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Early cognitive profiles predicting reading and arithmetic skills in grades 1 and 7

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ABSTRACT

The aim of this study was to investigate cognitive profiles composed of skills predicting the overlap between reading and arithmetic in kindergarten (phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge) and the relation of these profiles to reading and arithmetic skills at Grades 1 and 7. A total of four distinct cognitive profiles were identified in an unselected sample of 1,710 children aged 5–6 years: (1) high linguistic and high counting skills (39.2%), (2) low linguistic and low counting skills (25.4%), (3) high counting skills in relation to linguistic skills (15.3%), and (4) low counting skills in relation to linguistic skills (20.1%). Among most of the children (about 65%), the linguistic and counting skills varied together. Children characterized by high or low overall performance levels across linguistic and counting skills also showed, predictably, high or low overall performance levels in subsequent reading and arithmetic skills in Grades 1 and 7. Children characterized by a discrepancy between linguistic and counting skills (about 35% of the children) in turn showed somewhat discrepant subsequent levels of reading and arithmetic skills. The results point towards individual variation (i.e., heterogeneity) in cognitive profiles that predict both reading and arithmetic skills in Grades 1 and 7. Based on these findings, the linguistic and basic number skills predict differently the overlap between reading and arithmetic in Grades 1 and 7 depending on cognitive profile. The weaknesses across linguistic and counting skills are a greater risk for persistent overlapping difficulties in reading and arithmetic than weaknesses in only one of the learning domains. For difficulties in arithmetic skill development, however, weaknesses in only counting skills present an equal risk compared to weaknesses evident across linguistic and counting skills.

1. Introduction

Reading and arithmetic skills show substantial overlap across grade levels from primary to lower secondary school (Korpipää et al., 2017), and difficulties in one of the learning domains increases the risk for difficulties in the other domain (Landerl & Moll, 2010). The overlap of performance in these two domains has been suggested to be at least partly related to the shared cognitive factors of reading and arithmetic skill development (Cirino, Child, & Macdonald, 2018; Hecht, Torgesen, Wagner, & Rashotte, 2001; Koponen, Aunola, Ahonen, & Nurmi, 2007). However, the previous studies have mainly used a variable-oriented approach (i.e., linear techniques) and focused on the separate, unique impacts of different linguistic and basic number skills when explaining the overlap between reading and arithmetic. Because a variable-oriented approach applies a single model to the whole sample to estimate a single set of parameters (Mäkikangas et al., 2018), the possible interindividual differences (i.e., heterogeneity) in patterns of performance across the studied variables underlying the overlap have thus far been ignored. Whereas a variable-oriented method examines associations between different variables, a person-oriented approach examines individual differences in these associations (Hickendorff, Edelsbrunner, McMullen, & Schneider, 2018; Laursen & Hoff, 2006) and, thus, makes

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it possible to investigate not only whether there are subgroups of individuals showing different profiles of cognitive antecedents but also whether these different profiles end up with similar or different subsequent performance outcomes. If qualitatively different subgroups exist within a population, they are not accurately represented by the general model provided by variable-oriented approach (Hickendorff et al., 2018). Therefore, a person-oriented approach was used in the present study for identifying individual differences in cognitive profiles composed of shared predictors of reading and arithmetic skills (i.e., phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge) and finding out the typicality of different profiles (i.e., the proportion of the sample that shows a particular pattern). Furthermore, differences between the profiles in reading and arithmetic skills at Grades 1 and 7 were investigated. The aim was to complement the current understanding of the cognitive mechanisms—and possible heterogeneity in these mechanisms—that underlie both reading and arithmetic skill development, and, in this way, to provide insights on individualized ways to support the development of the overall performance level of these skills.

