2006). In addition, there are items measuring counting skills such as using number words, counting objects, enumeration, and application of numeracy in daily life situations (Aunio, Hautamäki, et al., 2006), which have been found to be also developing in 2- to 4-year-old children (Devlin et al., 2022b; Jordan et al., 2022; Salminen et al., 2021). Because, this ENT measure has not been previously validated for 3- to 4-year-olds, we aimed to first validate and adapt the measure. If it would be possible to use ENT with young children, it would provide a valuable method for research and educational practice to understand the development of early numeracy in very young children and potentially identify children at risk in their learning.

The second question was how the use and outcome-level factors of the multilevel supply-use model are associated with early numeracy skills. More specifically, we consider how individual-level pre-conditions of learning (i.e., language and gender) are associated with learning environmental factors (i.e., family SES and number of siblings), and how they affect the learning outcome (i.e. early numeracy) in young children. There were two research questions (RQs) in our study:

RQ1: What is the structural validity, internal consistency, and concurrent validity of the ENT in 3- and 4-year-old children?

Outhwaite and colleagues (2024) reported content validity, structural validity, internal consistency, reliability, and criterion validity as the most often reported types of psychometric evidence for measures of mathematics. The content validity of the ENT has been reported in previous studies and published test manuals (van de Rijt et al., 1999; Van Luit et al., 2006). We focused on empirical evidence for structural validity, internal consistency, and criterion validity (i.e., concurrent validity) for ENT in 3- and 4-year-old children. Based on previous studies with the ENT (Aunio et al., 2014; Aunio, Hautamäki, et al., 2006), we hypothesized that the ENT items would load on two separate factors: a numerical relational factor and a counting factor. We evaluated the internal consistency (reliability) of factors that were derived from the structural validity analysis. Concurrent validity was tested by investigating the association between an independent measure that also assesses number relations (i.e., the symbolic magnitude processing) (SYMP Test; Brankaer et al., 2017) and the ENT.

RQ2: How are 3- and 4-year-old children's family SES, number of siblings in the family, language skills, and gender associated with their learning of early numeracy?

Based on the literature (Anders et al., 2012; Bleses et al., 2023; Hornburg et al., 2024; Susperreguy et al., 2020), we expected to find positive relations between the early numeracy skills and parental educational level and parental income level. Siblings in the family have been reported to be a risk for early learning (Muñez et al., 2022), so we tested for possible effects of the number of siblings to children's

early numeracy performance. Next, we aimed to replicate the association between language and early numeracy skills (Bleses et al., 2023; Hornburg et al., 2024; Méndez et al., 2019; Peng et al., 2020) and examined whether language skills acted as a mediator of the association between family variables and early numeracy skills (Slusser et al., 2018). Finally, previous results concerning gender differences have been mixed, revealing no differences (e.g., Bakker et al., 2018) differences favoring girls (e.g., Sjoe et al., 2019) or boys (e.g., Thomas et al., 2023), for which reason we did not have a specific hypothesis for this issue.

Method

Participants

This study was part of the [name masked] Study. Participants were recruited from 16 preschools using Finnish as the language of education in the metropolitan area in October 2019. A research permit for the project was obtained from one large municipality in southern Finland, the preschools as well as from the ethical board of the university. The municipality suggested preschools from diverse demographic areas based on their own data for obtaining a heterogeneous sample. The participating children were then recruited from the preschools that permitted the research by sending the children's parents a permission form for each child involved in a 3- to 5-year-olds' playgroup. Invitation letters were delivered to the parents of children ($n = 632$) born in 2015 and 2016 in these preschools and a total of 319 children (146 boys, 173 girls) agreed to participate in this study. Each child whose parent gave informed consent was included in the study. The children were from 16 different preschools, representing diverse demographic areas. There were 146 3-year-olds (81 girls) and 173 4-year-olds (92 girls), mean age being 4 years 1 months ($SD = 0.57$ months, range from 2 years and 11 months to 5 years and 1 month).

Children came from families of which parental educational level (comprehensive school or none, upper secondary or vocational school, bachelor's degree, graduate degree) was quite similar compared to the municipalities' average according to the National Statistics (2021). However, parents with higher education degrees were slightly overrepresented in our sample. Family income level (less than 19,999 e/year; 20000–39,999 e/y; 40000–59,999 e/y; 60000–79,999 e/y.; more than 80,000 e/y) represented well the municipalities' average, according to the National Statistics (2021). The number of children in the family in our data varied between 1 and 5, with a mean of 2.04. This is slightly higher than the national mean for children in the family, which is 1.84 (National Statistics, 2021).

Measures

Early Numeracy Test

The Early Numeracy Test (ENT; Aunio et al., 2006; Van Luit et al., 2006) taps into eight aspects of numerical knowledge: comparison, classification, one-to-one correspondence, seriation, the use of number words, structured counting, resultative counting, and general understanding of numbers (see Appendix for item examples). Along with the total score, two subscales could be used as more specific measures of early numeracy: numerical relational tasks (items 1–20), which measure the understanding of basic logical principles underlying children's conception of quantities and relations, and counting tasks (items 21–40), which require skills to recite the number sequence and count entities (Aunio & Niemivirta, 2010). The items included in ENT may be considered appropriate for 3-year-old children, as similar tasks (e.g., counting blocks or dots, verbal counting, comparing a set of dots) have been shown to work with this age group in previous studies (e.g., Hornburg et al., 2018; Litkowski et al., 2020a). Previous studies in Finland have suggested a two-factor structure (numerical relational and counting skills) for the ENT (Aunio & Niemivirta, 2010), and a similar factor structure has also been found in children in mainland China, Hong Kong, Singapore, England, and Iran (Aunio et al., 2004; Aunio, Niemivirta et al., 2006;

Aunio et al., 2008, 2014). The ENT was administered individually and took about 30 minutes to complete. No baseline or stopping rule was applied in the administration. The items were scored by giving one point for a correct answer and zero for an incorrect answer with the maximum of 40 (e.g., van de Rijdt et al., 1999). The children were not given feedback as to whether their responses were correct or incorrect. The test situation was not timed. The ENT has been translated and validated to be used in Finland (Aunio et al., 2006) and has been widely used in Finnish preschools. The ENT is used in other European countries, such as in Italy (González et al., 2017) and Romania (David et al., 2015).

Adapted Symbolic Magnitude Processing

SYmbolic Magnitude Processing (SYMP) test taps into children's symbolic understanding and understanding of numerical relations (Brankaer et al., 2018). The SYMP test demands very little language processing; hence, it is well suited for our need for concurrent validity evidence. The original SYMP Test consists of three parts. In parts 1 and 2, children have to cross out the larger number of two presented one-digit (= one-digit test) and two-digit (= two-digit test) items, respectively, within the time limit. Part 3 consists of a motor speed test in which children have to cross out the black shape of two presented shapes (one black, one white) and serves as a control for children's (motor) processing speed. These three parts consist of 60 items each that are organized in four columns and one point was given for each correct answer. The SYMP test was originally designed for use with primary school children. In this study, we used it for the first time with younger children, with three relevant adaptations.

First, in the original SYMP test, there was one subtest with digits between 1 and 9 and a two-digit subtest with digits ranging from 11 to 99. In our study, children only completed the one-digit test. Second, in the original SYMP test, the children were asked to cross out the larger of the two digits. In our study, the experimenter crossed out the number that was pointed to by the child. Third, in the original SYMP test, children were given 30 seconds to solve as many items as possible. In our study, the children were instructed as follows: "Show me which of the numbers is larger, and I will mark it. You can go ahead once you have shown the answer. Do it as fast as you can but show the correct answer. I will tell you when the time is up." RAs did not read the number aloud for children. In our study, children were given a maximum of 3 minutes to complete the test. A composite score of all 60 items in the one-digit test was used in the analyses. For the current sample, the adapted SYMP one-digit test presented good internal consistency of $\alpha = .824$.

Family variables

Family variables were obtained by a parents' questionnaire. In line with current ethical suggestions, the parents are referred to with numbers (Parent 1 and Parent 2). The parents filled in information concerning age and gender of the child participating in the study, in addition to family socioeconomic information (education and income level), and the number of children in the family (one, two, three, four + more children). For the analysis, we calculated the mean parental education using information from both parents.

Language skills

Children's language skills were measured using receptive and expressive language items from standardized neurological measurement called LENE (i.e., Leikki-ikäisen neurologinen arvio; Preschool-aged children's neurological evaluation; Valtonen et al., 2007). Items measuring expressive and receptive language skills varied for different age groups. The 3-year-olds' test included 12 items that assessed their understanding of given instructions, ability to name parts of the human face and body, understanding of the difference between large and small, seriating of colors, and receptive vocabulary (Valtonen & Mustonen, 2007). The 4-year-olds' test included 18 items assessing understanding of instructions, answering questions, naming of

colors, and understanding of receptive vocabulary (Valtonen & Mustonen, 2007). For the current sample, good internal consistency was presented by the 3-year-olds' expressive and receptive language items $\alpha = .824$, as well as the 4-year-olds' expressive and receptive language items, $\alpha = .812$.

