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The effect of first school years on mathematical skill profiles

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Abstract

This study investigated the effect of children's first formal school years on mathematical skill profiles, measured by a variety of arithmetical skills and Spontaneous Focusing On Numerosity (SFON) tasks. By using person-centered approach the aim was to investigate whether the amount of formal schooling is associated with mathematical skills in the same way for all children, or, whether the associations differ according to the children's mathematical skill profiles. Data was analyzed from 652 4–7-year-old children from four European countries with different school entrance ages. A person-centered approach with latent profile regression analyses on four-factor score variables identified six mathematical skill profiles with both qualitative and quantitative differences. The results revealed significant, but small effects of the amount of schooling on mathematical profiles when chronological age and country-specific school entrance age were controlled for. Educational implications of the findings emphasize regarding the heterogeneity in children's mathematical skill profiles and the potentially different effects of starting formal schooling across different profiles.

Keywords: arithmetical skills; spontaneous focusing on numerosity; amount of schooling; schooling effects; latent profile analyses

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1. Introduction

Mathematical skills are among the most influential skills needed for survival and success in modern working life (FitzSimons, 2013), and different aspects of their development have inspired an increased research interest in the last few decades (Dowker, 2008). A novel dimension of recent research is the effect of different learning settings on mathematical development (Clements & Sarama, 2014). Here we focus on the question of formal school-entry-age and whether this has an effect on mathematical skill profiles. Specifically, by using person-centered approach, the aim is to investigate whether the amount of formal schooling is associated with mathematical skills in the same way for all children, or, whether the associations differ according to the children's mathematical skill profiles. This is motivated by ambiguous evidence of the effect of school starting age in previous research. On one hand, cross-country studies have shown that children from countries where formal school starts at a younger age demonstrate better mathematical skills than their peers from countries with older school entrance ages (Kavkler et al., 2000; Luyten, 2006; Wolke et al., 2015). Developmental data shows that starting formal instruction early has a positive effect on mathematical skills, both in the short term (Cliffordson & Gustafsson, 2010; Herbst & Strawiński, 2015) and in the longer term (Black, Devereux, & Salvanes, 2011; Melhuish et al., 2008; Sylva et al., 2008). On the other hand, within-country studies focusing on special groups of children as well as early interventions with both fading out and catching up effects (Clements & Sarama, 2014), indicate opposite trends (for a review, Datar, 2006) which call for and necessitate further investigation of these effects. For example, Altwicker-Hámori & Köllő (2012) showed that Hungarian children from low socioeconomic backgrounds benefit from starting formal school later, which was attributed to effective early math education in preschool. Similarly, even though there are overall positive schooling and age effects on cognitive development, younger entrance age was found to have negative effects on the economically and cognitively lowest group of a sample from different states in the United States (Datar, 2006). In addition, schooling may have different effects on different quantitative skills other than age (Bisanz, Morrison, & Dunn, 1995).

The current paper uses exogenous variation in formal school entrance age policies and a cross-sectional sample from four countries with different school entrance ages to examine the effects of variation in the years of formal education on mathematical skill profiles. This cross-national and cross-sectional sample provides a large variation not only in children's school entrance age but also in their amount of schooling, which is partly independent of the chronological age and school starting age variation in the sample. This allows for the investigation of these effects on mathematical skill profiles. There is not a linear relation between chronological age and school entrance age, neither between school entrance age and amount of schooling in our 4-age-group sample covering ages from 4 to 7 years. Therefore, we can investigate if a larger amount of schooling is associated with better mathematical outcomes in different skill profiles.

1.1 Mathematical Skills

This study aims to investigate the effects of formal education on mathematical skill profiles based on two sets of different aspects of mathematical thinking, namely arithmetical skills and Spontaneous Focusing On Numerosity (SFON) in children from four European countries in which the starting age of formal schooling is 4, 5, 6, or 7 years. Arithmetical skills represent typical mathematical skills explicitly taught in the beginning of formal school even though their learning starts well before (e.g. Clements & Sarama, 2014) while SFON is a measure of how frequently children focus their attention on numerical aspect and use their existing numerical skills in their everyday surroundings, thus a measure of more informal mathematical thinking that has been shown to be important predictor of later success in mathematics (e.g., Hannula & Lehtinen, 2005; Nanu et al., 2018). Having these both kinds of measures is important, since it has been shown that children do not learn and use mathematical skills only in formal learning situations, such as mathematics lessons, but also in their play and everyday life outside of explicitly mathematical, adult-guided tasks (Ginsburg & Seo, 1999; Hannula & Lehtinen, 2005). Also, one important goal of mathematics education is to produce transferable mathematical skills and knowledge, which can be used outside of formal learning contexts (De Corte, 1999). For these reasons, including both relatively formal and informal mathematical skills is necessary for broader coverage of developmentally relevant aspects of numeracy. Here we refer to informal and formal mathematical skills similarly to Ginsburg (1977) who defined informal mathematical knowledge as mathematical skills generally learned before or outside of school, often in spontaneous but meaningful everyday situations including play. It is characterized by the use of nonconventional and even self-invented symbols, strategies, or procedures rather than conventional written symbols or algorithms. Formal mathematical knowledge consists of mathematical skills and concepts taught in school and include the use of conventional written numerical notation and written algorithms (Ginsburg, 1977).

1.1.1 Arithmetical skills in 4- to 7-year-old children.

Before receiving formal instruction, children can read and write some Arabic digits (e.g., Clements & Sarama, 2007; Fuson, 1988) and perform basic nonverbal addition and subtraction operations (Huttenlocher, Jordan, & Levine, 1994). After learning to count objects and recite number word sequence, children integrate counting with their initial knowledge of arithmetical operations, which forms the foundation of calculation fluency, an important mathematical skill in primary school (Locuniak & Jordan, 2008). Several studies focusing on symbolic number knowledge recognize digit knowledge as an important predictor or mediator between informal and formal mathematical knowledge (Martin, Cirino, Sharp, & Barnes, 2014; Purpura, Baroody, & Lonigan, 2013). Formal mathematical learning is considered to start when children go to formal school and when, typically, the basics of both verbal and written arithmetic are systematically taught to children (Clements & Sarama, 2014). Dowker (2005) suggested that the most striking difference between arithmetic in formal and informal contexts is that schoolchildren learn mostly written arithmetic, while outside of school they rely, rather, on culturally-based mental strategies. When starting formal schooling, children are typically taught Arabic digits and counting-based strategies to solve addition and subtraction problems, strategies that increase the accuracy of calculation. Thus, tests of arithmetical skills, such as basic addition and subtraction as well as digit knowledge, are adequate output measures of mathematical development and so are included in the current study. In order to cover skills developing both in school, preschool, and day-care contexts, including both verbal and written arithmetic measures in addition to digit naming is necessary.