1.1. Cognitive antecedents predicting the overlap between reading and arithmetic skills

Previous studies that have investigated the role of different cognitive antecedents in the overlap (i.e., covariation) between reading and arithmetic skills suggest that this overlap is predicted more by linguistic and basic number skills than by general cognitive abilities (Cirino et al., 2018; Hecht et al., 2001; Koponen et al., 2007; Korpipää et al., 2017, 2019). According to Korpipää et al. (2017), phonological awareness (i.e., awareness of the phonological structure of a language), letter knowledge, rapid automatized naming (i.e., the ability to rapidly name familiar visual stimuli, such as letters, digits, colors, and objects), and counting sequence knowledge (i.e., reciting number words forwards, backwards, and in steps) are all independent predictors of the overlap between reading and arithmetic skills after controlling for working memory, nonverbal reasoning, and parental education level (see also Koponen et al., 2007; Korpipää et al., 2019). Also, Cirino et al. (2018) reported that linguistic and basic number skills, including phonological awareness, rapid automatized naming, and symbolic naming (number identification) accounted for a large amount (about 91%) of the overlap between reading and arithmetic fluency in Grade 1, whereas the role of counting sequence knowledge was less evident. In their study, a wide range of basic number skills was used for predicting the overlap (procedural and conceptual counting knowledge, symbolic comparison and symbolic naming), but letter knowledge was not included which may explain the role of symbolic number naming as a predictor of shared variance between reading and arithmetic fluency. In line with these findings, Hecht et al. (2001) found that the overlap of reading and arithmetic skills was almost completely accounted for by phonological awareness, rapid automatized naming, and phonological memory from Grade 2 to 5; however, counting sequence knowledge was not included in their study.

The study by Korpipää et al. (2017) showed further that phonological awareness and letter knowledge are related to the overlap between reading and arithmetic skills mainly at an early phase of skill development (Grade 1), when both reading and arithmetic skills are based on serial one-by-one processing of letter sounds and number words. It has been suggested that understanding the mapping between the letters in written words and the phonemes in spoken language improves the ability to use and manipulate written symbols for numbers and operators in arithmetic (Zhang et al., 2014). Counting sequence knowledge, in turn, was strongly related to both early (Grade1) and later (Grade 7) phases of skill development. In a study by Korpipää et al. (2017), counting sequence knowledge and rapid automatized naming were found to be the strongest predictors of the overlap between reading and arithmetic skills across grade levels from primary to lower secondary school. It has been shown that these two abilities are related to developing fluency in both domains and reflect the ease of forming and retrieving visual-verbal associations from long-term memory (Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016; Koponen, Salmi, Eklund, & Aro, 2013). However, linguistic and basic number skills also account for nonshared variance in reading and arithmetic skills due to the domain-specific content knowledge. For example, linguistic skills regarding phonological awareness and rapid automatized naming are more predictive of reading than of computation, and basic number skills, such as counting knowledge, are more predictive of computation than of reading (Cirino et al., 2018; see also Child, Cirino, Fletcher, Willcutt, & Fuchs, 2019).

In addition to linguistic and basic number skills, the development of reading and arithmetic skills (Bull, Espy, & Wiebe, 2008; Davis-Kean, 2005), as well as the overlap between these skills (Korpipää et al., 2017), have been shown to be predicted by more general cognitive abilities, such as working memory, attentional resources and parental education level. In previous studies, preschool measures of verbal short-term memory, working memory, and executive functioning skills have been found to predict academic achievement in reading and math throughout the early school years (Bull et al., 2008; see also Alloway & Alloway, 2010). Furthermore, phonological memory has been shown to contribute to the overlap between reading and arithmetic skills across Grades 1 and 7, along with nonverbal reasoning but to a lesser extent than linguistic and basic number skills (Korpipää et al., 2017, see also Hecht et al., 2001). Recent studies have demonstrated, however, that the associations of general cognitive abilities with the overlap between reading and arithmetic are mainly indirect via core predictors, such as linguistic and basic number skills, rather than direct (Koponen et al., 2019). Similarly, the role of parental education level (Koponen et al., 2019; Korpipää et al., 2017) has been shown to be minor in explaining the shared variance of reading and arithmetic.