Procedure

The city granted permission for the study; children's participation was voluntary, and parental consent was required. The University's ethics committee approved the study protocol. Measurements were conducted between November 2019 and December 2020. Research assistants (RAs) were recruited to work on the project for 3 years; they were all at least master-level students in education or sport sciences. The RAs' test training consisted of different steps: (1) RAs studied all of the test manuals individually; (2) RAs practiced doing the testing, with other RAs pretending to be a child; (3) they followed in preschools when the other RAs did the testing; and (4) the RAs did the testing with guidance of a more experienced tester and then alone with a child. The measures were administered in a quiet location in the children's own preschool during regular preschool hours. Teachers in the preschool gave time slots for researchers; hence, the time table was tailored to fit the program of the preschool average activities. The order of measures was random and three measures were collected (i.e., ENT, adapted SYMP, and language). All assessments were conducted individually in a separate room in children's own preschools during regular preschool hours. The assessments were divided into three separate sessions, one for each measure (i.e., expressive and receptive language, adapted SYMP, ENT) as the participants in our study were so young. Each assessment session lasted a maximum of 30 minutes. The COVID pandemic interrupted the data collection in March 2020 for 6 months. We were able to continue to collect data with limited access to two preschools from August onward. We tested the children who were present on the measurement days in the preschools and with the test they had not conducted yet. Data collection was finished by the end of 2020.

Data analysis

The SPSS statistical software was used in the preliminary analyses, while Mplus (Muthen & Muthen, 1998–2017) was used in the main analyses. To answer RQ1, confirmatory factor analyses (CFA) were used to investigate the structural validity of the ENT. The internal consistency using Cronbach alpha was calculated for the early numeracy factors as part of this main analysis. Structural equation modeling (SEM) was used to test concurrent validity and the relations between early numeracy skills and family background variables separately for both age groups. To answer RQ2, a SEM mediation model with language skills as a mediator between family variables and early numeracy latent factors was fitted to the data separately for both age groups. Due to categorical items, the WSLMV estimator was used in all analyses. Model fit was assessed with the χ^2 ($p > .05$), Comparative Fit Index (CFI; acceptable fit $> .90$), Tucker-Lewis Index (TLI; acceptable fit $> .90$), and Root Mean Square Error of Approximation (RMSEA; acceptable fit $< .08$) fit indices following general guidelines (e.g., Marsh et al., 2004). To compare competing models (i.e., one-factor versus two-factor), we used the recommendations of Chen (2007), where an increase in CFI $> .01$ and a decrease in RMSEA $> .015$ give support for the more complex model. To obtain unbiased parameter estimates for the indirect effects in the mediation model, bootstrapping with 5000 draws were performed to obtain 95% confidence intervals for the indirect effect (Shrout & Bolger, 2002).

Results

We started the analysis by examining item difficulties in the ENT separately for 3-year-olds and 4-year-olds. For 3-year-olds, 12 items out of 20 items in the counting skills scale were too difficult (above 95% incorrect) while none of the numerical relational skills items were too difficult. Too-

Table 1. Descriptive statistics and correlations for study variables by cohort.

Variable	1	2	3	4	5	6	7	<i>M(SD)</i> Total	<i>M(SD)</i> Girl/Boy
1. Numerical relational skills	—	.64***	.38***	.39***	.36***	-.24**	.54***	10.6 (4.3)	11.2(4.4)/9.9 (4.1)
2. Counting skills	.39***	—	.38***	.20*	.17*	-.11	.41***	4.2 (3.7)	4.6(3.9)/4.0 (3.8)
3. Symbolic magnitude comparison	.21*	.23*	—	.28***	.18*	-.06	.25**	35.3 (11.7)	36.6(12.4)/ 34.0(10.4)
4. Parental educational level	.07	-.01	.11	—	.50***	-.09	.39***	3.0 (0.8)	2.9(0.9)/3.0 (0.8)
5. Family income	.19	.06	-.01	.54**	—	-.03	.38***	3.3 (1.2)	3.1(1.2)/3.5 (1.2)
6. Number of siblings	-.20*	-.14	-.19	-.05	.02	—	-.10	2.0 (.81)	1.9(0.9)/2.0 (0.7)
7. Receptive and expressive language	.20*	.08	-.03	.09	.16	-.06	—	19.8 (3.7)	20.2(3.0)/ 19.3(4.3)
<i>M(SD)</i> Total	6.4(3.4)	1.3(1.5)	27.9(9.2)	3.1(0.9)	3.4(1.3)	2.1(0.9)	12.4(2.5)		
<i>M(SD)</i> Girl/Boy	6.8(3.6)/ 6.0(3.1)	1.6(1.9)/ 1.6(2.0)	27.7(8.5)/ 28.2(10.1)	3.2(0.9)/ 3.1(0.9)	3.3(1.3)/ 3.5(.14)	2.1(0.8)/ 2.1(0.9)	12.1(2.9)/ 12.7(1.9)		

Note. Correlations and means for 3-year-old children are presented on the left side of the diagonal and for 4-year-old children to the right. All correlations are Spearman’s rank-order coefficients due to slightly non-normal data. * $p < .05$. ** $p < .01$. *** $p < .001$.

difficult items were measuring counting skills using numbers larger than 10 in reciting number word sequence, enumerating and solving tasks with cardinality and ordinality contexts. Consequently, we decided to do subsequent analyses for the 3-year-olds with all (20 items) the numerical relational skills items and eight counting skills items (items 21, 22, 26, 27, 36, 37, 38, 39). For the 4-year-olds, only two items in the counting skills scale were too difficult (above 95% incorrect) and none of the numerical relational skills items. Therefore, we proceeded with the whole numerical relational skills scale in the subsequent analyses for the 4-year-olds but excluded the two items (34 & 35) that were too difficult from the counting skills items. In item 34, children were asked to count how many blocks (correct answer = 19 blocks) there were on the table without pointing to them. In item 35, the administrator hid five blocks under a piece of paper. The administrator then added seven more blocks under the same paper. After that, the administrator asked the child how many blocks there were altogether under the paper. All analyses are reported separately for the two age groups. Descriptive statistics and correlations for both age groups with items included in the further analysis are presented in Table 1.

Structural validity, internal consistency, and concurrent validity (RQ1)

To examine structural validity, we tested two competing models: a one-factor CFA model with an overall early numeracy factor, and a two-factor CFA model with a numerical relational skills factor and a counting skills factor. For 3-year-olds, both the one-factor CFA model [$\chi^2(350) = 391.467, p = .063, CFI = .927, TLI = .921, RMSEA = .028$] and the two-factor CFA model [$\chi^2(349) = 382.964, p = .102, CFI = .940, TLI = .935, RMSEA = .026$] fitted the data well. As the two-factor model displayed a better fit compared to the one-factor model ($\Delta CFI > .01, \Delta RMSEA = .002$) and the correlation between the numerical relational skills factor and the counting skills factor was not too high ($r = .80, p < .001$), we concluded that the two-factor model found in older children holds for 3-year-olds. For 4-year-olds, both the one-factor CFA model [$\chi^2(665) = 779.653, p < .001, CFI = .945, TLI = .942, RMSEA = .031$] and the two-factor CFA model [$\chi^2(664) = 739.548, p < .05, CFI = .964, TLI = .962, RMSEA = .026$] fitted the data well. As the two-factor model displayed a better fit compared to the one-factor model ($\Delta CFI > .01, \Delta RMSEA = .005$) and the correlation between the numerical relational skills factor and the counting skills factor was not too high ($r = .80, p < .001$), we concluded that the two-factor model found in older children holds for 4-year-olds.

The internal consistency for the numerical relational skills scale (20 items, $\alpha = .75$), counting skills scale (8 items, $\alpha = .73$), and the total score (28 items, $\alpha = .88$) in 3-year-olds were good. In 4-year-olds,

the internal consistency (RQ2) for the numerical relational skills scale (20 items, $\alpha = .83$), the counting skills scale (18 items, $\alpha = .83$), and the total score (38 items, $\alpha = .89$) were also good.

To examine concurrent validity for 3-year-olds, we correlated the latent early numeracy factors with symbolic magnitude processing (adapted SYMP Test) in the two-factor SEM model, $\chi^2(375) = 409.509$, $p = .106$, CFI = .941, TLI = .936, RMSEA = .025. The correlation between the numerical relational skills factor and adapted SYMP test was $r = .39$, $p < .001$. The correlation between the counting skills factor and adapted SYMP test was $r = .40$, $p < .001$. To examine the concurrent validity for 4-year-olds, we correlated the latent early numeracy factors with symbolic magnitude processing (adapted SYMP test) in the two-factor SEM model, $\chi^2(700) = 777.944$, $p < .05$, CFI = .964, TLI = .962, RMSEA = .025. The correlation between the numerical relational skills factor and adapted SYMP test was $r = .44$, $p < .001$. The correlation between the counting skills factor and adapted SYMP test was $r = .45$, $p < .001$. To conclude, in both age groups the numerical relational skills and counting skills factors were significantly related to adapted SYMP test, thus supporting concurrent validity.