1.1.2 Spontaneous Focusing on Numerosity (SFON).

Hannula and Lehtinen (2005) argued that the tendency to spontaneously notice exact numerosities, which leads to the self-initiated practice of mathematical skills, is particularly important for the development of early mathematical skills. Hannula, Lepola, and Lehtinen, (2010) defined SFON as:

> a process of spontaneously (i.e., in a self-initiated way not prompted by others) focusing attention on the aspect of the exact number of a set of items or incidents and using of this information in one's action. SFON tendency indicates the amount of a child's spontaneous practice in using exact enumeration in her or his natural surroundings. (p. 395)

More specifically, Hannula and Lehtinen (2005) showed that some children spontaneously pay attention to the numerical dimension of the environment and use that numerical information to perform different tasks, while others do not show any self-initiativeness to notice and utilize numbers in their actions. This variation is related to both concurrent and later mathematical skills even after controlling for the general attention and cognitive skills needed for the tasks (Batchelor, Inglis, & Gilmore, 2015; Bojorque, Torbeyns, Hannula-Sormunen, van Nijlen, & Verschaffel, 2016; Edens & Potter, 2013; Hannula et al., 2005, 2007, 2010; Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Nanu et al., 2018). Hannula and Lehtinen (2005) showed that SFON tendency can be enhanced at day-care by means of social interaction, and recently, Braham, Libertus and McCrink (2018) demonstrated that children's SFON can be promoted in an informal setting where parent-child pairs play shopping at a museum. In line with these findings, the word "spontaneous" does not refer to the developmental origins of this tendency, but only to a momentary self-initiated focusing on the aspect of number.

As evidenced by different SFON measures, individual differences in self-initiated practice using numerical skills can occur in different activities, such as copying pictures as well as performing different actions like feeding a bird, selecting the right number of socks for different monster toys, or describing pictures (Gray & Reeve, 2016; Batchelor et al., 2015; Hannula et al., 2009; Hannula & Lehtinen, 2005), thus children do not use and learn mathematical skills only in adult-guided explicitly mathematical tasks. Recent research suggested considerable contextual effects and variability across different kinds of SFON measures (Batchelor et al., 2015; Rathé, Torbeyns, Hannula-Sormunen, & Verschaffel, 2016). Thus, it is important to use multiple SFON tasks.

1.2 Person-centered Approach

Comparative studies on early mathematical skills and the onset of formal education have predominantly used variable-centered approaches that, while valuable in testing relations among variables, are detrimental in translating these relations at the individual level. Directly related to current investigation, a previous variable-centered study did not detect any systematic effects of starting age of schooling on a variety of early mathematical skills in a four-country cross-sectional study (Batchelor et al., in preparation). A person-centered approach identifies optimal combinations of skill levels, resulting in data-driven grouping of participants without having to use artificially cut-off scores (Hickendorff, Edelsbrunner, McMullen, Schneider, & Trezise, 2017; Magnusson, 2003). The identified groups with unique combinations of skill-levels can be utilized as units of analyses, allowing for the investigation of potential relations of profiles with external variables. Previous studies using person-centered approaches in early math mostly investigated how the children's mathematical skill profiles were related to different cognitive skills, as well as specific math measures (e.g., Gray & Reeve, 2016; Hannula-Sormunen et al., 2017). To our knowledge, no previous studies have analyzed the effects of formal schooling on early mathematical skill profiles based on both formal and informal set of mathematical skills. These analyses help identify children's unique mathematical skill profiles across a range of country-specific formal schooling settings, as well as investigate the effects of formal schooling on children with different mathematical skill profiles. What is more, these profile differences can be explored in relation to other relevant aspects such as socioeconomic status and chronological age, both factors that have been sources of individual differences in previous early math studies (Altwicker-Hámori & Köllő, 2012; Sprietsma, 2010). One advantage of person-centered approach is the way how it creates educationally relevant information for preparing tailored education for different groups of learners with their unique strengths and weaknesses across wide range of measures (McMullen & Hickendorff, 2018). This analytical strategy allows investigating whether school starting age and amount of schooling have differing effects on different groups of children as represented in the mathematical skill profiles.

1.3 The Present Study

The aim of the present study is to investigate the effects of children's first years in formal school on their mathematical skill profiles by using a person-centered approach. A cross-sectional sample with 4–7-year-old children came from four western European countries. The countries differ systematically in their starting age for school and, consequently, also in the amount of formal schooling they provide for children of the same age. Variability in the years of schooling may be a more sensitive indicator of the effects of formal education than just school entrance age, which reflects on both country-specific differences in formal schooling policies as well as entrance age effects. Our research question is as follows:

Does the amount of schooling have unique effects on children's mathematical skill profiles when chronological age, school starting age / country, and socioeconomic status, i.e., SES are controlled for? In order to investigate this question, first, mathematical skill profiles including both relatively informal and formal mathematical skills are formed. School entrance age refers to the age children start school based on policies in each country while the amount of schooling is a characteristic of an individual participant, indicating how many years they have been in formal school. Because of the wide age range of the participants, children that started school at same age vary in amount of schooling.

2. Method

2.1 Participants

Participants were 652 children aged from 4 to 7 years from Northern Ireland, England, Belgium, and Finland (ca. 40 per age group in each country), where formal schooling begins at different ages (4, 5, 6, or 7 years, respectively). The study is part of a larger project named International Comparison of Children's

Attention and Learning, ICCAL. Schools, preschools, and daycare centers were selected from middle SES neighbourhoods. Educators distributed and collected sealed parent questionnaires with SES information, including mothers' occupations, education, and income. Table 1 shows frequencies of participants by school entrance age and years of formal schooling.

Table 1.

Number of participants as a function of school entrance age/country, age in months and amount of schooling in years

			School entrance age / Country			
Years of formal school	*n*	Age in months *M (SD)*	Northern Ireland / At 4 years	England / At 5 years	Belgium / At 6 years	Finland / At 7 years
No formal schooling	246	62.63 (10.46)	0	42	84[1]	120[1]
One year	162	70.19 (16.60)	42	40	42	38
Two years	121	75.36 (12.34)	39	42	40	0
Three years	81	79.67 (6.25)	41	40	0	0
Four years	42	85.88 (3.71)	42	0	0	0

Note.[1]There were approximately 40 children in each age group (i.e., 4-, 5-, 6-, and 7-year-old groups) in each country, thus in the no formal schooling group, in Belgium, there were 42 children in 4- year-old and 42 5-year-old children's group, and in Finland 41 4-year-old, 40 5-year-old and 39 6-year-old children's age group. All countries had obligatory preschool education year before the actual formal school entrance age.

