Early Mathematical Skill Profiles of Prematurely and Full-term Born Children

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Abstract

Preterm birth is associated with low mathematical skills in children. This study on five-year-old Finnish children investigated whether mathematical skill profiles would differ between prematurely and full-term born children and how such profiles and other cognitive skills would be related. Mathematical skills included digit knowledge, spontaneous focusing on numerosity, arithmetic, counting and geometric skills. The investigated cognitive skills were phonological processing, working memory, instruction comprehension, speeded naming, inhibition and visuomotor skills. The participants were 119 preterm children with birth weight less than 1501 g and 100 full-term born children with normal birth weight. The results of latent profile analyses showed that preterm and full-term born children differed in both number and shape of latent mathematical skill profiles, indicating quantitative and qualitative disparities. After controlling for birth weight or gestational age, maternal education, and other cognitive skills phonological processing, visuospatial working memory and speeded naming were uniquely associated with prematurely born children’s five mathematical profiles. In full-term born children, only verbal working memory was related to their four mathematical profiles.

Keywords: prematurely born; VLBW; early mathematical skills; spontaneous focusing on numerosity; cogntive skills

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1. Introduction

Advances in medical care favour increasing survival rates of children who are born preterm or with a very low birth weight (VLBW) (Zeitlin et al., 2013). A recent action report involving 184 countries shows that more than one out of 10 babies are born preterm, and preterm birth rates are rising in most of these countries (Blencowe et al., 2013). In addition to the increased risk of severe disabilities, many of these children have neurodevelopmental problems that are reflected in persistently lower academic achievement. Specifically, when comparing prematurely and full-term born children in various academic areas, the largest difference has been found in mathematics (Aarnoudse-Moens, Smidts, Oosterlaan, Duivenvoorden, & Weisglas-Kuperus, 2009). Despite increasing research on prematurely born children’s mathematical skills at a general level, little is known about the variability of mathematical skill profiles in this population or how domain-general cognitive skills are related to different strengths and weaknesses in their mathematical skills. Furthermore, most studies have investigated prematurely born children’s mathematical skills only during formal schooling. This is problematic since early intervention before school entry would be the most effective way to prevent specific problems in mathematical development, and a better understanding of the unique issues of this population would aid in developing diagnostic tools for the recognition of at-risk children and designing targeted, early mathematical interventions. The current study aims to fill these knowledge gaps concerning VLBW prematurely born children’s mathematical skill profiles and their cognitive correlates well before formal schooling.

1.1. Mathematical Skills and other Cognitive Skills – Evidence from Research on Prematurely Born Children

Several studies have reported prematurely born and/or VLBW children's lower performance in mathematics, which could not be exclusively explained by general cognitive functioning indicated by the intelligence quotient (IQ) (Guarini et al., 2014; Johnson, Wolke, Hennessy, & Marlow, 2011; Simms et al., 2015; Taylor, Espy, & Anderson, 2009) or by serious neurocognitive impairments (Grunau, Whitfield, & Fay, 2004; Jaekel & Wolke, 2014; Johnson et al., 2011; Pritchard et al., 2009). It has been suggested that mathematical difficulties of prematurely born children are related to subtle cognitive deficiencies (Simms et al., 2013; Taylor et al., 2009), such as visuospatial processing (Geldof, van Wassenaer, de Kieviet, Kok, & Oosterlaan, 2012; Johnson et al., 2011) and perceptual motor abilities (Verkerk, Jeukens-Visser, van Wassenaer-Leemhuis, Kok, & Nollet, 2013), and executive functions, such as processing speed and working memory (Mulder, Pitchford, & Marlow, 2010; Rose, Feldman, & Jankowski, 2011). Birth weight was a robust predictor of calculation and problem solving in early school years (Espy et al. 2009).

Cross-sectional findings on the relations between prematurely born and/or VLBW children's mathematical and other cognitive skills have been confirmed by longitudinal studies, which indicate that their mathematical skills at school age are predicted by preschool, general cognitive skills such as IQ, perceptual motor skills and phonological processing (Breslau, Johnson, & Lucia, 2001; Johnson et al., 2011), motor performance (Sullivan & McGrath, 2003), global cognitive functioning and visuospatial processing skills (Assel, Landry, Swank, & Steelman, 2003; Johnson et al., 2011).

In these previous studies, all mathematical skills were measured when the children were already enrolled in formal education. Only a few studies on prematurely born and/or VLBW children have examined how different domain-general cognitive skills were related to mathematical skills before school. Espy and colleagues (2004) studied the relation between pre-schoolers' mathematical skills and executive functions in a sample of both full-term and preterm born children. Working memory and inhibition were related to a mathematical composite score after controlling for maternal education and child vocabulary (Espy et al., 2004). In a nationally representative panel study involving over 10,000 four-year-old children**,** late preterm children had significantly lower composite scores than their full-term born peers in terms of mathematical skills covering number sense, counting, operations, geometry and pattern recognition, even after controlling for parents' education, socioeconomic status and complications at birth (Nepomnyaschy, Hegyi, Ostfeld, & Reichman, 2012). In an Austrian sample, five-year-old prematurely born children scored significantly lower in numerical skills than their full-term peers (Kiechl-Kohlendorfer, Ralser, Pupp Peglow, Pehboeck-Walser, & Fussenegger, 2013). Among prematurely born children, 20% had numerical skill deficits; half of them also had a global cognitive deficit.

Altogether, these research studies pinpoint early childhood as a period when prematurity already affects mathematical skills, even if children's cognitive development is within the normal range. This effect is higher for children with lower socioeconomic status and lower gestational age and seems consistent across cohorts born decades apart (Nepomnyaschy et al., 2012; Wolke et al., 2014). This emphasises the need for a deeper understanding of prematurely born children's mathematical and other cognitive skills before school age so that effective early interventions could be developed.

1.2. Early mathematical skills

Mathematical knowledge develops in a cumulative manner, and both informal and formal numerical and basic geometrical skills constitute the foundation of formal mathematical skills (e.g., Clements & Sarama, 2009). Ample studies show counting skills as particularly significant predictors of later mathematical skills when children enter school (Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Koponen, Salmi, Eklund, & Aro, 2013; LeFevre et al., 2010; Martin, Cirino, Sharp, & Barnes, 2014). Before school age, children typically learn to produce an increasingly long list of number words, are able to use the number word sequence for determining the cardinality of a set of items by counting objects one at a time, and can solve simple arithmetical tasks based on their understanding of numbers (e.g., Fuson, 1988). Five principles govern and define counting of objects, as follows: one to one, stable-order, cardinal, abstraction and order-irrelevance principles (Gelman & Gallistel, 1978). These object-counting skills form the basis for connecting numerical magnitudes with number words and are thus developmentally important. The verbal number sequence elaboration skills include counting accurately forward and backward from a given number (for a review, see Fuson, 1988). Number sequence elaboration skills before school age are related to arithmetical skills measured concurrently (Fuson, Richards, & Briars, 1982; Johansson, 2005) and several years later in school (Hannula-Sormunen et al., 2015; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Lepola, Niemi, Kuikka, & Hannula, 2005). Arithmetical story problems are used for assessing contextualised numerical knowledge and skills (Jordan et al., 2007), and they are widely applied in mathematics education (Clements & Sarama, 2009). In addition to verbal number skills, learning written number symbols has been linked to later success in arithmetical skills (Baker et al., 2002; Purpura et al., 2013).