Children's family SES, number of siblings, language skills, gender, and early numeracy (RQ2)

To examine the relations between early numeracy and family variables for 3-year-olds, we correlated the latent early numeracy factors with mean educational level, income level, and number of children in the two-factor SEM model, $\chi^2(430) = 470.067$, $p = .09$, CFI = .931, TLI = .925, RMSEA = .025. All family variables had significant correlations with the numerical relational skills factor. Higher numerical relational skills were related to higher parental educational level ($r = .21$, $p < .05$), higher family income ($r = .29$, $p < .01$), and fewer number of children in the family ($r = -.27$, $p < .01$). None of the family variables were significantly related to counting skills ($ps > .41$).

To examine the relations between early numeracy and family variables for 4-year-olds, we correlated the latent early numeracy factors with mean educational level, income level, and number of children in the two-factor SEM model, $\chi^2(775) = 869.509$, $p < .001$, CFI = .955, TLI = .952, RMSEA = .027. Parental educational level was related to higher numerical relational skills ($r = .49$, $p < .001$) and counting skills ($r = .29$, $p < .01$). Higher family income was related to higher numerical relational skills ($r = .42$, $p < .001$) but not to counting skills ($r = .18$, $p = .07$). A smaller number of children in the family was related to higher numerical relational skills ($r = -.27$, $p < .001$) but not to counting skills ($r = -.18$, $p = .07$).

In the last step of the analyses, we predicted early numeracy with family variables, child's gender, and language skills. We fitted a SEM mediation model that included language skills, gender, and the significant family variables from the previous step. Furthermore, we did not include counting skills as an outcome for 3-years-olds, as none of the family variables were related to counting skills in the previous step.

For the 3-year-olds, language skills were specified as a mediator between gender, family variables, and numerical relational skills, $\chi^2(265) = 309.600$, $p < .05$, CFI = .888, TLI = .876, RMSEA = .040 (Figure 1). Of the family variables, only family income predicted language skills. No significant indirect effects from family variables to numerical relational skills were found. Gender was related to neither numerical relational skills (beta = .11, $p = .29$) nor language skills (beta = .05, $p = .65$). Language skills strongly predicted numerical relational skills, while none of the family variables had a significant direct effect. This model explained 20% of the variance in numerical relational skills.

For the 4-years-olds, we fitted a SEM mediation model that included the significant family variables from the previous step, child's gender, and language skills. Language skills were specified as a mediator between family variables, gender, and the early numeracy latent factors, $\chi^2(844) = 969.759$, $p < .001$, CFI = .915, TLI = .910, RMSEA = .033 (Figure 2). The only significant direct effect from family variables to early numeracy was from parental educational level to numerical relational skills. Only one indirect effect from family variables to early numeracy factors was found. There was a significant

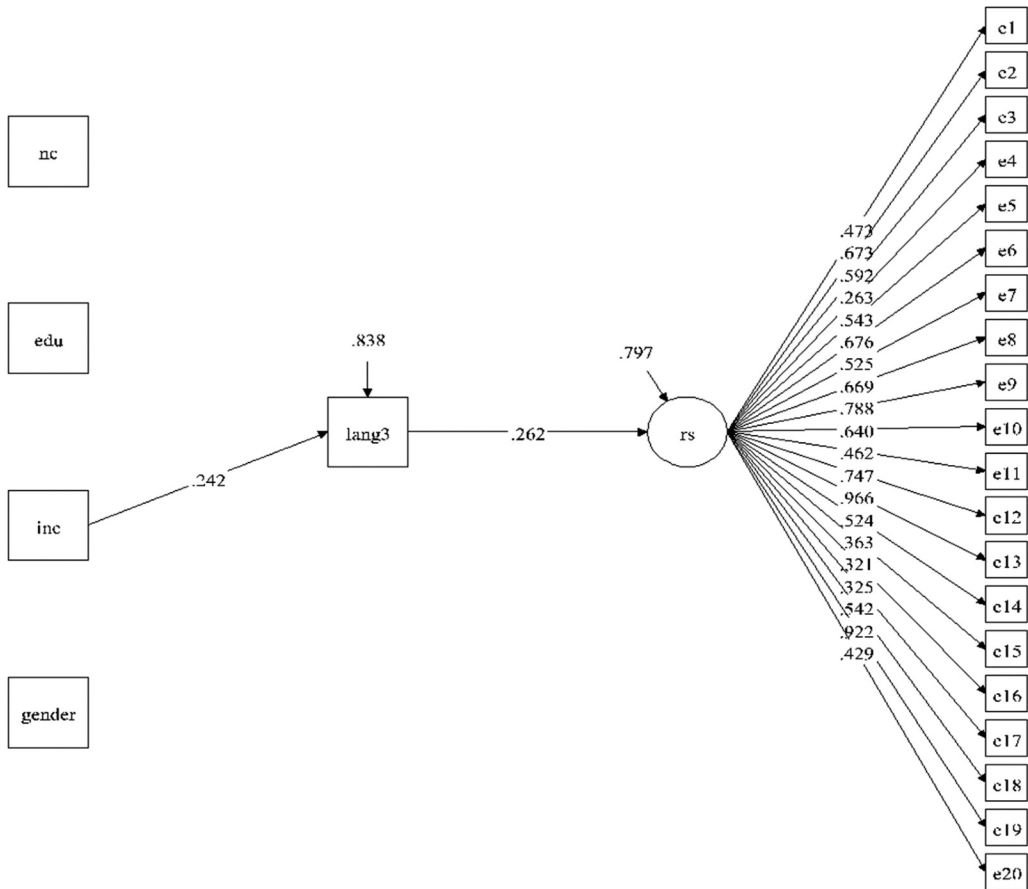


Figure 1. Individual differences in 3-year-old children. *Note.* Only significant paths are depicted ($p < .05$). inc = family income; nc = number of children; edu = parental educational level; lang3 = language skills; rs = numerical relational skills.

indirect effect from parental educational level to numerical relational skills ($\beta = 0.12$, 95% CI [0.03, 0.21]) but not counting skills. There were no direct or indirect effects of gender to language ($\beta = .13$, $p = .17$) and early numeracy (numerical relational skills: $\beta = .15$, $p = .05$; counting skills: $\beta = .04$, $p = .70$). Language skills strongly predicted both numerical relational and counting skills. Language skills were in turn predicted by family income and parental educational level.

Discussion

Although early numeracy has attracted a lot of research attention in the last 15 years (Clements & Sarama, 2021; Liu et al., 2025), the existing body of empirical studies in preschool has typically collapsed children in the age ranges between 3 and 4 years. As a result, we do not know how different types of numerical skills evolve in this quite “critical” two-year period (Purpura & Lonigan, 2015). In our study, we investigated young children’s early numeracy learning in a non-English-speaking country. First, we aimed to ensure the validity and reliability of a Finnish ENT in 3-year-olds and 4-year-olds, as this measure has previously been validated among older children. Second, we investigated the effect of family variables and gender on early numeracy skills, and we examined if language skills mediated this relationship. Our results show that it is possible to reliably measure the numerical relational and counting skills of 3- and 4-year-olds with the adapted ENT. Internal consistency proved to be good in all scales in both age groups. Both numerical relational and counting skills were clearly