Permission was obtained from parents and verbal assents from the children to conduct this research. The study followed the guidelines of the ethical advisory board at each institution, and permissions were granted by local school, kindergarten, and daycare administrators. For this study, we included a random selection of equally-sized samples from all countries and age groups so that all groups would be equally represented. According to T-tests, this sample (n = 652) did not differ from the original sample (N = 685) in SES, age, arithmetical skills, or SFON factor-score variables (all p's > 0.05).

A one-way ANOVA revealed a significant age difference between corresponding age group samples in the countries, F(3, 651) = 10.41, $p < 0.001$, = 0.05. Children in Northern Ireland (M = 68.22, SD = 14.06) and England (M = 66.86, SD = 13.70) were significantly younger in all age groups than those in corresponding age groups in Belgium (M = 73.48, SD = 13.69) and Finland (M = 73.46, SD = 13.44) because the cutoff date for entry to school in Northern Ireland and England is later in the calendar year (Northern Ireland vs. Belgium, t[328] = -3.44, $p = 0.003$, d = -0.38; Northern Ireland vs. Finland, t[320] = -3.42, $p = 0.004$, d = -0.38; England vs. Belgium, t[328] = -4.39, $p < 0.001$, d = -0.48; England vs. Finland, t[320] = -4.36, $p < 0.001$, d = -0.49). Also, there was a significant SES difference between the samples from four countries, F(3,456) = 5.22, $p < 0.001$, = 0.03. Post-hoc comparisons with Bonferroni correction showed that SES (see Table 2 for SES descriptives) was significantly higher in Belgium (M = 0.29, SD = 0.96) compared to Northern Ireland (M = -0.20, SD = 1.10, t[215] = 3.54, $p = 0.002$, d = 0.47), England (M = -0.06, SD = 1.02, t[226] = 2.69, $p = 0.047$, d = 0.35), and Finland (M = -0.07, SD = 0.92, t[255] = 3.22, $p = 0.015$, d = 0.40).

2.2 Procedure

Children were tested during the spring term in March-April, individually in a quiet space in their own school, preschool, or daycare setting by one of ten trained research assistants in two 30-minute testing sessions separated by a short break. Four SFON tasks—two imitation SFON tasks, a picture description SFON task, and a memory card game SFON task—were presented in the first session while digit naming, verbal arithmetic, and written arithmetic were assessed in the second session, and all tasks were administered in the same order for all participants. In order to ensure similar testing procedures across the 10 research assistants, group training was carried out before the assessments and videotaped test sessions were checked throughout the data collection period. In between the tasks, children were involved in short physical activities to refocus their attention and maintain engagement levels. The tester sat next to the child when administering the imitation tasks and sat behind the table opposite to the child in all other tasks.

During the assessment, children received general praise but no specific feedback. The tester ensured that the testing area did not have any numerical displays that might have prompted the children to focus on numbers or helped them to solve arithmetical problems. To keep the numerical aspect of the study concealed, children, parents, and teachers were told that the study was an international comparison of children's attention and learning. Multilingual, close to native, and speakers of the three languages involved (English, Dutch, and Finnish) translated and back-translated all task materials carefully to ensure that tasks were identical across countries and languages.

2.2.1 SFON Measures

Bird imitation task (Hannula & Lehtinen, 2005)

Materials were a toy parrot, placed on the table in front of the child, and two plates of differently colored glass berries placed in front of the parrot. In the first trial, the tester introduced the materials and said, "Watch carefully what I do, and then you do just like I did." The tester put three berries (two red and one blue), one at a time, into the parrot's mouth, and these dropped with a bumping sound into the parrot's stomach, where the child could not see them. Next, the child was told, "Now you do exactly like I did." Three green and two white berries were used in the second trial, and two yellow and three blue berries were used in the third. The tester filled out structured observation forms to record the child's behavior for any signs of counting or enumeration during the imitation and memory card game SFON tasks. All of the child's (a) utterances, including number words (e.g., "I'll give him two berries"), (b) use of fingers to express numbers, (c) counting acts, such as a whispered number word sequence and indicating acts by fingers, (d) other comments referring either to exact quantities or counting (e.g., "Oh, I miscounted them") or (e) interpretation of the task's goal as quantitative (e.g., "I gave an exactly right number") were identified. The child was given a SFON score of 1 if they produced the same numerosity as the tester and/or if they were observed presenting any of the mentioned (a–e) quantifying acts. The maximum score for the task was 3. Cronbach's alpha was 0.74.

Picture description task (Batchelor, Inglis, & Gilmore, 2015)

In each of the three trials, the child had to describe a cartoon picture that contained several elements (objects, people, and animals) that could be enumerated, such as an image of a landscape with two children flying in a hot balloon, three houses in the background, and three clouds. The tester displayed a picture and asked, "What can you see in this picture?" There was no time limit. When the child stopped describing the picture, the tester asked, "Is that everything?" before displaying the next picture. Responses were audio recorded. The child received a SFON score of 1 if they (a) mentioned cardinal or ordinal number words while describing the picture or (b) stated a number word list (at least two consecutive number words). The maximum score for this SFON task was 3. Because the Dutch word for "a" is the same as the word for "one," the number word "one" was excluded to avoid possible language effects. Cronbach's alpha was 0.74.

Postbox imitation task (Hannula & Lehtinen, 2005)

The materials were a postbox, placed in front of the child on the table, and six piles of ten envelopes, each pile different in color. Before starting each trial, two piles of envelopes were placed in front of the postbox. Verbal instructions were similar to the bird imitation task. For the first trial, the tester put one orange envelope and two green envelopes, one at a time, into the postbox. Then the child was asked to do exactly as the tester had done. For the second trial, two brown and three yellow envelopes, and for the third trial, three blue and two pink envelopes, were used. The scoring criteria was the same as the one used in the bird imitation task. The maximum score for this SFON task was 3. Cronbach's alpha was 0.69.

Memory card game (developed from Hannula, Grabner, & Lehtinen, 2009)

In this task, children were asked to look at a card, memorize it, and, immediately after turning it over, describe the card so that the tester could find a matching card from their pile of cards. There were four sets of cards with photos of an array of everyday items and toys. The child had a pile of cards in front of them at the table and the tester had four cards from each set in their hand. For each trial the tester asked the child to turn over their top card and look at it for five seconds. The tester then asked the child to turn the card facedown and describe what was on the card so that they could find the matching card from the tester's pile. The child caught a brief flash of the pile to show that the cards were "very similar," and thus, careful description was required. There was no time limit to respond. When the child stopped, the tester asked, "What else do you remember about this card?" The trial then finished with the tester playfully trying to find the matching card from their pile. There was one practice trial followed by three test trials. Responses were audio recorded and transcribed. For each trial, children scored either 0 or 1, depending on whether they focused on numerosity. The scoring was based on audio recordings and the tester's written observations of signs of counting during the game. They were determined to be focusing on numerosity if their description included any number word utterances referring to the items in the child's cards and/or if the tester observed any signs of counting or comments about the numerical goal of the task (e.g., "How many red ones were there?"). As with the picture task, the number word "one" was excluded to avoid language effects. Children received a total score out of 3 (Cronbach's alpha = 0.74).