Hannula and Lehtinen (2005) demonstrated that the development of counting skills from the age of three to six years was facilitated by self-initiated practice produced by children's spontaneous focusing on numerosity (SFON). The SFON refers to a separate attentional process, whereby persons spontaneously (i.e., self-initiated, not prompted by others) focus their attention on the exact number of a set of items or incidents and use this numerosity information in their action (Hannula & Lehtinen, 2005; Hannula, Lepola, & Lehtinen, 2010). The SFON tendency indicates the amount of a person's spontaneous practice of using exact enumeration in her or his natural surroundings (Hannula, Mattinen, & Lehtinen, 2005). Individual differences in children's SFON have been demonstrated to be positively and domain specifically related to mathematical skills before school age and from kindergarten to much later in primary school (Batchelor, Inglis, & Gilmore, 2015; Hannula-Sormunen et al., 2015; Hannula, Lepola, & Lehtinen, 2010; Hannula, Rasanen, & Lehtinen, 2007). Studies about prematurely born children's SFON tendency have not yet been published. Considering the evidence on SFON's significant role in early numeracy, it would be important to include SFON as one of the investigated mathematical subskills in the study.

Young children can identify basic geometric forms although they still struggle with integrating distance and angle information (Dillon et al., 2013; Izard & Spelke, 2009; Spelke, 2011). Commonly found among prematurely born children, impaired capacity in spatial reasoning (Geldof et al., 2012; Goyen, Lui, & Woods, 1998) could be related to difficulties with geometry, a less investigated mathematical domain among prematurely born children in preschool age.

1.3. Research Context and Aims

To our best knowledge, this research is the first to use a person-centred approach, i.e., multigroup latent profile analyses (Bergman & El-khouri, 2003; Taylor et al., 2009) to examine prematurely and full-term born children's mathematical skill profiles across a wide range of mathematical skills in preschool age. This kind of approach is needed since prematurely born children may form a heterogenic group, and it is unknown whether separate mathematical subskills forming various skill profiles differ from full-term born children's profiles. Some indications towards this hypotheses came from a longitudinal study investigating prematurely born children with and without school problems, which brought evidence that these children could follow different developmental pathways compared to full-term born children (Van Baar, Ultee, Gunning, Soepatmi, & De Leeuw, 2006).

The general cognitive variables measured in this study were based on the theoretical frameworks of Krajewski and Schneider (2009) and LeFevre and colleagues (2010), who documented the unique contributions of linguistic, spatial and quantitative abilities to early mathematics, such as enumeration, calculation, measurement and geometry. This study also referred to the work of Geary (1993), who proposed that visuospatial ability, semantic memory and executive processing contribute to mathematical performance.

Altogether, existing studies have given information about how different cognitive skills are related to mathematical skills of prematurely born children. Nearly nothing is known about whether these children form mathematical skill profiles that differ from those of full-term born children and how these different profiles are related to disparities in other cognitive skills. Our study aimed to fill this knowledge gap by using a person-oriented approach to analyse whether prematurely born children would form unique mathematical skill profiles that would qualitatively (i.e., differences in the shape or the number of profiles) or quantitatively (i.e., differences in prevalence) differ from those of full-term born children. This study intended also to explore the mathematical profiles of these two groups of children at the age of five, in relation to general cognitive abilities and maternal education. It aimed to answer the following research questions: (1) What are the kinds of quantitative and qualitative differences between the mathematical skill profiles of five-year-old, prematurely and full-term born children? (2) How are general cognitive skills, maternal education related to the mathematical skills of prematurely and full-term born children? Additionally, how are neonatal characteristics and perinatal medical treatments related to the mathematical skill profiles of prematurely born children?

2. Methods

2.1. Participants

This study is part of a regional and multidisciplinary, longitudinal research project called PIPARI ("Development and functioning of very low birth weight infants from infancy to school age"). The study sample consisted of 119 prematurely born children born in 2002–2003 at Turku University Hospital. The participants' birth weight was less than 1,501 g and their gestational age was less than 37 weeks (n=107), or less than 32 weeks (n=12). They belonged to a Finnish-speaking family residing in the hospital catchment area. Infants with severe congenital anomalies, IQ scores lower than 70 or diagnosed syndromes affecting their development were excluded. A control group of 100 healthy full-term infants born in 2002–2003 in the same hospital was recruited for the study by asking for the participation of the first healthy boy and the first healthy girl born on each week. The inclusion criteria for the control group were (1) birth weight > -2.0 *SD* according to the age- and gender-specific Finnish growth charts, and gestational age ≥ 37 weeks at birth, (2) no admission to neonatal care during the first week of life, (3) a Finnish-speaking family residing in the hospital catchment area. The exclusion criteria were (1) a congenital anomaly or syndrome, (2) a self-reported maternal use of illicit drugs or alcohol during the pregnancy and (3) birth weight ≤ -2.0 *SD* (less for gestational age according to age- and gender-specific Finnish growth charts).

Table 1 presents background variables of medical history, maternal education and IQ across prematurely and full term born samples.

Table 1
The Neonatal Characteristics, Maternal Education and IQ of Prematurely and Full-term Born Children

	Prematurely born *n* = 119	Full-term born *n* = 100
	M (SD)	*M (SD)*
Medical history		
Multiple birth (%)	70 (58.8)	-
Birth by C-section (%)	50 (42)	17 (17)
Birth weight (g) mean (*SD*) [min, max]	1140 (332.47) [485, 1970]	3666 (451.61) [2850, 4980]
Gestational age (weeks) mean (*SD*) [min, max]	29.19 (2.64) [23.86, 35.29]	40.15 (1.17) [37.29, 42.29]
SGA[1] mean (*SD*) [min, max]	-1.46 (1.32) [-4.4, 1.3]	0.06 (0.93) [-1.9, 2.8]
Female *n* (%)	49 (41.2)	52 (52.5)
Ductal ligation surgery (%)	16 (13.4)	-
Intestinal perforation (NEC included) (%)	3 (2.5)	-
Bronchopulmonary dysplasia[2] (BPD), (%)	19 (16.4)	-
Brain pathology in MRI[a] [3] (%)		
normal	62 (53)	-
minor	20 (17.1)	-
major	35 (29.9)	-
Vision not normal at 30 months[4] (%)	3 (2.6)	-
Maternal education[5]		
up to 12 years of education	41 (35.3%)	38 (38.8%)
12 or more years of education	75 (64.7%)	60 (61.2%)
IQ	101.53 (15.65)	111.51 (13.84)

Note. BPD is defined as supplemental oxygen at 36 weeks corrected age. SGA is defined as the difference of birth weight to the age and gender specific Finnish growth charts. [a]MRI pathology, see Munck et al. (2010). Missing data[1] 1 in prematurely born sample, [2] 3, [3] 2, [4] 3, [5] 9 in prematurely born sample and 2 in full term born sample.

2.2. Procedures

Written consent was obtained from all the parents after they were given oral and written information. The PIPARI study protocol was approved by the Ethics Review Committee of the Hospital District of Southwest Finland. The participants were assessed at five years of chronological age (+0–2 months) in two sessions in a separate room of a research unit in the hospital area. In the first session, the children completed the SFON tasks, numerosity tasks and the tasks on the Developmental Neuropsychological Assessment (NEPSY) subtests (Korkman, Kirk, & Kemp, 2008) in the following order: SFON imitation bird phonological processing, SFON back bag, counting of disarranged objects, comprehension of instruction, number sequence production and elaboration, speeded naming, recognition of number symbols, verbal working memory, inhibition, visuospatial working memory, visuomotor skills and design copy. In the second session, the children completed the Wechsler Preschool and Primary Scale of Intelligence – Revised (WPPSI–R) arithmetic and geometry subtests. Short breaks were provided between tasks as necessary. Parents filled in information regarding the length of maternal education.