1.2. A person-oriented approach to the cognitive antecedents of reading and arithmetic skills

Previous studies focusing on the cognitive antecedents of reading and arithmetic skills have typically applied a variable-oriented approach, mainly focusing on the associations of antecedent variables with reading and arithmetic or with the overlap between reading and arithmetic (Cirino et al., 2018; Hecht et al., 2001; Korpipää et al., 2017; Koponen et al., 2007, 2013). Although this approach provides valuable information about the unique contribution of different cognitive skills to reading and arithmetic development, it also has some limitations. The main limitation is that a variable-oriented approach assumes the studied associations to be the same for all children. Thus, the basic assumption is the homogeneity of a population. In contrast, the more rarely applied person-oriented approach is based on the assumption that the population can be heterogeneous with respect to the studied phenomena (Laursen & Hoff, 2006). This approach enables identifying subgroups of children with different cognitive profiles and examining whether these children develop either similarly or differently in their reading and arithmetic skills. Although previous studies have shown that linguistic and basic number skills correlate rather strongly with observed intercorrelations varying from 0.30 to 0.60 (Korpipää et al., 2017, 2019), the correlation pattern may not be the same across the whole population. Whereas variable-oriented approaches provide important information about the additive impacts (i.e., the unique linear associations of different independent variables after controlling for the impacts of other independent variables) of different linguistic and basic number skills on reading and arithmetic skills and their overlap, a person-oriented approach provides a valuable tool to examine the possible interactive effects of these antecedent cognitive skills. Based on variable oriented approaches, for example, high levels of linguistic skills with low levels of basic number skills lead to the same performance outcome in terms of overlap between reading and arithmetic than low levels of linguistic skills with high basic number skills or, for example, average levels of both linguistic and basic number skills. Consequently, person-oriented approaches can improve our understanding of individual differences in the patterns of how linguistic and basic number skills operate together in predicting reading and arithmetic skills and their overlap across grade levels.

Studies applying a person-oriented approach separately for reading (Ozernov-Palchik et al., 2017) and arithmetic (Gray & Reeve, 2016; Hart et al., 2016) have identified distinct cognitive profiles that predict the development of these skills, specifically in children who are struggling. For example, Ozernov-Palchik et al. (2017) found six different profiles in kindergarten regarding nonverbal reasoning, phonological awareness, verbal short-term memory, rapid automatized naming, and letter sound knowledge. According to their findings, difficulties in reading may derive from different cognitive profiles, including weaknesses either in phonological awareness or in rapid automatized naming or both. Similarly, Hart et al. (2016) found that difficulties in arithmetic fluency at age 12 resulted from different cognitive profiles regarding math achievement, numerosity, and anxiety rather than only one profile.

Overall, these previous studies suggest that there are subgroups of children representing differential relations regarding the cognitive antecedents associated with performance in reading and arithmetic. The limitation of these previous studies examining heterogeneity in cognitive profiles of reading and arithmetic skills is, however, that they have included mainly domain-specific predictors (i.e., cognitive antecedents of reading *or* arithmetic). Furthermore, longitudinal studies regarding the role of different cognitive profiles in predicting subsequent reading and arithmetic skills, as well as the overlap between these skills, are rare. Unlike previous studies, the present study simultaneously examines the relations among linguistic *and* basic number skills, which have been shown to have both shared and unique influences on reading and arithmetic skills (Cirino et al., 2018; see also Child et al., 2019). The aim was to find out how different patterns of performance across these cognitive antecedents are associated with performance levels in reading and arithmetic and overlap between these skills later on in school. Specifically, the focus of this study was on cognitive profiles predicting the overlap between reading and arithmetic skills rather than each skill separately at different stages of development. As linguistic and basic number skills regarding phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge have been shown to be the strongest independent predictors of the overlap between reading and arithmetic skills (Korpipää et al., 2017, 2019), the cognitive profiles were examined in terms of these measures. By applying a person-oriented approach, the present study has the potential to specify the associations of these cognitive antecedents with the overlap between reading and arithmetic skills and thus provide knowledge important for developing efficient means of support.

1.3. The aim of the present study

The present study examined the following research questions:

(1) What kinds of distinct cognitive profiles with regard to linguistic and counting skills (i.e., shared predictors of reading and arithmetic) can be identified in kindergarten? As previous studies suggest that there is high heterogeneity in cognitive profiles (i.e., subgroups of children representing differential relations between the cognitive antecedents) of reading (Ozernov-Palchik et al., 2017) and arithmetic (Gray & Reeve, 2016; Hart et al., 2016), it is assumed that heterogeneity also exists for the combination of linguistic and basic number skills. Furthermore, we assumed that both profiles typified by consistencies (i.e., high level or low level of both linguistic and counting skills) and profiles typified by discrepancies (i.e., high level of linguistic skills but low level of counting skills, and high level of counting skills but low level of linguistic skills) can be identified (Hypothesis 1).