2.2.2 Arithmetical Skills Measures

Digit naming

Participants were asked to read aloud a series of Arabic digits. There were ten blocks with three trials per block (ranging from one- to five-digit numbers). The test was discontinued when a child made a mistake on all three items within a block. Children scored 1 point for each correct identification of a digit, resulting in a maximum total score of 30 (Cronbach's alpha = 0.96).

Verbal arithmetical task

Verbal arithmetical skills (developed from Hannula & Lehtinen, 2005) were measured with a task containing addition and subtraction items. In the first part, six addition and subtraction items were illustrated with supporting material consisting of glass sweets (1.5 cm in diameter) and a non-transparent box. For instance, the tester quickly showed four glass sweets in her hand to the child and said, "There are four sweets over here. I put them in this box. Then I put three more sweets there. How many sweets are there in the box now?'' The child was not able to see the end result in the box. This comprehension support was used to make sure that the measure would target arithmetical skills without heavy reliance of verbal comprehension skills. One point was awarded for each correctly solved item, thus, there was a maximum total score of 6. Cronbach's alpha was 0.71.

The second part comprised nine items for addition and nine items for subtraction with one- to two-digit numbers. Children were asked this type of question: "What do you get when you add two and two together?" One point was awarded for each correctly solved item, thus there was a maximum total score of 18. Cronbach's alpha was 0.94.

Written arithmetical task

The written arithmetical task was developed from Aunola, Leskinen, Lerkkanen, and Nurmi's (2004) research. Children were asked to solve a series of written arithmetical problems that consisted of addition and subtraction operations. The problems increased in difficulty, ranging from one- to three-digit addends and subtrahends, and were arranged in four blocks of six items. Each subtest was discontinued when a child made two or more mistakes within a block. Children scored 1 point for each correct solution, giving a maximum total score out of 48 (Cronbach's alpha = 0.98).

2.3 Analytical Strategy

All analyses were completed using Mplus software, version 8 (Muthén & Muthén, 1998–2015). The full information 'maximum likelihood' estimation with 'robust standard errors' was used. Exploratory factor analyses on raw sum scores of all arithmetical skill measurements and categorical SFON scores were conducted (see Appendix A) in order to condense the data, to get the number of factors and to allow items of sub-tests to be represented as the factor scores based on their loadings. The main advantage of a factor score over a summated scale is that it is based on the factor loadings of all variables used in the analysis. CFAs were run to confirm the EFA solution for the entire sample as well as for all countries and age groups. Next, standardized factor scores of confirmatory factor analyses with the factors using whole sample were saved as variables. The variable school starting age / country refers to school starting ages, 4 for Northern Ireland, 5 for England, 6 for Belgium, and 7 for Finland. The amount of schooling was calculated as a categorical variable with the following categories: 0 no schooling, 1, 2, 3, and 4 years of formal schooling.

Using the CFA factor scores saved as variables, latent profile analysis (LPA) was utilized to identify groups of children with homogeneous mathematical skill profiles (i.e., LPA and mixture modelling) (Magidson & Vermunt, 2002; Nylund, Asparouhov, & Muthén, 2007). LPA is an explorative model-based procedure for identifying the smallest number of meaningful profiles that best group participants within a sample while accounting for the probability of belonging to each latent profile (Marsh, Lüdtke, Trautwein, & Morin, 2009). The models were evaluated by using a combination of theoretical interpretability of profiles and statistical indicators—Bayesian Information Criterion (BIC), Akaike´s Information Criterion (AIC), entropy, Vuong Lo Mendell Rubin likelihood ratio test (VLMR), and Bootstrap Likelihood Ratio Test (BLRT)—to identify the best-fitting model (Collins & Lanza, 2010). Smallest values of BIC and AIC are indicators of better model fit. The two likelihood ratio tests give a *p* value which indicates if a k-class model fits the data better compared to a k - 1 class model. In order to complement a variable-centered approach, LPA should identify groups that reflect a combination of level and shape differences (Marsh et al., 2009). The quality of classification is represented by the average posterior probabilities (close to 1) of being assigned to a specific latent profile and by the entropy value (greater than .8 or closest to 1.0 as acceptable value).

Next, in order to study the effects of schooling on mathematical skill profiles, LPA with covariates SES, age, school starting age / country, and amount of schooling was run, as this allows for simultaneous LPA and regression of the latent profiles on covariates (Nylund-Gibson & Masyn, 2016), and therefore determines their unique effects on latent profile membership and the mean levels of the profiles. This analytical strategy allows investigating whether covariates have differing effects on different groups of children as represented in the mathematical skill profiles. In addition, direct effects of covariates on factor score variables were tested by adding their effects individually to each factor score variable, as recommended in an LPA model building process with covariates (Masyn, 2013). Both pathways (the indirect effects via latent variable and the direct effects) through which a covariate could affect latent profile indicators were included in the model (Nylund-Gibson & Masyn, 2016). By allowing direct effects, potential differences in the indicators of the profiles as a function of the covariates are accounted for. Finally, likelihood ratio tests were used to evaluate the statistical significance of each covariate's unique effect on profile membership by adding covariates hierarchically and comparing the fit of the models following Collins and Lanza's (2010) procedure., The odds of belonging to a profile as a function of covariates were investigated in the final model. The odds ratios describe the strength of the association of the covariate on the profiles.

3. Results

3.1. Descriptives and Explorative Factor Analyses

Descriptives of all variables are presented in Table 2.

Table 2.

Descriptive statistics of the mathematical skill measures

Variables	*N*	*M*	*SD*	Skewness	Kurtosis	[Min, Max]
Age	652	70.49	14.02	-0.00	-1.10	[40, 97]
SES	460	-0.01	1.01	-0.51	0.16	[-3.03, 2.43]
Digit naming[1]	651	17.59	7.85	-0.50	-0.81	[0, 30]
Verbal arithmetical skills with comprehension support[1]	651	4.55	1.52	-0.73	0.10	[0, 6]
Verbal arithmetical skills[1]	651	6.06	5.18	0.60	-0.78	[0, 18]
Written arithmetical skills[1]	651	11.32	13.09	1.01	-0.05	[0, 47]
SFON bird imitation task	652	1.84	1.19	-0.48	-1.31	[0, 3]
SFON postbox task	652	1.86	1.14	-0.50	-1.19	[0, 3]
SFON memory card game[2]	640	1.25	1.20	0.31	-1.19	[0, 3]
SFON picture description task[2]	645	1.47	1.18	0.03	-1.50	[0, 3]

Note. SES was a standardized score (based on mothers' occupation, education, and income) modeled as a formative measure using principal component analysis [e.g., Caro & Cortés, 2012]). [1]A child was missing from the second testing session. [2]Missing data due to failure in audio recording or comprehension of the task.