2.2.1. Measures of Mathematical Skills

2.2.1.1. SFON imitation tasks. Each child's spontaneous focusing of attention on the exact number of a set of items was measured by two imitation tasks – the parrot and the back bag – modified from (Hannula and Lehtinen (2005). The SFON assessment was based on structured observations. Before the assessment, the experimenters were fully trained in testing and strategy observation procedures with videotaped test sessions and subsequent checking sessions throughout the testing period. When presenting the SFON tasks, the experimenters did not use any phrase that could have suggested the tasks as somehow mathematical or quantitative. The tasks included only very small numerosities, which all children could handle.

All 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 and/or the head, (d) other comments referring either to 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 accurate number of them") were identified. The child was scored as focusing on numbers if she or he produced the correct numerosity and/or was observed presenting any of the mentioned (a–e) quantifying acts. The scoring was based on analyses of video-recorded task situations. The maximum score for both SFON tasks was four. Due to the high correlation between the two tasks (0.79), the mean score was used for further analyses.

In the parrot imitation task (Hannula & Lehtinen, 2005), the materials were a blue toy parrot (capable of swallowing, placed on the table, in front of the child) and a plate of red glass berries (1 cm in diameter) placed in front of the parrot. The experimenter started the task by introducing the materials and then said, "Watch carefully what I do, and then you do just like I did". The experimenter put two berries one at a time into the parrot's mouth, and these dropped with a bumping sound into the parrot's stomach. Next, the child was told, "Now you do exactly like I did". The following trials included one, two and one berries. Cronbach's alpha for this task was 0.93.

In the back bag imitation task (modified from Hannula & Lehtinen, 2005), the materials were an empty blue bag and a basket of eight plastic, natural-sized oranges and eight pears. The tester sat opposite the child and held the bag open on his or her lap. The basket of fruits was placed on the table. The tester took two pears one at a time and put them into the back bag without letting the child see inside the bag while saying, "Let's play going outdoors and packing the back bag. Look carefully what I do. Then, you do it just like I did. Look, I do it. Now, please do it just like I did". After the child had imitated the tester, no feedback was given, and all fruits were returned to the basket. The second trial included the tester putting one orange into the back bag. The third trial was done similarly with a red back bag, eight tomatoes and eight lemons in a different basket; the tester put two tomatoes (third trial) and one lemon (fourth trial) into the back bag. The maximum score for the task was four. Cronbach's alpha for this task was 0.97.

2.2.1.3. Counting skills. Three tasks were used to measure the child's ability to count, as follows: counting of disarranged objects, number sequence production and number sequence elaboration. The composite score was calculated from the mean of three standardised scores and used for further analysis.

Object-counting skills were measured by asking the child to carefully count aloud how many objects there were on the table. These randomly set movable objects were pictures painted on wood (each about 3.4 cm in diameter). The sets of objects of the same kind were presented in the order of 3, 5, 7, 9, 13, 19 and 23. The highest number that was counted accurately determined the child's performance level. The counting was interpreted as accurate if the child said all the necessary number words in the right order, pointed once to every countable object and did not violate the one-to-one correspondence between number words and pointing. Counting without pointing was considered accurate if the child's number word sequence and cardinal number word were accurate. The maximum score for the task was 23, and Cronbach's alpha was 0.69.

The skill in developing a number word sequence was determined by the highest number that the child could accurately count aloud from one up, in one of two trials. The child's counting was stopped at 50, the maximum score for the task. Number sequence elaboration or the ability to produce breakable chains of numbers, starting from different given numbers, both upward and downward, was measured by a modified version of Salonen and colleagues' (1994) test. The child was asked to count forward from 3, 8, 12 to 19 and to count backward from 4, 8, 12 to 19. The child's counting was stopped after four counted number words. The maximum score for the task was 16, and Cronbach's alpha was 0.91.

2.2.1.4. Digit knowledge. Recognition of number symbols was measured by the Test of Early Mathematics Ability (TEMA 3) for digit knowledge (Ginsburg & Baroody, 2003). The child was asked to name 15 different, visually presented Arabic numerals, varying from one to four digits. One point was given for each correctly named digit, providing the maximum score of 15. Cronbach's alpha was 0.86.

2.2.1.5. Arithmetic skills. Arithmetic skills were measured by using the verbal arithmetic subtest of the WPPSI–R, Finnish translation (Wechsler, 1995). A sample item of the task was as follows: "Juha has three balls, and he loses one of them. How many does he have left?"

2.2.1.6. Geometry skills. Basic geometry facts were measured by using the geometry subtest of the WPPSI–R and the design copy subtest from the Finnish NEPSY-II (second edition) (Korkman et al., 2008). In the design copy subtest, the child had to copy two-dimensional geometric figures, which were displayed one at a time. Only items 1–11 were included.

2.2.2. Measures of Domain-general Cognitive Skills

The standardisation edition of the Finnish NEPSY-II (Korkman et al., 2008) was used. Because the scoring instructions from the NEPSY II were not yet finalised at the time of our study, the administration and scoring rules differed slightly from those of the published test versions. These differences are mentioned below.

2.2.2.1. Phonological processing. This was assessed with a phonological awareness task. In the first part, the child was asked to identify spoken words from word segments. In the second part, the child was asked first to repeat a word and then to utter a new word by omitting or substituting a syllable or a phoneme.

2.2.2.2. Verbal working memory. This was measured with a word list interference task. The child listened to pairs of word series, progressing from short to longer series. For each pair, the child had to repeat the first series of words immediately after it was presented, and then the second series of words after it was presented. Finally, both series of words had to be repeated in the order of the presentation. This test used the total recall score.

2.2.2.3. Comprehension of instruction. This subtest assessed the ability to receive and process oral instructions of increasing syntactic complexity. The test material consisted of a sheet with rabbits or circles and crosses in different colours. The child was presented with a sequence of figures, for instance, and asked to point to appropriate stimuli in the appropriate order.

2.2.2.4. Speeded naming. This subtest assessed the speed and accuracy of the child's semantic access to over-learned items. The child was asked to name arrays of figures according to their colours, shapes and sizes as quickly as possible. The size/colour/shape naming condition for children from the age of seven and up was administered in this study, but the scoring was more lenient than in the final NEPSY-II version. For instance, the child was allowed to use the word "ball" in addition to "circle". This test used the combined norm score.

2.2.2.5. Inhibition. This subtest assessed the ability to inhibit automatic responses. In the first part, the child was asked to look at a series of black and white shapes and to name them as fast as possible. In the second part, the child should name them in an alternate way as fast as possible, saying “circle” for “square” and “square” for “circle”. Both time and correct answers were combined to form a composite score.

2.2.2.6. Visuospatial working memory. This was measured with a memory-for-design subtest. The child was shown a series of non-figure designs placed on a grid. After each presentation, they were removed from view, and the child was asked to select the appropriate designs from a set of cards and to place them on an empty grid in the same location as was shown. The child was not penalised for putting too many cards but was instructed on how many cards should be placed on the grid.

2.2.2.7. Visuomotor skills. These were measured with a visuomotor precision subtest that assessed graphomotor skills and accuracy. The child had to draw a line inside a curvilinear track representing the route of a car. Only the car track item was used. This test used the combined norm score.

2.2.2.8. Maternal education. The length of maternal education was grouped into two categories – less than 12 years and 12 or more years of education – based on the mothers' self-reported data when the children were born.