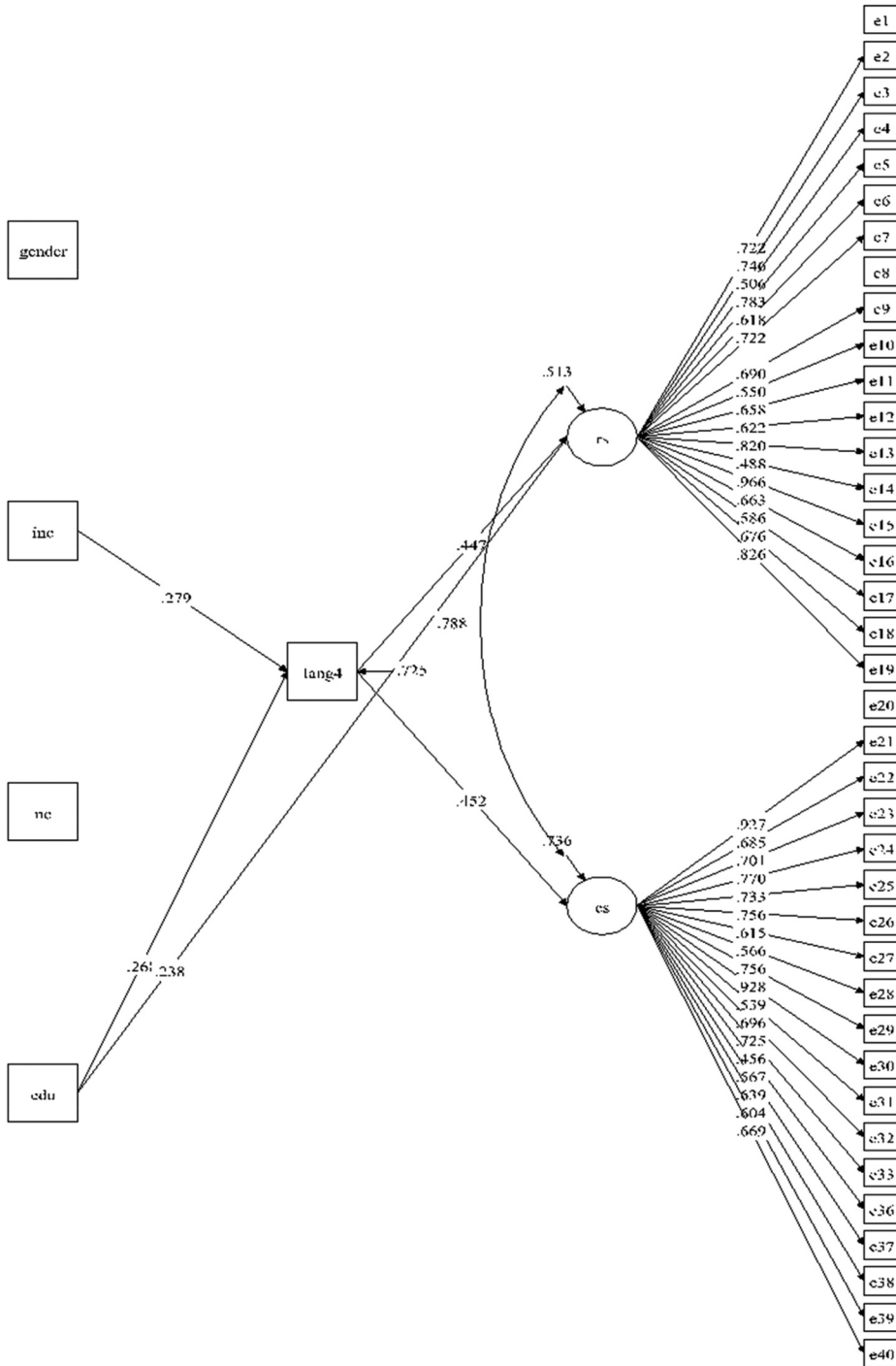


Figure 2. Individual differences in 4-year-old children. *Note.* Only significant paths are depicted ($p < .05$). *inc* = family income; *nc* = number of children; *edu* = parental educational level; *lang4* = language skills; *rs* = numerical relational skills; *cs* = counting skills.

related to another early numeracy measure, adapted SYMP test measuring similar skills. Turning to the family variables, we found that both 3- and 4-year-old children's higher numerical relational skills were related to higher parental educational level, higher family income, and to fewer number of children in the family. In the 4-year-olds group, higher counting skills were related to higher parental educational level, but family income and the number of children in the family were not related to counting skills. We also investigated how language skills mediated the relationship between family variables, gender, and early numeracy skills. Family variables were no longer significantly related to early numeracy skills when language skills were included in the model, with the exception of parental educational level that predicted numerical relational skills both directly and indirectly in 4-year-olds. Language skills were the strongest predictor of early numeracy skills in both age groups. We found no significant gender differences with 3-year-olds' and 4-year-olds' early numeracy.

The evidence of structural validity, reliability, and concurrent validity of ENT

The previous body of evidence has left it unclear as to whether early numeracy skills can be reliably measured in 3-year-old children, because most studies have investigated preschool children without dividing them into age groups (Clements et al., 2008; Norwalk et al., 2014; Polignano & Hojnoski, 2012; Purpura et al., 2011). In our study, we could reliably measure numerical relational and counting skills in **3-year-olds**. However, it was only possible to use a selective set of counting tasks (8 items), namely those that measured counting skills with numbers smaller than 10. This result is partly in line with Sjoe et al. (2019) who reported that their brief Danish version of TEAM was not suitable to measure 3-year-old children's early numeracy skills. TEAM is a comprehensive battery of skills that includes numerical relational, counting, and arithmetic skills. It seems plausible to conclude that not all of these skills can be reliably assessed at the age of 3, but some, such as number sequence skills forward and backward and enumeration with small numbers, can be measured. Also Ryoo et al. (2015) showed something similar with Test of Early Mathematics Ability 3 (TEMA-3) longitudinal data (children were 4 years 7 months old when they started). It seems plausible to conclude that we can reliably and validly measure 3-year-olds' numerical relational skills and some counting skills, such as number sequence skills forward and backward and enumeration with small numbers. This suggests that when we measure early numeracy in young preschool children, it is imperative to break early numeracy into different components rather than a comprehensive battery with a total score, as was done in Sjoe et al. (2019) study. Our results are also in line with Litkowski et al. (2020a) study in which they measured the one-to-one correspondence "point and count," cardinality (how many), cardinality (give n), recite number word sequence, number identification, and story problems (addition and subtraction) with mainly number range 0–20 and reported that 3-year-olds have challenges in all tasks if the numbers range was larger than 10. Our results indicate that numerical relational skills, such as comparison and one-to-one correspondence, should be the focus when measuring early numeracy skills in 3-year-olds. It is important to highlight that our relational tasks did not require the use of number word sequence as we asked questions such as *Here you see buildings. Point out the lowest building.* to measure comparison and [e.g., gives the child a work paper and a pencil.] *Here you see three pictures of chickens and eggs. Can you find the picture where each chicken has laid one egg? You may draw lines,* to measure one-to-one correspondence.

With **4-year-olds**, we distinguished the two hypothesized factors: numerical relational and counting skills. We also provided reliability and validity evidence for both factors. Our study showed that previously obtained data in older preschool children can be applied to younger ones (i.e., children as young as 4 years old) (Aunio et al., 2019; Hellstrand et al., 2020; Lopez-Pedersen et al., 2021). Our study is in line with previous studies (Assel et al., 2020; Floyd et al., 2006; Thomas et al., 2023) with 4-year-old children reporting multi-factorial structure of early numeracy.

In line with our expectations, we found that early numeracy skills were positively related to symbolic magnitude comparison in both age groups, thus supporting concurrent validity of our measure. To be able to perform well in symbolic number processing tasks, children need to understand

the cardinality meaning of number symbols and make a statement about which one is larger, hence demonstrating understanding about the relation between two numbers. These results corroborate previous findings with older students concerning the relations between early numeracy skills and symbolic magnitude comparison (Schneider et al., 2017).

Our study emphasizes the need to critically evaluate reliability and validity evidence when implementing already-established scales to new age groups in future studies. This is because significant adaptations might be needed. For example, with 3-year-olds, the number range should be 0–10. Our results contribute to the existing evidence of developing educational measurements on early numeracy outside English-speaking countries, which has been scarce so far (Outhwaite et al., 2024)

Individual differences in early numeracy in 3-year-olds and 4-year-olds

Our study contributes to the multilevel supply-use model, as we aimed to describe the conditions of children's early numeracy learning (Brühwiler & Blatchford, 2011). We focused on parental education, parental income level, and number of children in the family as learning environment factors, language skills (use level) as individual-level preconditions for learning, and early numeracy (outcome levels) in the Finnish context. Previous studies have reported that low SES of the family has a negative effect on young children's numeracy learning (Bleses et al., 2023; DeFlorio & Beliakoff, 2015; Hornburg et al., 2018, 2024; Thomas et al., 2023). There is variability in how SES has been operationalized in studies of early numeracy. For instance, Anders et al. (2012) measured family SES (income, education level, occupation) and found it to predict early numeracy (i.e., total score) at age of 3 years. We operationalized family SES by asking the parents to report their educational level and family income level. In 3- and 4-year-old children, both higher parental educational and family income level were related to higher numerical relational skills. This is in line with previous research, as for instance Susperreguy et al. (2020) showed that parental education predicted early numeracy (i.e., total score) at age 4. In our current study, we distinguished parental education and family income level. While both were related to numerical relational skills, only parental education level was related to counting skills. To understand why and how SES and early numeracy are related, we need more data – for instance, data related to numerical activities at home (Daucourt et al., 2021) – as the effect of SES on early numeracy is most likely included in complex reciprocal developmental relationship with other factors such as child's general cognitive ability level or parental math activities at home (DeFlorio & Beliakoff, 2015; Elliott et al., 2024; Elliott et al., 2021; Lugo-Gil & Tamis LeMonda, 2008; Muñoz et al., 2021; Salminen et al., 2021). We also had an additional family factor, number of children in the family, as we wanted to understand if the presence of siblings has an effect on early numeracy in young children. We found that in 3- and 4-year-old children, higher numerical relational skills were related to a fewer number of children in the family. This is in line with Muñoz et al. (2022), investigating a similar issue in Singaporean children age 4.5 years. These results are following the resource-dilution model (Blake, 1981), which indicates the possibility that with only few children in the family parents have more time to socially interact with their children and have more resources to support children's development.

Our results showing that 3-year-olds' counting skills not being related to family variables in Finland was in line with previous results by Salminen et al. (2021), as their results showed that mothers' and fathers' educational level were not significantly associated with children's skills in counting object, number production, number sequence, number identification, and number naming tasks in children age 2–3 years and 5–6 years. We found no gender differences in early numeracy performance in both of our age groups, which is in line with some previous studies (Bakker et al., 2018; Bleses et al., 2023; Hornburg et al., 2024; Hornburg et al., 2018). It is plausible that gender differences only emerge at older ages (e.g., Aunio et al., 2006; Stoet & Geary, 2018). These gender differences might be explained by environmental factors, such as gender stereotypes, rather than gender differences in cognitive skills.