Exploratory factor analyses on raw sum scores of all arithmetical skill measurements and categorical SFON scores were conducted. These showed the best fit for a four-factor solution with factors of (Factor 1) arithmetical skills consisting of digit naming, verbal and written arithmetical items, and all SFON items loading along their task type, i.e., (Factor 2) SFON imitation, (Factor 3) SFON memory, and (Factor 4) SFON picture description (see Appendix A). Next, CFA was run to confirm the EFA solution. Results showed good model fit, χ^2 (98) = 164.88, $p < .001$, CFI = 0.99, RMSEA = 0.032. The same model fitted well (Hu & Bentler, 1999) also for each school starting age / country and for each age group. CFI values for the models of the countries, and also, age groups varied between 0.96 and 1.00, while RMSEA values for the models of the countries varied between 0.00 and 0.05 and for the age groups between 0.00 and 0.04.

3.2 Latent Profile Analysis

Latent profile analysis (LPA) was used to identify groups of children with homogeneous mathematical skill profiles. Table 3 illustrates the fit indices for all LPA solutions. Although the minimum BIC and AIC were not found, the BIC value becomes more stable at the third and the sixth profile solutions. In addition, VLMR LRT do not improve significantly in the 7-profile solution, thus supporting the 6-profile solution (i.e., LPA and mixture modelling) (Magidson & Vermunt, 2002; Nylund, Asparouhov, & Muthén, 2007). The 6-profile solution recognizes sub-groups that are both qualitatively and quantitatively differing from each other. Importantly, qualitative differences are theoretically supported by previous research showing variability and contextual effects across different SFON and math measures (see Rathe et al., 2016), unlike the 3-profile solution, which has only quantitative (i.e. level) differences (Marsh, Lüdtke, Trautwein, & Morin, 2009). Thus, the 6-profile solution was chosen. After calculating the LPA, it was checked whether the used CFA scores masked possible higher order interactions. For this purpose, the LPA analysis was repeated with scale values that were calculated independently. The structural results of the first LPA were basically confirmed.

Table 3.

Fit measures of the 2- to 7-latent profile models for mathematical latent factor score variables

Number of profiles (sample sizes per profile)	AIC	BIC	Entropy	VLMR (*p*)	BLRT (*p*)
2 (335, 317)	6139.76	6197.10	0.87	< 0.001	< 0.001
3 (229, 254, 169)	5731.39	5812.03	0.86	< 0.001	< 0.001
4 (156, 188, 182, 126)	5637.52	5740.56	0.79	0.450	< 0.001
5 (137, 164, 83, 123, 145)	5524.18	5649.62	0.82	0.066	< 0.001
6 (125, 149, 82, 114, 129, 53)	**5433.55**	**5581.39**	**0.83**	**0.045**	**< 0.001**
7 (136, 43, 127, 118, 109, 66, 53)	5381.46	5551.70	0.85	0.182	< 0.001
8[1]					

Note. [1]Unstable solution. Selected solution is marked with bold.

3.3 LPA with covariates

First, we investigated the significance of each covariate in relation to profile structure. We constructed separate LPA models for each covariate (SES, age, school starting age / country, or amount of schooling) and compared the fit of each model with the fit of a model without any covariates. Based on chi-square difference tests, age ($\Delta\chi2(8) = 426.77$, $p < 0.0001$), school starting age / country ($\Delta\chi2(8) = 54.29$, $p < 0.0001$), and amount of schooling ($\Delta\chi2(8) = 162.64$, $p < 0.0001$) were significantly related to mathematical skill profiles, while SES was not ($\Delta\chi2(5) = 4.97$, $p = 0.419$). Therefore, SES was not included in further analyses.

In the following step, we investigated whether the amount of schooling contributes significantly to the prediction of latent profile membership over and above the contribution of age and school starting age / country. Multicollinearity was tested for the covariates of age, school starting age / country, and amount of schooling. Spearman correlations between covariates ranged from 0.17 for age and school starting age / country to -0.67 for school starting age / country and amount of school. VIF was smaller than 10 and tolerance was larger than 0.01, as recommended by Menard (1995) and Myers (1990) for all the covariates (age: VIF = 4.35, Tolerance = 0.23; school starting age / country: VIF = 5.78, Tolerance = 0.17; amount of schooling: VIF = 7.65, Tolerance = 0.13). Thus the analyses could be continued. The effects of amount of schooling were tested by hierarchically adding the covariates and comparing the models with chi-square difference tests (Table 4, Figure 1). Significant direct effects of the covariates on the mathematical skills factor score variables were also included in all models.

Table 4.

Statistical significance of adding the covariates hierarchically in the prediction of latent profile membership

Step	Covariate	ℓ Adding Covariate	Likelihood-Ratio Statistic	*df*	*p*
1	No covariate	-2683.78			
2	Age	-2257.07	426.77	8	< 0.0001
3	School entrance age / country	-2180.80	76.27	9	< 0.0001
4	Amount of schooling	-2155.41	25.39	7	0.0006

Note. ℓ represents log-likelihood from fit models. Statistical significance of each covariate was tested with the likelihood-ratio test.

The final latent profile regression model, where all covariates are allowed to have both direct effects on profile membership and significant direct effects on factor score variables, is illustrated in Figure 1.

These results show that the amount of schooling had a significant, unique effect on the profile structure. Also, the amount of schooling had direct effects on arithmetical skills and on SFON imitation when all other covariates were controlled for. Chronological age had direct effects on arithmetical skills and on SFON picture description.