2.3. Analytical Strategy

Mathematical skills were standardised according to the full term born group. For cognitive skills, norm scores of the tests were used. The latent profile analysis (LPA) was used to identify groups of children with homogeneous mathematical profiles (i.e., LPA and mixture modelling; Magidson & Vermunt, 2002; Nylund, Asparouhov, & Muthén, 2007). The LPA integrates the information from different quantitative continuous measurements into latent variables that describe the mean profiles and allow identifying groups of individuals who can be characterised by the same profile (Kiuru et al., 2012). It is a probabilistic method of estimating the least number of latent profiles needed to effectively group the participants. Different models were explored, starting from one latent profile.

The models were evaluated through a combination of statistical indicators to identify the best-fitting model. The Vuong Lo Mendell Rubin likelihood ratio test (VLMR) and the Bootstrap likelihood ratio test (BLRT) were carried out to support the *k*-profile solution in comparison with the *k* – 1-profile solution so that a significant result would suggest the superiority of a model over the model with one less profile in it. A better fit would be indicated by low values for the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Individuals are assigned to latent profiles based on their maximum probability of membership. The quality of classification is represented by the average posterior probabilities of being assigned to a specific latent profile and by the entropy value, which varies between zero and one. Values approaching one indicate an accurate profile membership with a high probability of belonging to a specific profile and very low probabilities of belonging to other profiles. We also considered the interpretability of the profiles to ensure that the profiles would make theoretical sense. For reasons of parsimony, solutions with too many latent profiles or unstable solutions were avoided. To investigate whether prematurely born children would form different mathematical profiles than full-term born children, a multigroup LPA (MGLPA) was performed (see e.g., Collins & Lanza, 2010; Morin, Meyer, Creusier, & Biétry, 2015). Based on the sequence of steps proposed by Morin and colleagues (2015), first, configural similarity was determined by exploring whether the same number of profiles could be identified across samples. If confirmed, subsequent tests of similarity concerning the profile means and prevalence were used to investigate the nature of the differences in mathematical profiles between prematurely and full-term born children. The LPA model was estimated separately for each group, with and without equality constraints concerning the means of the profiles. The estimated models were compared by using the Satorra–Bentler (S–B) chi-square difference test (Satorra & Bentler, 2001).

Finally, multinomial logistic regression was used to explore the unique association of maternal education, neonatal characteristics, perinatal medical treatments and cognitive skills with mathematical profiles. In these analyses, latent profile membership was predicted with the background variables. Multinomial logistic regression would provide the odds of a child being assigned to one latent profile versus another based on the cognitive variables measured. Multinomial logistic regression coefficients were estimated with the IBM SPSS (version 22.0) software, which allowed the investigation of unique effects while controlling for other variables. In a series of analyses, all profiles were compared hierarchically with one another by using lower group as the reference.

3. Results

3.1. Multigroup Latent Profile Analysis (MGLMPA)

The first research question intended to identify mathematical skill profiles in a sample of prematurely and full-term born, five-year-old children, as well as to explore if the number, shape and prevalence of latent profiles would differ across the two samples. First, we identified the best-fitting model for the whole sample. Table 2 presents the fit indices and group frequencies for compared LPA solutions. The comparison of different solutions suggested that according to the information criteria and the BLRT, both 3-profile and 4-profile solutions fitted the data well. In turn, the VLMR indicated that the fourth profile was not needed. Moreover, the BIC slope flattened after the 3-profile solution, signifying that it was optimal for this data. Because the fourth profile did not provide a notable additional value from the content perspective (i.e., some profiles were rather similar), making it irrelevant to be analysed in relation to distal outcomes, and the sample size of some profiles became small (likely too small for a subsequent multigroup analysis), we chose the 3-profile solution as the final model for parsimony reasons. The average individual posterior probabilities of being assigned to a specific latent profile in the 3-profile model were 0.961, 0.929 and 0.964, respectively, indicating a clear classification.

Table 2

Fit Measures of the 1-, 2-, 3- and 4-Latent Profile Models for Mathematical Measures

Number of profiles (sample sizes per profile)	*N* = 219				
	AIC	BIC	Entropy	VLMR (*p*)	BLRT (*p*)
1 (219)	3004.01	3037.90	-	-	-
2 (136; 83)	2737.75	2791.97	0.81	0.439	< 0.001
3 (108; 84; 27)	**2620.63**	**2695.19**	**0.89**	**<0.001**	**< 0.001**
4 (68; 81; 34; 36)	2542.43	2637.33	0.89	0.332	< 0.001
5 [a]					

[a]Unstable solution

In the second step, the MGLPA was used to test whether the similarity in the shape of the profiles would be maintained between the samples of prematurely and full-term born children. Meeting this assumption would be needed to further investigate prematurely and full-term born children as one sample in the LPA and/or to compare the quantitative differences of them. The 3-profile model was next fitted both for prematurely and full-term born children, and the model similarity analysis was conducted (see e.g., Collins & Lanza, 2010). The unconstrained MGLPA model and the MGLPA model with equality constraints regarding the mean values of mathematical skill variables were estimated and compared in terms of goodness-of-fit. The prevalence values were freely estimated. In the constrained model, it was assumed that the shapes of the profiles would be invariant between the preterm and full-term children, whereas the number of preterm and full-term children (i.e., prevalence) in different profiles was allowed to differ. The model with three latent profiles being equal between the groups of prematurely and full-term born children was not supported (S-B $\Delta\chi^2(15) = 79.84$, $p < 0.001$), implying that the nature of the mean profiles was different between the groups. Therefore, the profiles were not generalised between the groups, suggesting that in addition to possible quantitative differences group differences were qualitative in nature. Partial measurement similarity was also examined by testing the potential hypothesis that mean levels would differ between the prematurely and full-term born children in some variables, but partial similarity was not supported. Thus, it was concluded that the latent mean profiles of mathematical skills were different between the prematurely and full-term born groups, confirming the qualitative nature of these differences. Therefore, potential differences in profile prevalence could not be directly explored, and further analyses were carried out separately for prematurely and full-term born children.

3.2. Prematurely Born VLBW Children

3.2.1. Latent profile analysis. Table 3 illustrates the fit indices for all LPA solutions for prematurely born children. Although the minimum BIC and AIC were not found, the 5-profile model was supported by the VLMR LRT. Furthermore, the 5-profile model provided a theoretical advantage over the other models since it was able to differentiate between the children in terms of both profile shape and profile level (Marsh, Lüdtke, Trautwein, & Morin, 2009). The five profiles comprised $n = 38$ (31.9%), $n = 35$ (29.4%), $n = 14$ (11.7%), $n = 25$ (21%) and $n = 7$ (5.8%) children, respectively. The average individual posterior probabilities of being assigned to a specific latent profile in the 5-profile model were 0.970, 0.990, 0.941, 0.946 and 0.989, respectively, indicating a clear classification.

Table 3
Fit Measures of the 2-, 3-, 4-, 5-, and 6-Latent Profile Models for Mathematical Measures (Prematurely Born Children)

Number of profiles (sample sizes per	$N = 119$

profile)	AIC	BIC	Entropy	VLMR LRT (*p*)	BLRT (*p*)
1 (119)	1580.16	1607.95	-	-	-
2 (75; 44)	1442.74	1487.21	0.89	0.001	< 0.001
3 (70; 41; 8)	1385.01	1446.15	0.91	0.001	< 0.001
4 (15; 40; 51; 13)	1331.39	1409.20	0.95	0.277	< 0.001
5 (38; 35; 14; 25; 7)	**1286.61**	**1381.10**	**0.94**	**0.035**	**< 0.001**
6 (36; 27; 15; 13; 21; 7)	1246.38	1357.55	0.95	0.556	< 0.001
7 [a]					

[a] Unstable solution

Figure 1 presents an overview of the profiles, based on mean values (see details of profile differences in Appendix 1). Profile 1 *Low mathematical skills* gathered 32% of the prematurely born children, who had low mathematical scores in all measured variables. Profile 2 *Low mathematical skills with high SFON*, had a comparable percentage of children (29.4%) who had low scores in arithmetic, counting and geometry but above average SFON. Multiple comparisons by using the Bolck, Croon and Hagernaas procedure (Bolck, Croon &Hagenaars, 2004) revealed that SFON and geometry scores of children in profile 1 were significantly lower than those in profile 2. Around 12% of the prematurely born children were grouped into a highly variable skill profile 3 *Average mathematical skills, high digit knowledge with low SFON.* Profile 4 *Above or average mathematical skills* comprised 21% of the children and registered above average scores in all mathematical measurements. Profile 3 outperformed profile 4 in digit knowledge while in contrast in SFON profile 4 outperformed profile 3.