Given that the general cognitive abilities together with parental education level form the foundation for developing knowledge needed for learning both reading and arithmetic (Alloway & Alloway, 2010; Bull et al., 2008; Davis-Kean, 2005; Korpipää et al., 2017), differences between the profiles regarding working memory, short-term memory, nonverbal reasoning, inattention/hyperactivity, and parental education level were also investigated.

(2) To what extent do the identified cognitive profiles predict subsequent reading and arithmetic skills, and overlap between these skills, at Grades 1 and 7? As previous studies suggest both shared and unique associations of linguistic and basic number skills with reading and arithmetic skills (Cirino et al., 2018; see also Child et al., 2019), it is assumed that children characterized by high or low overall performance levels across phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge will show more consistent skill levels of reading and arithmetic (being evident as either consistently high or low skill levels across reading and arithmetic) than children characterized by discrepant cognitive profiles (i.e., profiles with high linguistic skills and low counting skills, or, alternatively, high counting skills and low linguistic skills). More specifically, children typified by high overall performance levels across linguistic and counting skills are assumed to show high skill levels across both reading and arithmetic, whereas children typified by low overall performance levels across linguistic and counting skills are assumed to show low skill levels across both reading and arithmetic (Hypothesis 2). Furthermore, it is assumed that children typified by high linguistic skills but low counting skills perform higher in reading than in arithmetic, whereas those typified by high counting skills but low linguistic skills will show the opposite pattern of results (Hypothesis 3). Because previous studies investigating the shared cognitive antecedents of reading and arithmetic have applied a variable-oriented approach, it is not, however, possible to set more solid predictions for the levels of reading and arithmetic skills among those showing discrepant profiles.

2. Method

2.1. Participants

The study is part of an extensive longitudinal age cohort study (Lerkkanen, Poikkeus, & Ketonen, 2006–2016), which follows up a community sample of children (n = 1,880) from one rural and three urban municipalities in Finland from kindergarten entry (age M = 74.0 months ± 3.6 months) to the end of Grade 9 (age 15). The children comprised the whole age cohort from the rural and from two of the three urban municipalities, and about half of the age cohort from the remaining urban municipality. All parents were asked for written consent for their child to participate.

The present study included all children for whom data were available for reading and arithmetic skills at the end of Grades 1 and/or 7, as well as for their linguistic and basic number skills (phonological awareness, letter knowledge, rapid automatized naming, counting sequence knowledge) in kindergarten. This resulted in a total sample size of 1,710 children (52.2% boys, 47.8% girls). The children were five to six years of age upon entering kindergarten in the Fall (M = 73.95 months, SD = 3.49 months). Of the children's mothers, 26.1% had a Master's degree or higher, 30.8% a Bachelor's degree or vocational college degree, 28.5% a vocational school degree, and 6.8% had taken vocational courses or had no education beyond lower secondary school. Of the children's fathers, 20.8% had a Master's degree or higher, 33.1% a Bachelor's degree or vocational college degree, 35.0% a vocational school degree, and 8.5% had taken vocational courses or had no education beyond lower secondary school. This was relatively representative of the average family background characteristics in Finland (Official Statistics of Finland (OSF): Educational structure of population [e-publication], 2017). Additional background information regarding working memory, short-term memory and inattention/hyperactivity was available for a subsample of 480 to 584 children participating in individual test situations and receiving teacher ratings in Grade 1.

In Finland, the basic compulsory education consists of Grades 1 to 6 in primary school, followed by Grades 7 to 9 in lower secondary school. Before the start of primary school in the year the child turns 7 years old, there is an obligatory year of kindergarten for 6-year-olds. With regard to academic skills, the preschool curriculum supports pre-literacy and pre-numeracy skills, but formal and systematic reading and arithmetic instruction starts in Grade 1. The data concerning linguistic and basic number skills (phonological awareness, letter knowledge, rapid automatized naming, counting sequence knowledge) were assessed individually during the last year of kindergarten, and the data on reading and arithmetic skills were assessed in group settings during the Spring term (March/April) of Grades 1 and 7. General cognitive abilities, including working memory and short-term memory, were assessed individually in Grade 1, and nonverbal reasoning in Grade 3. All tests were carried out by trained researchers or students of psychology/education.