In our current study, we found that language skills were important predictors for early numeracy in general. Our findings are similar to studies reporting association between early numeracy and language (Bakker et al., 2023; Bleses et al., 2023; Hornburg et al., 2024; Méndez et al., 2019; Peng

et al., 2020; Purpura et al., 2017, 2019). Our study is one of the first to investigate how language skills mediate the effect of family variables on early numeracy. Language skills partly mediated the effect of parental educational level on numerical relational skills in 4-year-olds, while all other family variables failed to contribute when language skills were added to the model. In previous studies, parental educational level has been found to have an impact on both language (Hoff, 2003), numeracy skills (DeFlorio & Beliakoff, 2015; Hornburg et al., 2018; Thomas et al., 2023), and cognitive development in general (Rindermann & Baumeister, 2015). Our results were supported by Slusser et al. (2018), who found that general vocabulary and number word knowledge mediated the effect of parental educational level on early numeracy in a sample of U.S. 4-year-olds. Based on our results, it is likely that parents with a higher education-level use and support language skills more than parents with lower educational level and that this is especially affecting numerical relational skills.

The multilevel supply-use model (Brühwiler & Blatchford, 2011) helps to understand how the use of learning opportunities (e.g., parental education) affects children's learning, by highlighting the relevance of learning context and complex relations between the factors. In Finland, children are mostly taken care of at home until they are 2 years old; after that, the attendance to early childhood education increases (National Statistics, 2023). This makes it relevant to take the family variables into account when investigating the individual differences in learning outcomes, especially in young age groups. Although Finnish early education has some unique characteristics (e.g., non-academic core curriculum, ECE provided by the municipalities), our study demonstrated that early numeracy learning is related to similar learning environmental factors in other countries (Bleses et al., 2023; Hornburg et al., 2024; Jordan et al., 2006; Muñoz et al., 2021, 2022; Thomas et al., 2023): higher parental educational level, higher family income, and fewer numbers of children in the family were related to children's higher numerical relational skills. Interestingly, we found that in the 4-year-olds group, higher parental educational level was related to higher counting skills, but family income and the number of children in the family were not. The effects of characteristics of the learning environment is, at least in the Finnish context, dependent on children's age and mathematical skills (outcome) measured. This should be acknowledged in future studies, for instance, when selecting outcome measures. Another important finding, related both to learning environment and outcomes level in the multilevel supply-use model, was the relevance of language skills to early numeracy, also found in other studies (Bakker et al., 2023; Bleses et al., 2023; Hornburg et al., 2024, 2018; Purpura & Reid, 2016; Thomas et al., 2023; Salminen et al., 2021; Peng et al., 2020, for a meta-analysis). In our study, language skills also had an important mediating role between learning environmental factors and early numeracy in both age groups. This suggests that we might compensate for the effects of low parental education and income with educational support for language and early numeracy development in early childhood education.

Limitations and future research

Our study had some weaknesses, which should be addressed in future studies. Due to the COVID-19 pandemic, we were only able to collect a smaller set of data than we planned. It also took longer time to collect data due to preschools forbidding the visitors. Because our study had to adhere to specific rules imposed by our ethics committee, the parents are referred to with numbers (Parent 1 and Parent 2), for which reason it was not possible to distinguish mother's and father's educational background or income level.

Our work has similar strengths and shortcomings as other studies reporting the validity and reliability evidence of early numeracy measurements for preschoolers (Outhwaite et al., 2024). Some structural validity, internal consistency, and concurrent validity evidence has been often (Assel et al., 2020; Cheng et al., 2017; Clements et al., 2008; Dong et al., 2021; VanDerheyden et al., 2006), but not always, reported in studies focusing on preschool measures. We reported all three of them. In future studies, it would be important to study longitudinally how early numeracy skills at ages 3 and 4 predict later performance and learning difficulties. Such data would produce predictive validity evidence,

which has also been seldom acquired so far, luckily with some exceptions (Laracy et al., 2016; Methé et al., 2008; VanDerheyden et al., 2006).

In future studies, it would also be important to study how domain-general cognitive variables (e.g., executive functioning, spatial skills) can explain individual differences in early numeracy in young children, as has been found mainly with older children (Atit et al., 2022; De Smedt, 2022; Spiegel et al., 2021). It would be essential to collect longitudinal evidence about how various factors of early numeracy are differentially related to intercept (level) and slope (development) in mathematics skills in primary education. Cross-cultural studies would further enable us to compare the early development in other European, Asian, and African countries. The outcome of this work would contribute significant ways to the multilevel supply-use model (Brühwiler & Blatchford, 2011) of early numeracy learning.

Conclusions

Our results showed that it is possible to use the adapted Early Numeracy Test (ENT) to measure 3- to 4-year-old children's early numeracy skills, which is valuable as it is one of the few measures used outside English-speaking countries (see also Bleses et al., 2023; Sjoë et al., 2019; ten Braak & Störksen, 2021; Thomas et al., 2023). Early numeracy is related already at this age to family characteristics, especially higher parental educational level and higher family income; fewer numbers of children in the family were related to children's higher numerical relational skills. Early numeracy is consistently related to early language skills. Our results showed that language skills partly mediated the effect of parental education to early numeracy in 4-year-old children. Our results increase the existing knowledge about the contribution of language and family background to early numeracy skills in preschoolers (LeFevre et al., 2010; Purpura et al., 2011; Sowinski et al., 2015).

Acknowledgments

The authors thank all the families, children, and preschools in the city of Helsinki for participating in the study. We also want to thank everyone who participated in collecting the data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Opetus- ja Kulttuuriministeriö [OKM/42/626/2019]; Suomen Kulttuurirahasto [Huhtamäen rahasto, 2019].

ORCID

Pirjo Aunio  <http://orcid.org/0000-0002-0901-3874>

Bert De Smedt  <http://orcid.org/0000-0002-3313-3278>

Terhi Vessonen  <http://orcid.org/0000-0001-8810-4389>

Johan Korhonen  <http://orcid.org/0000-0001-9666-9400>

References

Anders, Y., Rossbach, H., Weinert, S., Ebert, S., Kuger, S., Lehl, S., & von Maurice, J. (2012). Home and preschool learning environments and their relations to the development of early numeracy skills. *Early Childhood Research Quarterly*, 27(2), 231–244. <https://doi.org/10.1016/j.ecresq.2011.08.003>