Only 6% of the prematurely born children belonged to profile 5 *High mathematical skills* with significantly higher scores in arithmetic, digit knowledge and counting skills than other profiles. This profile had equal SFON and geometry skills with two other profiles.

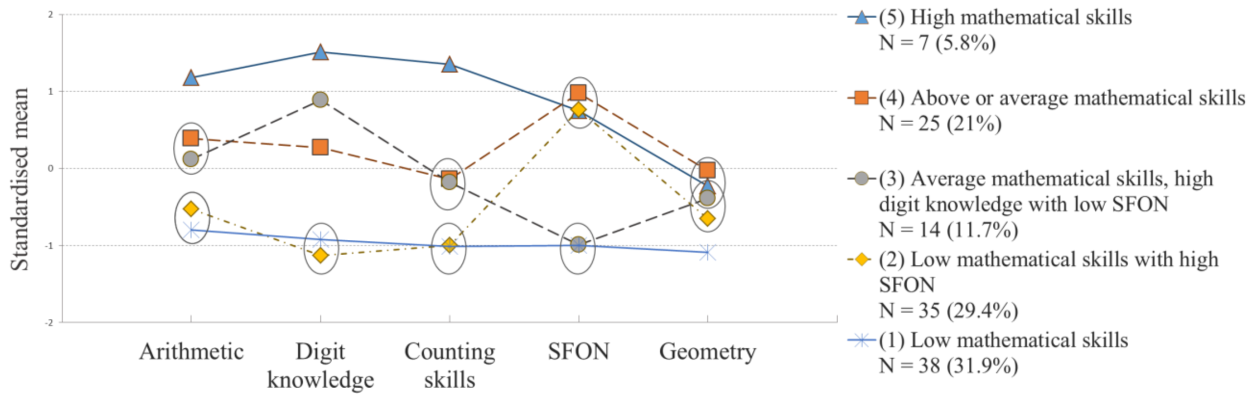

Figure 1. Mathematical skill profiles of prematurely born children. The y-axis represents the means of each standardized variable. Circle marks the profile means which do not differ (p>.05) from each other.

3.2.2. Associations among mathematical profile membership, neonatal characteristics, perinatal medical treatment, maternal education and cognitive skills.

No other neonatal characteristics or perinatal medical treatments except for gestational age and birth weight (see, Table 1) were related to mathematical skill profiles when analysed with individual chi-square tests and multinomial regression analyses. Due to high correlation (r=.74, p <.001) of birth weight and gestational age they were not entered simultaneously into the same model. Replacing birth weight with gestational age resulted in highly similar results as the original model with the exception of inhibition being significantly related to profiles (χ^2 (36) = 101.3, $p < 0.001$, $R^2 = 0.63$ (Cox–Snell), 0.67 (Nagelkerke). Inhibition was different in two lowest profiles by odds ratio OR of 1.39. SGA added to either model was not related to profile membership. Due to slightly stronger relation of birth weight than gestational age with the profiles, we decided to include birth weight in our further analyses.

Hierarchical multinomial logistic regression analyses were used to investigate the importance of maternal education, birth weight and cognitive skills in mathematical profile membership among prematurely born children. When maternal education alone, or with birth weight, was entered into the equation, the model was not significant χ^2 (8) = 9.820, p = n.s., R^2 =

0.08 (Cox–Snell), 0.07 (Nagelkerke). However, when next all the cognitive skills were added, birth weight was significantly associated with the five profiles (see, Table 4). The new model explained a significant amount of variance; χ^2 (36) = 102.70, $p <.001$, $R^2 = 0.64$ (Cox–Snell), 0.67 (Nagelkerke). All group differences were investigated one by one in a series of multinomial LRAs by changing the reference group. Figure 2 presents all significant odd ratios ($p <.05$) for separate cognitive skills when maternal education, birth weight and all other cognitive skills were controlled. The odds ratios represent the increased probability in units of a measured variable for belonging to a higher mathematical skill profile when compared to a lower mathematical skill profile. Thus, for example for each additional unit in phonological processing measure in children of profile 2 *Low mathematical skills with high SFON*, the odds in belonging to profile 4 *Above or average mathematical skills* increased by 2.05. As can be seen from Figure 3, phonological processing differentiates the highest two profiles from the lower ones, while speeded naming differs across all profiles except for between two two highest profiles. Birth weight differed between profiles 1 and 2, profiles 2 and 3, profiles 3 and 4, as well as between profiles 1 and 4.

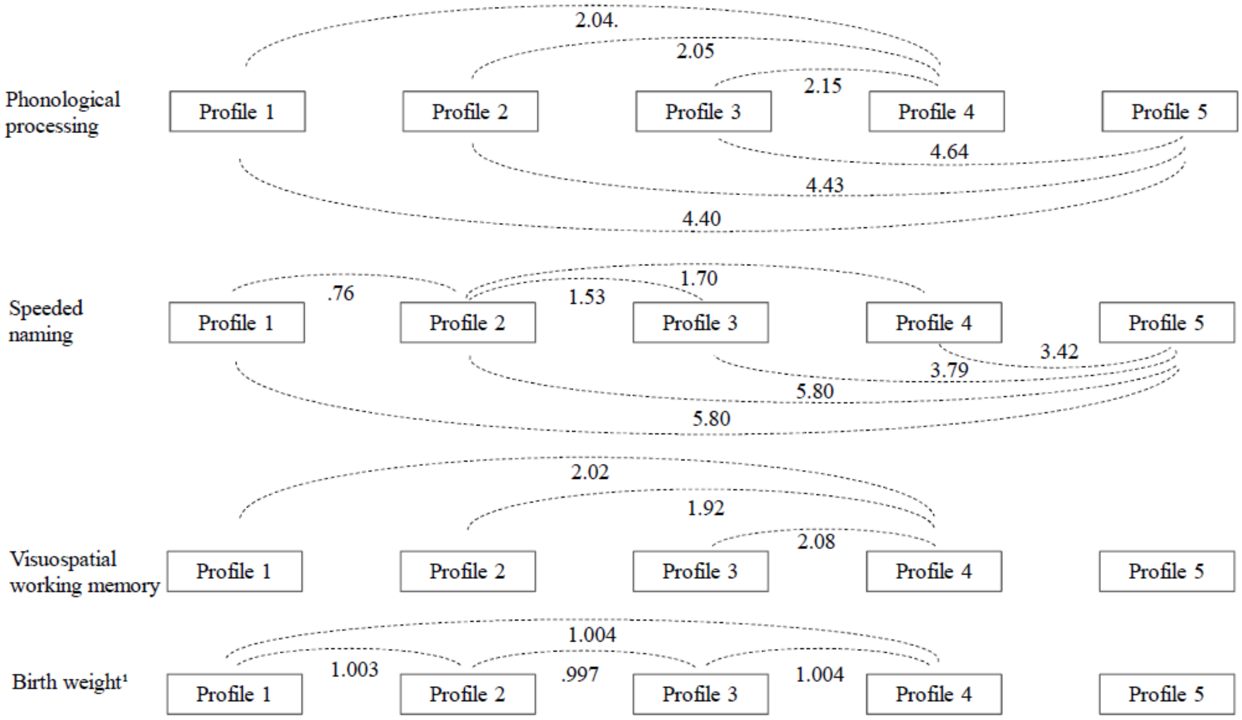

Figure 2. Statistically significant (*p* <.05) odd ratios of cognitive skills and birth weight (OR) of prematurely born VLBW children. OR represents the increased probability in units of a measured variable for belonging to a higher profile when compared to a lower profile. [1]Confidence interval does not overlap 1. Profile 1=*Low mathematical skills*, profile 2=*Low mathematical skills with low SFON*, profile 3= *Above average mathematical skills, high digit knowledge with low SFON*, profile 4 = *Above or average mathematical skills*, profile 5 = *High mathematical skills*