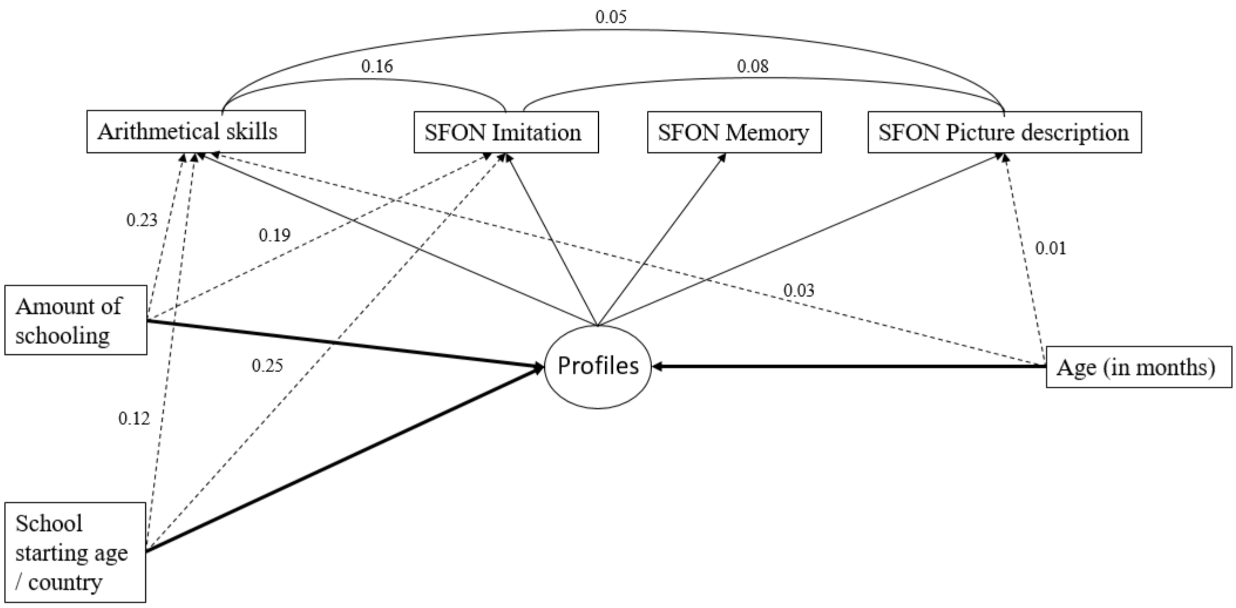

Figure 1. Final latent profile regression model (last model from the hierarchical steps). All presented regression coefficients are significant at $p < 0.001$. School starting age /country refers to the child's school entrance age in years (4, 5, 6, or 7 years of age), and amount of schooling refers to how many years the child had experienced formal schooling at the time of testing (ranging from 0 to 4 years). Age (in months) refers to child's chronological age at the time of testing.

Figure 2 illustrates the estimated means of factor score variables for the six mathematical skill profiles when the covariates age, school starting age / country, and amount of schooling are included in the model. The average posterior probabilities of being assigned to a specific latent profile in the final 6-profile model were 0.90, 0.89, 0.96, 0.91, 0.93, and 0.94, respectively, indicating a clear classification. Profiles were ordered from lowest to highest based on arithmetical skills and SFON imitation. Identified profiles differed both in their mean levels of factor score variables and their shape. There are only factor score mean level differences in arithmetical skill and SFON imitation factors across all profiles, indicating that these two skill factors are highly associated at the person-centered level. Not only quantitative level differences, but also qualitative differences appear in Profiles 2, 3, 4 and 5 in SFON memory and Picture description, suggesting that the tasks requiring verbal responses do not follow the same pattern of individual profile levels as arithmetical and SFON Imitation factor scores.

The lowest profile 1 had lowest mathematical skills in all factor score variables. The second lowest Profile 2 had below average scores in all other mathematical skills except for SFON Picture description, in which they had above average scores. The profile 3 had average mathematical skills in all other factors except for their high SFON Picture description skill while the children in the Profile 4 had average factor scores in all other factors, except for in SFON Picture description, in which they had lower than average scores. The second highest Profile 5 children had above average factor scores in all other measures, except for in the SFON Picture description, in which they were on average. The highest Profile 6 children had highest mathematical skills in all factor score variables.

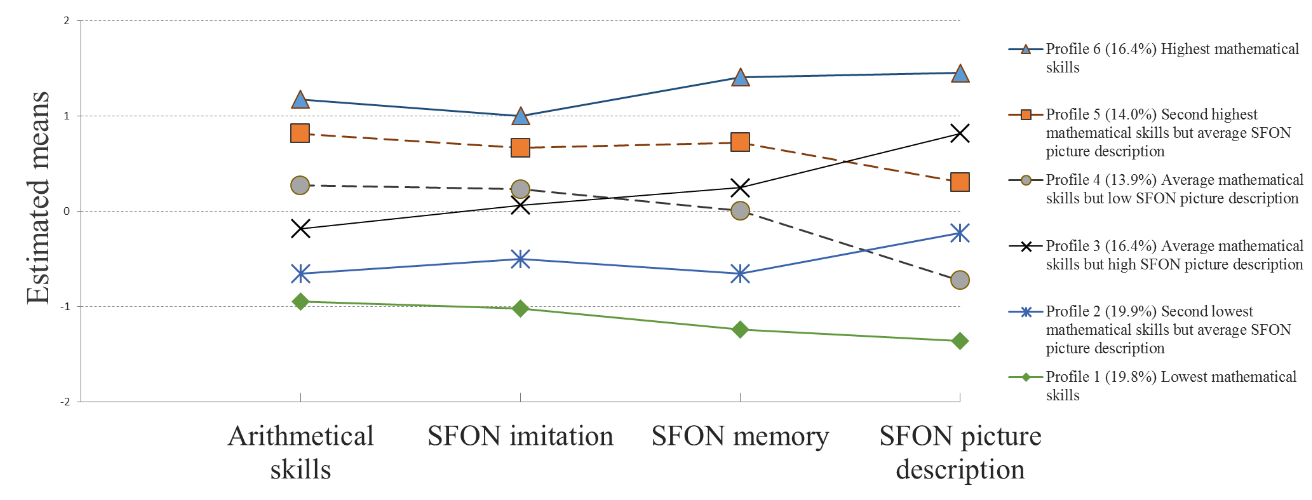

Figure 2. Latent profiles of mathematical factor score variables with covariates age, school starting age / country, and amount of schooling. Percentages represent proportion of the sample in each profile.

3.4 Odds ratios

Odds ratios were computed to investigate the change in odds of membership to different profiles as an effect of each covariate (Figure 3) when all other covariates were controlled for. We chose the Profile 1 – Lowest mathematical skills to be the comparison group and compared the odds of other five profiles in covariates to the odds of this group. Results show that there was a a significant difference in the odds ratios in age when comparing the profile 1 with all other five profiles and significant difference in the odds ratios of amount of schooling when comparing the profile 1 with the profiles 4 and 5. When age increases with one unit, in comparison to profile 1, the odds of belonging to one of the higher-level profiles are significantly higher. For the amount of schooling, the odds of belonging to profile 4 - Average mathematical skills but low SFON picture description [b = -1.060, p = .030, OR = .347 (95% CI: .133, .903)], and profile 5 – Second highest mathematical skills but average SFON picture description [b = -1.061, p = .037, OR = .346 (95% CI: .128, .938)], are significantly lower if the amount of schooling increases with one unit in profile 1. Due to large variation in the school starting age / country and amount of schooling, profile 6 – Highest mathematical skills did not differ significantly from profile 1. For school starting age / country, no significant odds ratio was found.