- Assel, M., Montroy, J., Williams, J., Foster, M., Landry, S., Zucker, T., Crawford, A., Hyatt, H., & Bhavsar, V. (2020). Initial validation of a math progress monitoring measure for prekindergarten students. *Journal of Psychoeducational Assessment*, 38(8), 1014–1032. <https://doi.org/10.1177/0734282920922078>
- Atit, K., Power, J. R., Pigott, T., Lee, J., Geer, E. A., Uttal, D. H., Ganley, C. M., & Sorby, S. A. (2022). Examining the relations between spatial skills and mathematical performance: A meta-analysis. *Psychonomic Bulletin & Review*, 29, 699–720. <https://doi.org/10.3758/s13423-021-02012-w>
- Aubrey, C., Godfrey, S., & Dahl, R. (2006). Early mathematics development and later achievement: Further evidence. *Mathematics Education Research Journal*, 18(1), 27–46. <https://doi.org/10.1007/BF03217428>
- Aunio, P., Aubrey, C., Godfrey, R., Yuejuan, P., & Liu, Y. (2008). Children's early numeracy in England, Finland and People's Republic of China. *International Journal of Early Years Education*, 16(3), 203–221. <https://doi.org/10.1080/09669760802343881>
- Aunio, P., Ee, J., Lim, A., Hautamäki, J., & Van Luit, J. E. H. (2004). Young children's number sense in Finland, Hong Kong and Singapore. *International Journal of Early Years Education*, 12(3), 195–216. <https://doi.org/10.1080/0966976042000268681>
- Aunio, P., Hautamäki, J., Heiskari, P., & Luit, J. E. H. V. (2006). The early numeracy test in Finnish: Children's norms. *Scandinavian Journal of Psychology*, 47(5), 369–378. <https://doi.org/10.1111/j.1467-9450.2006.00538.x>
- Aunio, P., Hautamäki, J., Heiskari, P., & Van Luit, J. E. (2006). The early numeracy test in Finnish: Children's norms. *Scandinavian Journal of Psychology*, 47(5), 369–378.
- Aunio, P., Korhonen, J., Bashash, L., & Khoshbakht, F. (2014). Children's early numeracy in Finland and Iran. *International Journal of Early Years Education*, 22(4), 423–440. <https://doi.org/10.1080/09669760.2014.988208>
- Aunio, P., Korhonen, J., Raggot, L., Törmänen, M., Mononen, R., & Henning, E. (2019). Multi-factorial approach to early numeracy—The effects of cognitive skills, language factors and kindergarten attendance on early numeracy performance of South African first graders. *International Journal of Educational Research*, 97, 65–76. <https://doi.org/10.1016/j.ijer.2019.06.011>
- Aunio, P., & Niemivirta, M. (2010). Predicting children's mathematical performance in grade one by early numeracy. *Learning and Individual Differences*, 20(5), 427–435. <https://doi.org/10.1016/j.lindif.2010.06.003>
- Aunio, P., Niemivirta, M., Hautamäki, J., Van Luit, J. E. H., Shi, J., & Zhang, M. (2006). Young children's number sense in China and Finland. *Scandinavian Journal of Educational Research*, 50(5), 483–502. <https://doi.org/10.1080/00313830600953576>
- Bakker, M., Torbeyns, J., Verschaffel, L., & De Smedt, B. (2023). Longitudinal pathways of numerical abilities in preschool: Cognitive and environmental correlates and relation to primary school mathematics achievement. *Developmental Psychology*, 59(3), 442–459. <https://doi.org/10.1037/dev0001491>
- Bakker, M., Torbeyns, J., Wijns, N., Verschaffel, L., & De Smedt, B. (2018). Gender equality in four- to five-year-old preschoolers' early numerical competencies. *Developmental Science*, 22(1), e12718. <https://doi.org/10.1111/desc.12718>
- Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, 81(6), 1641–1660. <https://doi.org/10.1111/j.1467-8624.2010.01499.x>
- Blake, J. (1981). Family size and the quality of children. *Demography*, 18(4), 421–442. <https://doi.org/10.2307/2060941>
- Bleses, D., Moos, M., Purpura, D. J., & Dale, P. S. (2023). General and math vocabulary contributions to early numeracy skills in a large population-representative sample. *Frontiers in Developmental Psychology*, 1, 1279691. <https://doi.org/10.3389/fdyps.2023.1279691>
- Brankaer, C., Ghesquière, P., & De Smedt, B. (2017). Symbolic magnitude processing in elementary school children: A group administered paper-and-pencil measure (SYMP test). *Behavior Research Methods*, 49(4), 1361–1373. <https://doi.org/10.3758/s13428-016-0792-3>
- Brühwiler, C., & Blatchford, P. (2011). Effects of class size and adaptive teaching competency on classroom processes and academic outcome. *Learning & Instruction*, 21(1), 95–108. <https://doi.org/10.1016/j.learninstruc.2009.11.004>
- Bugden, S., & Ansari, D. (2011). Individual differences in children's mathematical competence are related to the intentional but not automatic processing of Arabic numerals. *Cognition*, 118(1), 32–44. <https://doi.org/10.1016/j.cognition.2010.09.005>
- Chan, J. Y. C., Sera, M. D., & Mazzocco, M. M. (2022). Relational language influences young children's number relation skills. *Child Development*, 93(4), 956–972. <https://doi.org/10.1111/cdev.13737>
- Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Structural Equation Modeling*, 14(3), 464–504. <https://doi.org/10.1080/10705510701301834>
- Cheng, W., Lei, P., & DiPerna, J. (2017). An examination of construct validity for the EARLI numeracy skill measures. *The Journal of Experimental Education*, 85(1), 54–72. <https://doi.org/10.1080/00220973.2015.1101532>
- Cheryan, S., Lombard, E. J., Hailu, F., Pham, L. N. H., & Weltzien, K. (2025). Global patterns of gender disparities in STEM and explanations for their persistence. *Nature Review Psychology*, 4(1), 6–19. <https://doi.org/10.1038/s44159-024-00380-3>
- Chu, F. W., vanMarle, K., & Geary, D. (2015). Early numerical foundations of young children's mathematical development. *Journal of Experimental Child Psychology*, 132, 205–212. <https://doi.org/10.1016/j.jecp.2015.01.006>

- Clements, D., & Sarama, J. (2021). *Learning and teaching early math. The learning trajectories approach* (3rd ed). Routledge.
- Clements, D. H., Sarama, J. H., & Liu, X. H. (2008). Development of a measure of early mathematics achievement using the Rasch model: The research-based early maths assessment. *Educational Psychology*, 28(4), 457–482. <https://doi.org/10.1080/01443410701777272>
- Daucourt, M. C., Napoli, A. R., Quinn, J. M., Wood, S. G., & Hart, S. A. (2021). The home math environment and math achievement. *Psychological Bulletin*, 147(6), 565–596. <https://doi.org/10.1037/bul0000330>
- David, C., Dobrean, A., & van Luit, J. E. H. (2015). Psychometric properties of early numeracy test in Romanian language: Preliminary data. *Transylvanian Journal of Psychology*, 16(1), 57–69.
- Davis-Kean, P. E. (2005). The influence of parent education and family income on child achievement: The indirect role of parental expectations and the home environment. *Journal of Family Psychology*, 19(2), 294–304. <https://doi.org/10.1037/0893-3200.19.2.294>
- De Smedt, B. (2022). Individual differences in mathematical cognition: A Bert's eye view. *Current Opinion in Behavioral Sciences*, 46, 1011175. <https://doi.org/10.1016/j.cobeha.2022.1011175>
- DeFlorio, L., & Beliakoff, A. (2015). Socioeconomic status and preschoolers' mathematical knowledge: The contribution of home activities and parent beliefs. *Early Education & Development*, 26(3), 319–341. <https://doi.org/10.1080/10409289.2015.968239>
- Devlin, B. L., Jordan, N., & Klein, A. (2022). Predicting mathematics achievement from subdomains of early number competence: Differences by grade and achievement level. *Journal of Experimental Child Psychology*, 217, 105354. <https://doi.org/10.1016/j.jecp.2021.105354>
- Devlin, D., Moeller, K., & Sella, F. (2022). The structure of early numeracy: Evidence from multi-factorial models. *Trends in Neuroscience and Education*, 26, 100171. <https://doi.org/10.1016/j.tine.2022.100171>
- Dong, Y., Clements, D. H., Day-Hess, C. A., Sarama, J., & Dumas, D. (2021). Measuring early childhood mathematical cognition: Validating and equating two forms of the research-based early mathematics assessment. *Journal of Psychoeducational Assessment*, 39(8), 983–998. <https://doi.org/10.1177/07342829211037195>
- Downey, D. B. (2001). Number of siblings and intellectual development: The resource dilution explanation. *The American Psychologist*, 56(6–7), 497–504. <https://doi.org/10.1037/0003-066X.56.6-7.497>
- Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, 43(6), 1428–1446. <https://doi.org/10.1037/0012-1649.43.6.1428>
- Dunekacke, S., Van Den Ham, A.-K., Grüfßing, M., & Heinze, A. (2024). Structure and development of kindergarten children's mathematical competence. *Journal of Early Childhood Research*, 22(3), 442–457. <https://doi.org/10.1177/1476718X231221393>
- Elliott, L., & Bachman, H. J. (2024). Mothers' strategies to support children's early learning in low-income homes: A qualitative investigation. *Journal of Child & Family Studies*, 33(3), 793–804. <https://doi.org/10.1007/s10826-023-02652-7>
- Elliott, L., Votruba-Drzal, E., Miller, P., Libertus, M. E., & Bachman, H. J. (2023). Unpacking the home numeracy environment: Examining dimensions of number activities in early childhood. *Early Childhood Research Quarterly*, 62, 129–138. <https://doi.org/10.1016/j.ecresq.2022.08.002>
- Elliott, L., Zheng, P., & Libertus, M. (2021). Individual differences in parental support for numeracy and literacy in early childhood. *Education Sciences*, 11(9), 541. <https://doi.org/10.3390/educsci11090541>
- Ernst, J. R., Pan, S. E., & Carlson, S. M. (2024). Remote assessment of the association between early executive function and mathematics skills. *Infant and Child Development*, 33(5), e2534. <https://doi.org/10.1002/icd.2534>
- Floyd, R., Hojniski, R., & Key, J. (2006). Preliminary evidence of the technical adequacy of the preschool numeracy indicators. *School Psychology Review*, 35(4), 627–644. <https://doi.org/10.1080/02796015.2006.12087967>
- Fuson, K. (1988). *Children's counting and concept of number*. Springer-Verlag.
- Geary, D., & vanMarle, K. (2018). Growth of symbolic number knowledge accelerates after children understand cardinality. *Cognition*, 177, 69–78. <https://doi.org/10.1016/j.cognition.2018.04.002>
- Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Harvard University Press.
- González, I., Benvenuto, G., & Lanciano, N. (2017). Dificultades de Aprendizaje en Matemática en los niveles iniciales: Investigación y formación en la escuela italiana. *Psychology, Society, & Education*, 9(1), 135–145. <https://doi.org/10.25115/psye.v9i1.468>
- Hanich, L. B., Jordan, N. C., Kaplan, D., & Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology*, 93(3), 615–626. <https://doi.org/10.1037/0022-0663.93.3.615>
- Hellstrand, H., Korhonen, J., Räsänen, P., Linnanmäki, K., & Aunio, P. (2020). Reliability and validity evidence of the early numeracy test for identifying children at risk for mathematical learning difficulties. *International Journal of Educational Research*, 102, 101580. <https://doi.org/10.1016/j.ijer.2020.101580>
- Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, 74(5), 1368–1378. <https://doi.org/10.1111/1467-8624.00612>