Table 4

Means, Standard Deviations and Association of Mathematical Profiles with Maternal Education, Birth Weight and Cognitive Skills

Variable	Profile 1 Low mathematical skills (n = 30)	Profile 2 Low mathematical skills with high SFON (n = 26)	Profile 3 Average mathematical skills, high digit knowledge with low SFON (n = 14)	Profile 4 Above or average mathematical skills (n = 24)	Profile 5 High mathematical skills (n = 7)	
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	χ^2
Maternal education[1]	-	-	-	-	-	5.08
Birth weight	1093.26 (374.28)	1184.49 (293.79)	1048.57 (311.07)	1187.60 (289.00)	1186.43 (302.57)	15.68**
Phonological processing	8.03 (2.19)	8.23 (1.99)	8.79 (2.89)	10.56 (2.33)	11.14 (2.41)	26.09***
Speeded naming	8.46 (2.90)	7.34 (2.40)	9.71 (1.94)	10.44 (3.01)	12.57 (1.27)	25.62***
Visuospatial working memory	6.82 (3.13)	7.64 (2.55)	7.86 (2.85)	9.00 (1.66)	9.00 (2.52)	13.60**
Inhibition	7.29 (2.89)	9.25 (2.92)	9.21 (3.59)	9.48 (3.23)	11.43 (1.99)	9.39
Verbal working memory	7.30 (3.58)	7.42 (3.85)	10.36 (2.98)	9.83 (3.86)	11.29 (2.29)	4.92
Comprehension of instruction	8.13 (2.37)	8.85 (2.18)	10.50 (2.56)	11.44 (3.24)	12.29 (1.80)	4.78
Visuomotor skills	7.59 (3.22)	7.89 (3.21)	8.07 (3.87)	8.72 (3.60)	9.29 (3.35)	4.08

Note. [1]Two categories were used (less than 12 and 12 or more years of maternal education). Profile 1: 1st category – 38.9%, 2nd category – 61.10%; profile 2: 1st category – 44.1%, 2nd category – 55.9%; profile 3: 1st category – 42.9%, 2nd category – 57.1%; profile 4: 1st category – 20.0%, 2nd category – 80.0%; profile 5: 1st category – 14.3%, 2nd category – 85.7%. Two-tailed hypotheses, **p* < 0.05, ***p* < 0.001.

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3.3. Full-term Born Children

3.3.1. Latent profile analysis. Table 5 illustrates the fit indices for the full-term born children's LPA solutions. The goodness-of-fit indices suggested that both three and four-profile solutions represented the data fairly well. However, the VLMR indicated that the fifth profile was not needed. After three-profile solution, the BIC value stabilizes, supporting 4-profile solution which is able to differentiate profiles of high and low performing children (Marsh et al., 2009). The average individual posterior probabilities of being assigned to a specific latent profile in the four group models were 0.915, 0.942, 1.000 and 1.000, respectively, indicating a clear classification. The four profiles comprised *n* = 29 (28.5%), *n* = 10 (10%), *n* = 44 (44.2%), and *n* = 17 (17.2%) children, respectively.

Table 5

Fit Measures of the 2-, 3-, 4- and Latent Profile Models for Mathematical Measures (Full-term Born Children)

Number of profiles (sample sizes per profile)	*N* = 100				
	AIC	BIC	Entropy	VLMR LRT (*p*)	BLRT (*p*)
1 (100)	1379.16	1405.22	-	-	-
2 (64; 36)	1265.38	1307.06	0.82	0.038	< 0.001
3 (10; 45; 45)	1191.01	1248.33	0.99	0.023	< 0.001
4 (17; 29; 44; 10)	**1152.75**	**1225.69**	**0.95**	**0.046**	**< 0.001**
5 (29; 16; 30; 10; 15)	1108.93	1197.50	0.93	0.545	< 0.001
6 [a]					

[a]Unstable solution

Based on the 4-profile model solution, 28.5% of full-term born children belonged to profile 1 *Low mathematical skills* and situated clearly below the mean in all mathematical variables (Figure 3 and Appendix 1 for profile differences). Profile 2 *Average mathematical skills* and profile 3 *Above average mathematical skills with high SFON* were situated slightly around the mean in all measured variables except for in SFON in which Profile 3 had higher SFON scores than any other group. Profile 4 *High mathematical skills with low SFON*, comprised 17.2% of the children, with all other mathematical skills except for SFON at the high level.

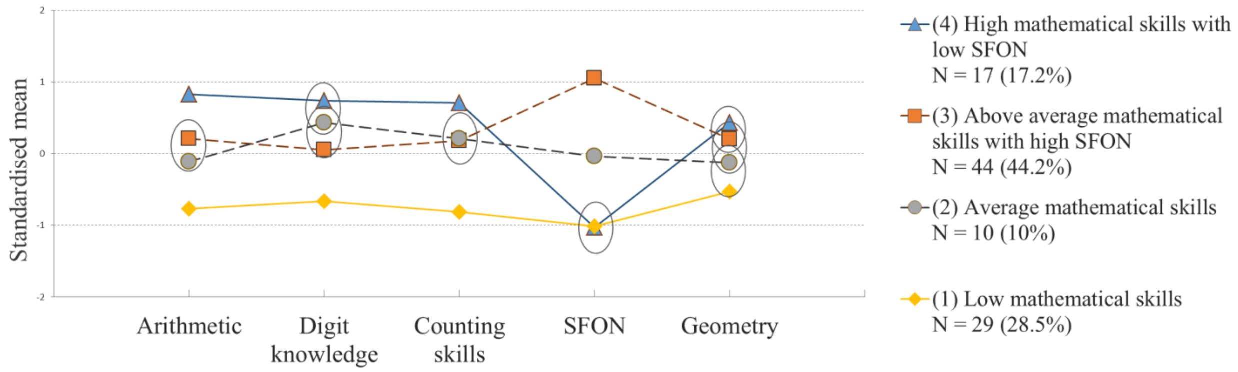

Figure 3. Mathematical skill profiles of full-term born children. The y-axis represents the means of each standardized variable. Circle marks the profile means which do not differ (*p*>.05) from each other.

3.3.2. Associations between mathematical profile membership and cognitive skills.

Table 6 presents the means and standard deviations for each cognitive skill across different mathematical profiles of full-term born children.