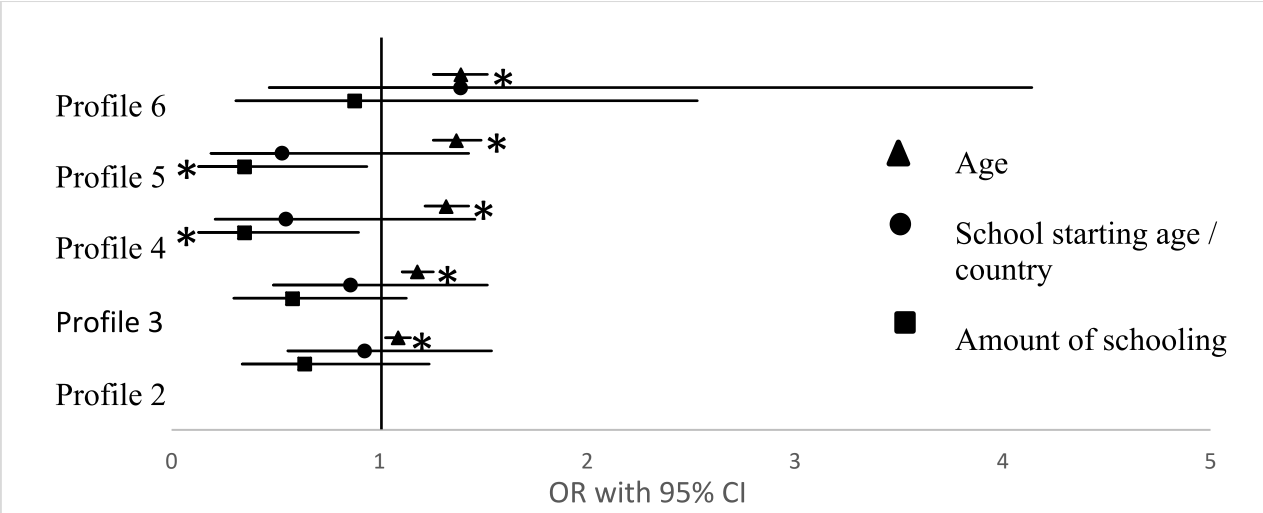

Figure 3. Odds ratios (OR) of age, school starting age / country, and amount of schooling having profile 1 as a reference class. Significant OR are marked with * and 95% confidence intervals are illustrated by the straight lines. OR represent the odds of belonging to a higher profile compared to profile 1 when there is one unit increase in age, school starting age / country, or amount of schooling, when the other two covariates are controlled for. If OR = 1, groups have the same odds ratio.

4. Discussion

In this study, we investigated mathematical skill profiles in relation to their amount of formal schooling. The sample comprised of children who started school within a four-year range in four countries, and thus differed largely also in their years of schooling. Particularly, by using person-centered approach, the aim was to investigate whether the amount of formal schooling is associated with mathematical skills in the same way for all children, or, whether the associations differ according to children's mathematical skill profiles. To build up the profiles, we measured formal mathematical skills, such as digit naming and written and verbal arithmetical skills, with more informal mathematical skill called spontaneous focusing on numerosity (SFON), which is a form of self-initiated mathematical activity leading to differences in mathematical practice (Hannula & Lehtinen, 2005). Having the school entrance age spread across four years offered a unique opportunity to disentangle the effects of country-specific school entrance age, amount of schooling, and chronological age (Herbst & Strawinski, 2016).

Our results showed that years of formal schooling had unique effects on mathematical skill profiles before and after the effects of chronological age and country-specific school entrance age were controlled for. SES was not significantly related to math skill profiles. Differences in the profile levels and shape illustrate both quantitative and qualitative differences in mathematical skill profiles, which confirms the existence of a nonlinear relation between the investigated early mathematical skills and years of schooling (Chew, Forte, & Reeve, 2016). Almost one third of the participants belonged to profiles with variable skill levels across our measurements, thus having: either high arithmetical skills and SFON imitation combined with either low SFON memory card and SFON picture description skills, or low arithmetical skills and SFON imitation combined with high SFON memory card and SFON picture description skills. This is in line with previous research showing task-related variability in SFON (Batchelor, Inglis, & Gilmore, 2015; Rathe et al., 2017).

The multiple comparisons provided by odds ratios suggest that the relationship between schooling years and mathematical skill profiles is negative when school entrance age and chronological age are controlled for, specifically when comparing the lowest level profile with two higher level profiles (profiles 4 and 5, which have above average or average mathematical skills across nearly all factor score variables), so that children have a higher likelihood of belonging to profile 1, the lowest level profile, if they have experienced a larger amount of schooling. This negative association may first seem counterintuitive, but it is similar to typical unique age-related effects in contrast to composite age-effects (Herbst, 2016). Chronological age had strong, positive effects in our model showing that older children have better chances for belonging to profiles with higher levels of sub-skills, thus, controlling for its effects on skill profiles is needed when any other effects are investigated. In this respect, our results of the lowest skill profile are similar to Datar (2006) who shows that younger entrance age for kindergarten negatively affects the economically and cognitively lowest group of the sample. Recognition of the negative association of schooling and specific mathematical skills in a particular sub-group of children adds educationally-relevant knowledge to previous variable-centered research findings, which showed positive educational effects on early numeracy on average level (Bojorque et al., 2016; Hannula, Mattinen & Lehtinen, 2005; Watts et al., 2017). Identifying these kinds of unique associations on sub-populations can be educationally beneficial when dealing with heterogeneous populations (Abenavoli, Greenberg, & Bierman, 2017). Along these lines, the generally positive effects of schooling on mathematical skills that have been found (Kavkler et al., 2000; Luyten, 2006; Wolke et al., 2015) are accompanied by recent research showing that for lower achievers, instructional quality is more strongly related to performance than for high achievers (Crosnoe et al., 2010; Hamre & Pianta, 2005). Our findings raise important questions concerning, first, the differences in nature and quality of our participants' early mathematical support in different educational contexts, such as at day care, in preschool or in school, and, second, the differing effects early formal school start may have for some sub-groups of children. Over-representation of children with more years of formal schooling in the lowest mathematical skill profile could indicate that formal school math settings as they are provided in the countries which start school early is not optimal for early mathematical development. However, and importantly, this effect is rather small, and it needs replications with larger samples and wider set of mathematical skills studied before conclusions concerning school starting age policies can be made.