- Hornburg, C. B., King, Y. A., Westerberg, L., Schmitt, S. A., & Purpura, D. J. (2024). The roles of mathematical language and emergent literacy skills in the longitudinal prediction of specific early numeracy skills. *Journal of Experimental Child Psychology*, 244, 105959. <https://doi.org/10.1016/j.jecp.2024.105959>
- Hornburg, C. B., Schmitt, S. A., & Purpura, D. J. (2018). Relations between preschoolers' mathematical language understanding and specific numeracy skills. *Journal of Experimental Child Psychology*, 176, 84–100. <https://doi.org/10.1016/j.jecp.2018.07.005>
- Jordan, N. C., Kaplan, D., Olah, L. N., & Locuniak, M. N. (2006). Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development*, 77(1), 153–175. <https://doi.org/10.1111/j.1467-8624.2006.00862.x>
- Jordan, N. J., Devlin, B. L., & Botello, M. (2022). Core foundations of early mathematics: Refining the number sense framework. *Current Opinion in Behavioral Sciences*, 46, 101181. <https://doi.org/10.1016/j.cobeha.2022.101181>
- Kersey, A. J., Csumitta, K. D., & Cantlon, J. F. (2019). Gender similarities in the brain during mathematics development. *NPJ Science of Learning*, 4(19). <https://doi.org/10.1038/s41539-019-0057-x>
- Krajcsi, A. (2021). Follow-up questions influence the measured number knowledge in the give-a-number task. *Cognitive Development*, 57, 1–10. <https://doi.org/10.1016/j.cogdev.2020.100968>
- Kyttälä, M., Aunio, P., Lepola, J., & Hautamäki, J. (2014). The role of the working memory and language skills in the prediction of word problem solving in 4-to 7-year-old children. *Educational Psychology*, 34(6), 674–696. <https://doi.org/10.1080/01443410.2013.814192>
- Laracy, S. D., Hojniski, R. L., & Dever, B. V. (2016). Assessing the classification accuracy of early numeracy curriculum-based measures using receiver operating characteristic curve analysis. *Assessment for Effective Intervention*, 41(3), 172–183. <https://doi.org/10.1177/1534508415621542>
- Law of Early Childhood Education 3 §. (2018). <https://www.finlex.fi/fi/laki/alkup/2018/20180540>
- Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition*, 105(2), 395–438. <https://doi.org/10.1016/j.cognition.2006.10.005>
- LeFevre, J.-A., Fast, L., Skwarchuk, S.-L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner, W. M. (2010). Pathways to mathematics: Longitudinal predictors of performance. *Child Development*, 81(6), 1753–1767. <https://doi.org/10.1111/j.1467-8624.2010.01508.x>
- Lei, P.-W., Wu, Q., DiPerna, J. C., & Morgan, P. L. (2009). Developing short forms of the EARLI numeracy measures: Comparison of item selection methods. *Educational and Psychological Measurement*, 69(5), 825–842. <https://doi.org/10.1177/0013164409332215>
- Litkowski, E., Duncan, R., Logan, J., & Purpura, D. (2020a). When do preschoolers learn specific mathematics skills? Mapping the development of early numeracy knowledge. *Journal of Experimental Child Psychology*, 195, 104846–104846. <https://doi.org/10.1016/j.jecp.2020.104846>
- Liu, Y., Peng, P., & Yan, X. (2025). Early numeracy and mathematics development: A longitudinal meta-analysis on the predictive nature of early numeracy. *Journal of Educational Psychology*, 117(6), 863–883. <https://doi.org/10.1037/edu0000925>
- Lopez-Pedersen, A., Mononen, R., Korhonen, J., Aunio, P., & Melby-Lervåg, M. (2021). Validation of an early numeracy screener for first graders. *Scandinavian Journal of Educational Research*, 65(3), 404–424. <https://doi.org/10.1080/00313831.2019.1705901>
- Lugo-Gil, J., & Tamis LeMonda, C. (2008). Family resources and parenting quality: Links to children's cognitive development across the first 3 years. *Child Development*, 79(4), 1065–1085. <https://doi.org/10.1111/j.1467-8624.2008.01176.x>
- Marsh, H., Hau, K. T., & Wen, Z. (2004). In search for golden rules: Comment on the hypothesis testing approaches to setting cutoff values for fit indexes and dangers in overgeneralising Hu & Bentler's (1999) findings. *Structural Equation Modeling*, 11(3), 320–341. https://doi.org/10.1207/s15328007sem1103_2
- Méndez, L., Hammer, C., Lopez, L., & Blair, C. (2019). Examining language and early numeracy skills in young Latino dual language learners. *Early Childhood Research Quarterly*, 46, 252–261. <https://doi.org/10.1016/j.ecresq.2018.02.004>
- Methe, S. A., Hintze, J. M., & Floyd, R. G. (2008). Validation and decision accuracy of early numeracy skill indicators. *School Psychology Review*, 37(3), 359–373. <https://doi.org/10.1080/02796015.2008.12087883>
- Muñoz, D., Bull, R., & Lee, K. (2021). Socioeconomic status, home mathematics environment and math achievement in kindergarten: A mediation analysis. *Developmental Science*, 24(6), e13135. <https://doi.org/10.1111/desc.13135>
- Muñoz, D., Bull, R., & Lee, K. (2022). Maternal education and siblings: Agents of cognitive development in kindergarten. *Developmental Science*, 25(4), e13218. <https://doi.org/10.1111/desc.13218>
- Muthén, L. K., & Muthén, B. O. (1998–2017). *Mplus user's guide* (8th ed). Muthén & Muthén.
- National Core Curriculum for Early Childhood Education and Care (ECEC). (2022). *The Finnish National Agency for Education*. https://www.oph.fi/sites/default/files/documents/Varhaiskasvatussuunnitelman_perusteet_2022_2.pdf
- National Statistics. (2021). *Statistics Finland*. <https://www.stat.fi/en/statistics/vkour>
- National Statistics. (2023). *Statistics Finland*. <https://www.stat.fi/en/statistics/vkour>
- Norwalk, K. E., DiPerna, J. C., & Lei, P.-W. (2014). Confirmatory factor analysis of the early arithmetic, reading, and learning indicators (EARLI). *Journal of School Psychology*, 52(1), 83–96. <https://doi.org/10.1016/j.jsp.2013.11.006>

- Outwaite, L. A., Aunio, P., Leung, J. K. Y., & Van Herwegen, J. (2024). Measuring mathematical skills in early childhood: A systematic review of the psychometric properties of early maths assessments and screeners. *Educational Psychology Review*, 36(4), 110. <https://doi.org/10.1007/s10648-024-09950-6>
- Peng, P., Lin, X., Únal, Z. E., Lee, K., Namkung, J., Chow, J., & Sales, A. (2020). Examining the mutual relations between language and mathematics: A meta-analysis. *Psychological Bulletin*, 146(7), 595–634. <https://doi.org/10.1037/bul0000231>
- Polignano, J. C., & Hojnosi, R. L. (2012). Preliminary evidence of the technical adequacy of additional curriculum-based measures for preschool mathematics. *Assessment for Effective Intervention*, 37(2), 70–83. <https://doi.org/10.1177/1534508411430323>
- Purpura, D. J., Hume, L., Sims, D. M., & Lonigan, C. J. (2011). Early literacy and early numeracy: The value of including early literacy skills in the prediction of numeracy development. *Journal of Experimental Child Psychology*, 110(4), 647–658. <https://doi.org/10.1016/j.jecp.2011.07.004>
- Purpura, D. J., Logan, J. R., Hassinger-Das, B., & Napoli, A. R. (2017). Why do early mathematics skills predict later reading? The role of mathematical language. *Developmental Psychology*, 53(9), 1633–1642. <https://doi.org/10.1037/dev0000375>
- Purpura, D. J., & Lonigan, C. J. (2013). Informal numeracy skills: The structure and relations among numbering, relations, and arithmetic operations in preschool. *American Educational Research Journal*, 50(1), 78–209. <https://doi.org/10.3102/0002831212465332>
- Purpura, D. J., & Lonigan, J. (2015). Early numeracy assessment: The development of the preschool early numeracy scales. *Early Education & Development*, 26(2), 286–313. <https://doi.org/10.1080/10409289.2015.991084>
- Purpura, D. J., Napoli, A. R., & King, Y. (2019). Development of mathematical language in preschool and its role in learning numeracy skills. In D. C. Geary, D. B. Berch, & K. M. Koepke (Eds.), *Cognitive foundations for improving mathematical learning* (pp. 175–193). Academic Press. <https://doi.org/10.1016/B978-0-12-815952-1.00007-4>
- Purpura, D. J., & Reid, E. E. (2016). Mathematics and language: Individual and group differences in mathematical language skills in young children. *Early Childhood Research Quarterly*, 36, 259–268. <https://doi.org/10.1016/j.ecresq.2015.12.020>
- Ramani, G. B., & Siegler, R. S. (2011). Reducing the gap in numerical knowledge between low-and middle-income preschoolers. *Journal of Applied Developmental Psychology*, 32(3), 146–159. <https://doi.org/10.1016/j.appdev.2011.02.005>
- Rindermann, H., & Baumeister, A. E. E. (2015). Parents' SES vs. parental educational behavior and children's development: A reanalysis of the Hart and Risley study. *Learning and Individual Differences*, 37, 133–138. <https://doi.org/10.1016/j.lindif.2014.12.005>
- Ritchie, S. J., & Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychological Science*, 24(7), 1301–1308. <https://doi.org/10.1177/0956797612466268>
- Ryoo, J. H., Molfese, V. J., Brown, E. T., Karp, K. S., Welch, G. W., & Bovaird, J. A. (2015). Examining factor structures on the test of early mathematics ability - 3: A longitudinal approach. *Learning and Individual Differences*, 41, 21–29. <https://doi.org/10.1016/j.lindif.2015.06.003>
- Salminen, J., Khanolainen, D., Koponen, T., Torppa, M., & Lerkkanen, M.-K. (2021). Development of numeracy and literacy skills in early childhood—a longitudinal study on the roles of home environment and familial risk for reading and math difficulties. *Frontiers in Education*, 6. <https://doi.org/10.3389/educ.2021.725337>
- Schneider, M., Beeres, K., Coban, L., Merz, S., Susan Schmidt, S., Stricker, J., & De Smedt, B. (2017). Associations of non-symbolic and symbolic numerical magnitude processing with mathematical competence: A meta-analysis. *Developmental Science*, 20(3), e12372. <https://doi.org/10.1111/desc.12372>
- Shapka, J. D., Domene, J. F., & Keating, D. P. (2006). Trajectories of career aspirations through adolescence and young adulthood: Early math achievement as a critical filter. *Educational Research & Evaluation*, 12(4), 347–358. <https://doi.org/10.1080/13803610600765752>
- Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, 7(4), 422–445. <https://doi.org/10.1037/1082-989X.7.4.422>
- Sjoe, M., Bleses, D., Dybdal, L., Tideman, E., Kirkeby, H., Sehested, K., Nielsen, H., Kreiner, S., & Jensen, P. (2019). Short Danish version of the tools for early assessment in math (TEAM) for 3-6-year-olds. *Early Education & Development*, 30(2), 238–258. <https://doi.org/10.1080/10409289.2018.1544810>
- Slusser, E., Ribner, A., & Shusterman, A. (2018). Language counts: Early language mediates the relationship between parent education and children's math ability. *Developmental Science*, 22(3), e12773. <https://doi.org/10.1111/desc.12773>
- Sowinski, C., LeFevre, J.-A., Skwarchuk, S.-L., Kamawar, D., Bisanz, J., & Smith-Chant, B. (2015). Refining the quantitative pathway of the pathways to mathematics model. *Journal of Experimental Child Psychology*, 131, 73–93. <https://doi.org/10.1016/j.jecp.2014.11.004>
- Spelke, E. (2017). Core knowledge, language, and number. *Language Learning and Development*, 13(2), 147–170. <https://doi.org/10.1080/15475441.2016.1263572>

- Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. *Psychological Bulletin*, 147(4), 329–351. <https://doi.org/10.1037/bul0000322>
- Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science*, 29(4), 581–593. <https://doi.org/10.1177/0956797617741719>
- Susperreguy, M., DiLonardo Burr, S., Xu, C., Douglas, H., & LeFevre, J. (2020). Children's home numeracy environment predicts growth of their early mathematical skills in kindergarten. *Child Development*, 91(5), 1663–1680. <https://doi.org/10.1111/cdev.13353>
- ten Braak, D., & Størksen, I. (2021). Psychometric properties of the Ani Banani Math Test. *The European Journal of Developmental Psychology*, 18(4), 610–628. <https://doi.org/10.1080/17405629.2021.1879046>
- Thomas, A., Tazouti, Y., Hoareau, L., Luxembourger, C., Hubert, B., & Jarlégan, A. (2021). Early numeracy assessment in French preschool: Structural analysis and links with children's characteristics. *International Journal of Early Years Education*, 1–18. <https://doi.org/10.1080/09669760.2021.1938518>
- Thomas, A., Tazouti, Y., Hoareau, L., Luxembourger, C., Hubert, B., & Jarlégan, A. (2023). Early numeracy assessment in French preschool: Structural analysis and links with children's characteristics. *International Journal of Early Years Education*, 31(4), 1018–1035. <https://doi.org/10.1080/09669760.2021.1938518>
- Toll, S. W. M., & Van Luit, J. E. H. (2014). The developmental relationship between language and low early numeracy skills throughout kindergarten. *Exceptional Children*, 81(1), 64–78. <https://doi.org/10.1177/0014402914532233>
- Valtonen, R., Ahonen, T., Lyytinen, P., & Lyytinen, H. (2007). Co-occurrence of developmental delays in a screening study of 4-year-old Finnish children. *Developmental Medicine & Child Neurology*, 46(7), 436–443. <https://doi.org/10.1111/j.1469-8749.2004.tb00502.x>
- Valtonen, R., & Mustonen, K. (2007). *LENE - Leikki-ikäisen lapsen neurologinen arvio* [Preschool-aged children's neurological evaluation]. Niilo Mäki Institute.
- van de Rijt, B. A. M., van Luit, J. E. H., & Pennings, A. H. (1999). The construction of the Utrecht early mathematical competence scales. *Educational and Psychological Measurement*, 59(2), 289–309. <https://doi.org/10.1177/0013164499592006>
- VanDerheyden, A., Broussard, C., & Cooley, A. (2006). Further development of measures of early math performance for preschoolers. *Journal of School Psychology*, 44(6), 533–553. <https://doi.org/10.1016/j.jsp.2006.07.003>
- VanDerheyden, A. M., Broussard, C., Fabre, M., Stanley, J., Legendre, J., & Creppell, R. (2004). Development and validation of curriculum-based measures of math performance for preschool children. *Journal of Early Intervention*, 27(1), 27–41. <https://doi.org/10.1177/105381510402700103>
- Van Luit, J. E. H., Van de Rijt, B. A. M., & Aunio, P. (2006). *Lukukäsitetesti (the early numeracy test)*. Psykologien Kustannus.
- Van Luit, J. E. H., van de Rijt, B. A. M., & Pennings, A. H. (1994). *Utrechtse getalbegrip toets* [Utrecht test of early numeracy]. Graviant.
- Workman, J. (2017). Sibling additions, resource dilution, and cognitive development during early childhood. *Journal of Marriage & Family*, 79(2), 462–474. <https://doi.org/10.1111/jomf.12350>
- Wynn, K. (1990). Children's understanding of counting. *Cognition*, 36(2), 155–193. [https://doi.org/10.1016/0010-0277\(90\)90003-3](https://doi.org/10.1016/0010-0277(90)90003-3)
- Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology*, 24(2), 220–251. [https://doi.org/10.1016/0010-0285\(92\)90008-P](https://doi.org/10.1016/0010-0285(92)90008-P)
- Zhang, H., Wee, C., Poh, J., Wang, Q., Shek, L., Chong, Y., Fortier, M., Meaney, M., Broekman, B., & Qiu, A. (2019). Fronto-parietal numerical networks in relation with early numeracy in young children. *Brain Structure & Function*, 224(1), 263–275. <https://doi.org/10.1007/s00429-018-1774-2>

Appendix

A description of the ENT items (van de Rijt et al., 1999; Van Luit et al., 1994; Van Luit et al., 2006)

Numerical relational skills (Items 1–20)

- (1) These tasks measure the use of concepts in making comparisons between two non-equivalent cardinal, ordinal, and measurement situations. *A sample item: Here are some men. Can you point out the man who has fewer books than the one you see here?*
- (2) These tasks measure skills to classify the objects in a class on the basis of one or more features. *A sample item: Look at these boxes. Can you point out the box with four triangles blocks but no squares?*
- (3) These tasks measure children's understanding about one-to-one relationships of simultaneously presented objects. *A sample item: (The child has 12 blocks.) The administrator shows a drawing representing two dice with showing 4 and 3. Then the administrator asks: Can you put as many blocks on the table as are shown on the dice here?*
- (4) These tasks measure skills to seriate. *A sample item: (The child has a paper and pencil.) Here are some cats. Each cat is going to fetch a ball. The big cat is going to fetch a big ball and the small cat is going to fetch a small ball. Can you draw lines from all of the cats to the balls that they fetch?*

Counting skills (Items 21–40)

- (1) These tasks assess the skills to use number words in the number-word sequence up to 20. *A sample item: Count further from 7 to 14.*
- (2) These tasks measure the skills to count objects in organized and unorganized arrangements by pointing. *A sample item: The administrator puts 15 blocks on the table in an unorganized manner. The child is required to count the blocks. The child is allowed to point to the blocks with his/her finger or to move them.*
- (3) These tasks measure enumeration skills: pointing is not allowed. *A sample item: The administrator puts 16 blocks on the table in four rows of four with some space between them, and asks: How many blocks are there? The child is not allowed to point to the blocks with his/her finger or to move them.*
- (4) These tasks measure skills to use numeracy in daily life situations, which are represented in drawings. *A sample item: The administrator points to a picture of eight sheep and says: A farmer has eight sheep. He buys two more. The administrator then points to the picture with two sheep and continues: How many sheep does the farmer have now? Show the box with the right answer. The administrator points to the row of squares at the bottom of the paper.*