Table 6

Means, Standard Deviations and Association of Mathematical Profiles with Maternal Education and Cognitive Skills

Variables	Profile 1 Low mathematical skills (n = 24)	Profile 2 Average mathematical skills (n = 9)	Profile 3 Above average mathematical skills with high SFON (n = 43)	Profile 4 High mathematical skills with low SFON (n = 16)	
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	χ^2
Maternal education[1]	_	_	_	-	0.96
Phonological processing	9.55 (1.88)	9.90 (2.08)	10.64 (2.86)	11.41 (1.73)	1.66
Verbal working memory	8.18 (3.36)	9.89 (1.83)	10.57 (2.13)	11.06 (1.56)	10.22*
Comprehension of instruction	9.38 (2.57)	12.10 (2.96)	10.34 (2.79)	11.12 (1.54)	6.73
Speeded naming	8.48 (2.23)	10.00 (2.21)	10.05 (2.41)	11.29 (2.57)	2.82
Inhibition	8.83 (2.84)	8.70 (1.83)	10.37 (2.78)	10.82 (2.19)	4.59
Visuospatial working memory	9.75 (2.27)	9.10 (3.51)	9.66 (1.82)	11.12 (1.69)	5.05

Visuomotor skills	8.72 (4.13)	9.50 (3.10)	8.84 (3.29)	10.06 (3.45)	1.52

Note. [1]Two categories were used (less than 12 and 12 or more years of maternal education). Profile 1: 1st category – 53.6%, 2nd category – 46.4%; profile 2: 1st category – 40%, 2nd category – 60%; profile 3: 1st category – 38.6%, 2nd category – 61.4% and profile 4: 1st category – 12.5%, 2nd category – 87.5% Two-tailed hypotheses, $*p < 0.05$, $**p < 0.001$.

Multinomial logistic regression was used to investigate the importance of maternal education and cognitive skills in mathematical profile membership, while controlling for each other's effect. If only maternal education was entered into the equation, the model was not significant χ^2 (3) = 6.75, $p = 0.080$, $R^2 = 0.07$ (Cox–Snell), 0.08 (Nagelkerke). In the second model, all cognitive variables were added. The model explained a significant amount of variance: χ^2 (24) = 45.44, $p < 0.01$, $R^2 = 0.39$ (Cox–Snell), 0.43 (Nagelkerke). Verbal working memory was significantly associated with the four mathematical profiles. For each unit increase in verbal working memory scores, the odds of belonging to profile 3 *Above average mathematical skills with high SFON* (OR = 1.51, $p = 0.020$) and the odds of belonging to profile 4 *High mathematical skills with low SFON* (OR = 1.76, $p = 0.011$) were significantly higher compared to profile 1 *Low mathematical skills*.

4. Discussion

This study has investigated the mathematical skill profiles of prematurely and full-term born preschoolers across a variety of mathematical skills. This study's novel contribution is its person-centred approach to exploring differences in mathematics skills between five-year-old prematurely and full-term born children. Contrary to the variable-level approach, where previous results constantly show lower mathematical levels for prematurely born children, the person-centred approach enables identifying typologies of children with respect to their mathematical skills and allows exploring the structure of differences in mathematical subskills. The results of the MGLPA show that prematurely and full-term born children differed in the number and shape of latent mathematical skill profiles. These results suggest both quantitative and qualitative differences between the two samples. In sum, this study shows that prematurely born children may have partly different combinations of strengths and weaknesses in mathematical and other cognitive skills compared to full-term born children. Our sample of prematurely born children with VLBW tested two years before the beginning of school forms a heterogeneous group. Thus, although prematurity seems to be a risk factor for low mathematical skills, profiles with average and above average mathematical skills also existed among this population, as recently shown by Tatsuoka and colleagues (Tatsuoka et al., 2016). They found weaker numerical subskills but also substantial individual variability in mathematical skill profiles of extremely preterm born children during the first year of school.

4.1. Mathematical Profiles of Prematurely Born Children

In the prematurely born sample, the identified profiles are diverse at the mathematical skill level. Importantly, mathematical skill profiles did not differ only in the overall level of math skills across all sub-skills, but different strengths and weaknesses in sub-skills and their cognitive correlates could be recognized. Two mathematical skill profiles are stabile across all mathematical skill levels (i.e., profile 1 and profile 4), while the other three profiles demonstrate variability in the levels of different mathematical skills. Profile 2 gathers children with high SFON and close to average geometry but low numerical skills, while profile 3 groups children with low SFON but high digit knowledge, and profile 5 has children with high numerical skills and average geometry. The lower level profiles tend to gather larger numbers of children. These results are in line with previous research findings that prematurely born children have lower mathematical skills (Aarnoudse-Moens, Oosterlaan, Duivenvoorden, van Goudoever, &

Weisglas-Kuperus, 2011; Schneider, Wolke, Schlagmüller, & Meyer, 2004; Taylor et al., 2009). However, even high performance in a broad range of mathematical skills could be found among prematurely born children, which is in line with Tatsuoka and colleagues (2016). Small number of children in the highest mathematical skill profile warrants some caution in conclusions.

4.1.1. Cognitive Skills and Mathematical Profiles of Prematurely Born Children

Speeded naming, phonological processing and visuospatial working memory were significantly associated with the five mathematical skill profiles while controlling for all other cognitive skills, maternal education and either birth weight or gestational age. Only birth weight and gestational age out of all neonatal characteristics and perinatal care variables were related to mathematical skill profiles, but the odd ratios in the multinomial regression analyses showed that their effect was small. This finding is supported by previous research that reports the gestational weeks' and weight are related to basic mathematical skills (Espy, Fang, Charak, Minich & Taylor, 2009; Wolke et al., 2014).

Specifically, the odds ratio suggests that phonological processing and visuospatial working memory are relevant when distinguishing above average profiles from lower level profiles but irrelevant when comparing below average profiles, while speeded naming is associated with all the mathematical profiles. This finding is in line with previous research documenting that verbal processing speed explains group differences in mathematics between prematurely and full-term born children (Mulder et al., 2010), and processing speed is often impaired among prematurely born children (Gnigler et al., 2015; Mulder, Pitchford, Hagger, & Marlow, 2009).

Phonological processing is not always found to be lower among the prematurely born children (Wocadlo & Rieger, 2007). The relevance of this skill for high achievers might suggest its potential protective valence in relation to counting skills. Its unique association with above average mathematical profiles might be explained by the fact that these children excel in counting, a skill strongly related to language abilities (LeFevre et al., 2010; Purpura & Napoli, 2015; Schneider et al., 2004;) although there is no agreement on the theoretical explanation for this association.

Visuospatial working memory followed the same pattern by differentiating the profile of above or average mathematical skills from the three below average profiles. Visuospatial processing skills are known to be relevant contributors to basic mathematical skills (Krajewski & Schneider, 2009; LeFevre et al., 2010; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). This result adds to previous findings that in prematurely born children as well, visuospatial skills contribute to variance in mathematics when controlling for other cognitive skills (Aarnoudse-Moens, Weisglas-Kuperus, Duivenvoorden, van Goudoever, & Oosterlaan, 2013), showing that the relation is already present when children reach five years of age. Along with visuomotor skills, visuospatial processing skills comprise a weak area among prematurely born children (Geldof et al., 2012; Johnson et al., 2011). However, in our sample, visuomotoric skills were not associated with mathematical profiles, maybe because our investigation included geometric skills unlike most of the studies involving prematurely born children.

Our decision of not controlling for IQ, but instead investigating specific cognitive skills in relation with mathematical skill profiles was based on previous literature stating that general IQ tests are not ideal for detecting specific cognitive strengths and weaknesses (Lezak, Howieson, Bigler, & Tranel, 2012). Specific neuropsychological measures are needed for these purposes (Anderson, 2014).

We did not find support for a relation between the mothers' basic education and mathematical skill profiles. Similarly, in 11-year-old children, Johnson and colleagues (2011) found no significant effect of maternal education while controlling for neuropsychological outcomes measured at six years of age. In contrast, Saavalainen and colleagues (2008) report that maternal education significantly contributed to mathematical performance at the age of 16. Unfortunately, we lack information about further education of the mothers allowing a more comprehensive investigation of this relation.