This study adds to our current knowledge of children's domain-specific attentional skills in relation to formal mathematical skills and formal education. First, the observed similarity in SFON measures within most of the profiles is in line with previous studies showing that there is a more general SFON tendency component across different SFON measures (Gray & Reeve, 2016; Hannula & Lehtinen, 2005; Hannula-Sormunen et al., 2015). However, the factor structure suggested that SFON might be a multidimensional construct, unlike digit naming, verbal and written arithmetic, which formed only one factor. This is in line with a series of studies showing discrepancies between a relatively new picture description task and the original action-based SFON measures (Batchelor et al., 2015; Rathé, et al. 2017). Interestingly, the variation in the means of different profiles across SFON measures was such that the mean level of imitation tasks followed the same pattern as arithmetical skills, while the qualitative differences in the profiles were in the measures requiring verbal responses. Additional research is needed to investigate the potential multidimensional structure of SFON tendency. So far, data has suggested that verbally-based SFON is different from action-based SFON (Batchelor et al., 2015; Rathé et al., 2017). Since SFON Picture description task drives qualitative differences between profiles, it would be worth exploring more closely what aspects of this verbally-based task produce these differential effects. Whether these differences are related to deeper processing requirements for Imitation and Memory Card Game in contrast to SFON Picture description with continuously visible stimuli, need to be further investigated in the future. In Imitation and Memory Card Game SFON tasks the stimuli disappears from sight before the child performs the acts defining his or her focusing aspect. Our study showed for the first time that by adding a verbal SFON measure that requires memory retrieval skills, factor analyses suggested a three-factor structure for SFON while previous studies had been demonstrating differences between verbal and non-verbal tasks (Batchelor, Inglis & Gilmore, 2015; Rathé et al., 2017).

4.1. Limitations

The analyses of the effects of age, school starting age / country, and amount of schooling on mathematical profiles were limited by the cross-sectional design of our study, even though the sample covering different school entrance ages across same-aged children also allows for the exploration of these effects. Longitudinal data would be required to explore the developmental trajectories of mathematical profiles, and experimental designs to draw conclusions on causality between covariates and mathematical development. Importantly, our study focused on a rather limited set of formal and informal mathematical measures, thus any generalizing to a broader mathematical achievement should be done cautiously. There were no measures of verbal skills, working memory or inhibitory control, which could affect the association of formal schooling and mathematical skills. For instance, Welsh et al. (2010) showed that working memory and attention control predicted growth in numeracy skills between 4 and 6 years of age. However, Gray and Reeve (2016) showed that patterns of strength and weaknesses in mathematical skill profiles in preschoolers are mostly related to domain-specific abilities such as numerical distance effect and SFON, while general cognitive skills (working memory, response inhibition, attention, and vocabulary) do not differ between profiles.

In addition, this study investigated only how the amount of formal schooling, in years, and school entrance age is related to mathematical skill profiles while chronological age was controlled for. Equally important would be to study the content and quality of mathematics education in different educational settings. This remains to be investigated in future research. We utilized standardized means in the analyses. Therefore, the identified profiles can only be compared with the average skill level in the present sample. In addition, age groups in each school starting age / country were rather small and came from middle-SES areas, thus more representative, larger samples as well as measures of other developmentally important and academic skills would be required for drawing conclusions that policy makers could use in deciding about school entrance age policies. However, current study demonstrates how, potentially, person-centered approach with its focus on individual skill profiles can shed light on differing educational effects of school starting age policies.

The countries were purposely selected so that participants would differ in school entrance age but would have relatively similar, middle-SES western European backgrounds. Previous cross-cultural comparisons of early mathematical skills typically showed similar early mathematical skills when comparing children from countries with similar cultural backgrounds (Aunio, Korhonen, Bashash, & Khoshbakht, 2014; Van de Rijt et al., 2003). Our selection of the sample allowed us to identify the effect of formal schooling on mathematical skill profiles. Our sample comes from four different countries, three languages, and spreads across four years in age, which all improve generalizability of the profiles of formal and informal mathematical skills. However, we were not able to gather more specific information about the educational settings.

4.2 Conclusions and Future Directions

The person-centered approach adopted in this study demonstrated that children's amount of formal schooling have unique effects on their mathematical skill profiles when controlling for chronological age and school starting age / country. Educational implications of the findings emphasize the heterogeneity in mathematical skills across sub-groups of children, as well as the need to address these individual differences in the assessment and support of early mathematical development. Is earlier formal mathematics instruction the best option to develop arithmetical skills and SFON tendencies, as well as other mathematical skills, for all children, particularly those with the lowest mathematical skill profile? This is an exciting and important question for future studies focusing on the elements of different early learning environments. These studies should clarify what kind of educational arrangements would optimally support mathematical development in the early years.

Keypoints

- Latent profile regression model was used to study schooling effects
- Cross-sectional sample from 4 countries with different school entrance ages enabled investigation
- Arithmetical skills and spontaneous focusing on numerosity formed skill profiles
- Amount of schooling has unique, and differing effect on math skill profiles
- Specifically lowest math skill profile was related to negative schooling effect

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Appendix A

Fit indices for exploratory factor models of the mathematical skills

	χ^2	*df*	CFI	TLI	RMSEA
1 Factor	1052.34*	104	0.817	0.789	.12
2 Factors	580.02*	89	0.905	0.872	.09
3 Factors	262.98*	75	0.964	0.942	.06
4 Factors	67.97*	62	0.999	0.998	.01
5 Factors	48.68	50	1.000	1.001	.00
6 Factors	33.28	39	1.000	1.003	.00

Note. χ^2 = chi square goodness of fit statistic; *df* = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker Lewis Index; RMSEA = Root-Mean-Square Error of Approximation; * Indicates χ^2 is statistically significant.

Summary of exploratory factor loadings

	Factor Loadings			
Item	Arithmetical skills	SFON Imitation	SFON Memory	SFON Picture description
Digit naming	**.90**	-.03	.02	-.03
Verbal arithmetical skills with comprehension support	**.70**	.07	.05	.07
Verbal arithmetical skills	**.94**	-.01	-.07	.03
Written arithmetical skills	**.80**	.07	.07	-.01
SFON bird imitation task– trial 1	.07	**.80**	-.05	.07
SFON bird imitation task – trial 2	-.04	**.80**	.07	.05
SFON bird imitation task – trial 3	.07	**.76**	-.03	.05
SFON Post box task – trial 1	-.01	**.87**	-.06	-.02
SFON Post box task – trial 2	-.04	**.72**	.14	-.06
SFON Post box task – trial 3	.19	**.64**	.07	-.03
SFON memory card game – trial 1	-.06	.01	**.83**	.05
SFON memory card game – trial 2	.17	-.03	**.81**	.01
SFON memory card game – trial 3	.10	.08	**.70**	.01
SFON picture description task – trial 1	.16	.09	.08	**.83**
SFON picture description task – trial 2	.01	.06	.08	**.81**
SFON picture description task – trial 3	-.01	-.05	-.03	**.70**

Note. Factor loadings over .40 appear in bold.