4.2. Mathematical Profiles of Full-term Born Children

The mathematical skill profiles of full-term born children were characterized by (a) high level of all other mathematical skills except for SFON, which was at the low level,(b) above average mathematical skills with high SFON, (c) average mathematical skills , and (d) low mathematical skills in on all math tasks. A cross-sectional study using LPA across early mathematical skills found five distinct skill profiles in a sample of three-and-a-half to five-year-old children (Gray & Reeve, 2016). Also in their study SFON differentiated across different profiles. In the current study SFON was measured in a very small number range, which could explain its more variable appearance across profiles in comparison to other numerical skills which were measured at the counting range. Future studies will be needed to discover whether SFON measured at the counting range would differentiate mathematical skill profiles similarly.

4.2.1. Cognitive Skills, Maternal Education and Mathematical Profiles of Full-term Born Children

When controlling for other cognitive skills and maternal education, only verbal working memory was a relevant predictor of profile membership. Children in the low mathematical skills profile had significantly lower verbal working memory than highest two profiles. This finding of domain-specificity of the profiles is consistent with Gray and Reeve's similar analyses (2016), of mathematical profiles and a set of counting skills. They found only vocabulary being marginally related to profiles. Maternal education was not related to profiles unlike in previous research by Anders and colleagues (2012).

4.3. Limitations and Implications for Further Research

Due to small sample size our results should be taken cautiously. Some profiles became small along the analyses, and it might be possible to identify more profiles or statistically significant regressors with a larger sample. However, our ability to identify several different skill profiles with clearly differential mean levels of sub-skills suggests that our conclusions are warranted. Further research with larger samples would be needed to confirm the qualitative nature of the differences between prematurely and full-term born children.

The identified association of mathematical profiles with different cognitive skills is limited by the cross-sectional design of our study; for example, we cannot assume any causality about the significance of the cognitive skills for mathematical development. Longitudinal data would be required to explore developmental trajectories of mathematical profiles and related cognitive skills of prematurely born children. It might be that the relevance of different cognitive skills would change over time (Aunola et al., 2004; Johnson et al., 2011). In a longitudinal design, it would also be possible to analyse potentially different developmental paths, as well as to assess the probability of changes in profile membership across several measurement points (Collins & Lanza, 2010).

Our full-term born sample was selected to include healthy children , excluding children with low birth weight, neonatal care for any reason during the first week, congenital anomaly or syndrome and children whose mothers had alcohol or drug abuse during pregnancy. This might have led to the sample's higher than average cognitive skill level, as indexed by the children's above average, full-scale IQ scores. The prematurely born children with VLBW also comprise a selected group, with only those without severe developmental disorders participating. Thus, these results cannot be generalised to all prematurely born VLBW children but only to those whose general cognitive development is part of the typical variations among preterm children. Prematurely born children have more vision impairments (Schraeder & McEvoy-Shields, 1990), but these were extremely rare in our sample. Yet, it may be that more specific vision examination could have revealed vision-related characteristics which could have been related to mathematical skill profiles.

4.4. Conclusions

It has been suggested that a person-centred approach may be beneficial in exploring the characteristics of prematurely born children to identify potential subgroups linked to gestational weeks, birth weight and neonatal complications (Taylor et al., 2009). The present study's findings add to the limited understanding of the mathematical characteristics of prematurely born children at such a young age by suggesting that their mathematical skill profiles are not similar to full-term born children's profiles. Based on the identified profiles, prematurely born children possess quite diverse mathematical skills, ranging from very high counting skills and SFON tendencies to very low mathematical skills as well as different combinations of strengths and weaknesses. These 'non-linear' combinations of mathematical skills can only be identified by using person-centered approaches. The study also reveals that various combinations of cognitive skills are related to different mathematical profiles of these two groups. Within prematurely born children there are sub-groups, whose early mathematical development might benefit more from broader educational interventions including extra support not only for mathematical but also for general cognitive skills such as phonological processing, speeded naming and visuospatial working memory. Comparing prematurely born cohorts from two countries, Wolke and colleagues (2014) found differences in mathematical attainment scores. Early school entry in one of the countries accounts for such disparities, suggesting the educational context's major impact on the development of numeracy among prematurely born children. A better understanding of wide range of prematurely born children's mathematical and other cognitive skill structures well before formal schooling, as provided by person-centered approach such as LPA, is beneficial for the development of diagnostic assessments and early intervention programmes that could prevent later difficulties in learning mathematics.

ACKNOWLEDGEMENTS

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Appendix 1

Descriptives and differences in mathematical skills across mathematical profiles of prematurely born children

Variables	Profile 1 Low mathematical skills (n = 38)	Profile 2 Low numerical and geometrical skills with high SFON (n = 35)	Profile 3 Average mathematical skills, high digit knowledge with low SFON (n = 14)	Profile 4 Above or average mathematical skills (n = 25)	Profile 5 High mathematical skills (n = 7)	Chi-square test using BCH method	Comparison (BCH method)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	χ^2	
Arithmetic	-0.83 (0.71)	-0.56 (0.71)	0.12 (0.71)	0.44 (0.71)	1.19 (0.71)	71.73***	5 > 4,3,2,1; 4,3 > 2,1
Digit knowledge	-0.97 (0.47)	-1.19 (0.47)	0.90 (0.47)	0.33 (0.47)	1.52 (0.47)	424.91***	5 > 4,3,2,1; 4 > 3,2,1; 3 > 2,1
Counting skills	-1.03 (0.38)	-1.04 (0.38)	-0.18 (0.38)	-0.11 (0.38)	1.37 (0.38)	292.59***	5 > 4,3,2,1; 4,3 > 2,1
SFON	-1.00 (0.32)	-0.80 (0.32)	-0.99 (0.32)	1.01 (0.32)	0.77 (0.32)	1329.14***	5,4,3 > 2,1
Geometry	-1.11 (0.85)	-0.67 (0.85)	-0.38 (0.85)	0.00 (0.85)	-0.24 (0.85)	25.90***	5,4,3 > 2,1; 2>1

Note. All χ^2 values are significant at $p < .001$. *SD* estimated as equal across profiles.

Appendix 2

Descriptives and Differences in mathematical skills across mathematical profiles of full term born children

Variables	Profile 1 Low mathematical skills (n = 29)	Profile 2 Average mathematical skills (n = 10)	Profile 3 Above average mathematical skills with high SFON (n = 44)	Profile 4 High mathematical skills with low SFON (n = 17)	Chi-square test using BCH method	Comparison (BCH method)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	χ^2	
Arithmetic	-0.76 (0.84)	-0.11 (0.84)	0.22 (0.84)	0.76 (0.84)	55.57***	4> 3,2,1; 3,2 > 1
Digit knowledge	-0.66 (0.87)	0.43 (0.87)	0.06 (0.87)	0.70 (0.87)	41.50***	4,3 > 2,1; 2 >1
Counting skills	-0.82 (0.74)	0.21 (0.74)	0.19 (0.74)	0.64 (0.74)	76.57***	4 > 3,2 > 1
SFON	-1.01 (0.14)	-0.04 (0.14)	1.06 (0.14)	-1.03 (0.14)	4393.89***	3 > 2,1,4; 2 > 1,4
Geometry	-0.52 (0.83)	-0.13 (0.83)	0.21 (0.83)	0.39 (0.83)	21.56***	4,3 > 2,1

Note. All χ^2 values are significant at $p < .001$. *SD* estimated as equal across profiles.