2.2. Measurements

2.2.1. Cognitive variables in kindergarten

2.2.1.1. Phonological awareness. Phonological awareness was assessed individually by using an initial phoneme identification task (Lerkkanen et al., 2006). The task contained ten items (phonemes) for which students were shown the pictures of four objects at the same time and told their names. After this, the children were asked to indicate the picture that began with the phoneme requested. (e.g., "At the beginning of which word do you hear ___?"). The score was based on the total number of correct items (maximum = 10). Cronbach's alpha reliability based on the current sample was.78.

2.2.1.2. Letter knowledge. The Letter Knowledge Test (Lerkkanen et al., 2006) included all 29 uppercase letters of the Finnish alphabet arranged along three rows in a random order. Each child was asked to name the letters one row at a time, and the sum score was the number of correct items (maximum = 29). Cronbach's alpha reliability based on the current sample was 0.95.

2.2.1.3. Rapid automatized naming (RAN). Rapid automatized naming was assessed using the standardized Finnish version, by Ahonen, Tuovinen, and Leppäsaari (1999), of an object naming task (Denckla & Rudel, 1974). Each child was asked to name, as rapidly as possible, a series of five familiar visual stimuli replicated 10 times on a matrix in fixed, pseudorandom order. Documented errors and self-corrections were few, and they were not included in the analysis. The score was the time (in seconds) children needed to complete the total matrix (five rows of 10 items). According to the manual, the test–retest reliability coefficients ranged from 0.84 to 0.92 for all age groups (Zhang et al., 2005).

2.2.1.4. Counting sequence knowledge. In the Number Sequences Test (Salonen et al., 1994), each child was asked to count aloud forward and backward as instructed: (1) counting forward from number 1 (counting was stopped after 31); (2) counting forward from number 6 to 13; (3) counting backward from number 12 (counting was stopped after 7); and (4) counting backward from number 23 to 1. For each of the four tasks, two points were given for the correct outcome, one point for completing the task with up to two errors, and zero points if the student made more than two errors or failed to complete the task (maximum score = 8). Cronbach's alpha reliability based on the current sample was 0.74.

2.2.2. Outcome variables for Grades 1 and 7

2.2.2.1. Reading skills. On average, Finnish students can fluently read whole sentences by the end of Grade 1 (Lerkkanen, 2003). The Test of Silent Reading Efficiency and Comprehension (TOSREC; Wagner, Torgesen, Rashotte, & Pearson, 2009; Finnish version by Lerkkanen, Poikkeus, & Ketonen, 2008) was used to assess silent reading efficiency at the end of Grade 1. In this sentence verification task respondents were given three minutes to read 60 sentences (e.g., "*Strawberries are blue"*) and instructed to rate the sentences as correct or incorrect as accurately and rapidly as they can. At the end of Grade 7, a sentence verification task from a standardized Finnish reading test for lower secondary school was used (YKÄ; Lerkkanen, Eklund, Löytynoja, Aro, & Poikkeus, 2018). Participants were given two minutes to read 70 sentences and instructed to rate the sentences as correct or incorrect as accurately and rapidly as they can. The outcome score for all tasks was the number of correct answers given within the time limit. Both tests had the same aim and used the same instructions but featured different items and a different number of items. Correlations between different tests were very similar to the stability correlates within tests, suggesting that the same skill was assessed despite changes in test items. Similar measures have been used in previous studies examining the comorbidity of fluency problems in reading and arithmetic (see Landerl & Moll, 2010). The Cronbach's alpha reliabilities for the test in the current sample were 0.89 at Grade 1 and 0.94 at Grade 7.

2.2.2.2. Arithmetic skills. The Basic Arithmetic test (Aunola & Räsänen, 2007) was used to assess students' arithmetic skills at the end of Grades 1 and 7. The students were asked to complete as many items as possible within a three-minute time limit. In Grade 1, the test consisted of 14 additions (e.g., *2 + 1 = _?; 3 + 4 + 6 = _?*) and 14 subtractions (e.g., *4 – 1 = _?; 20 – 2 – 4 = _?*). In Grade 7, the test consisted of a mix of addition, subtraction, multiplication and division tasks (e.g., *40 : 8 – 3 = _?; _ – 18 = 45 – 12?; 11 × 3.2 = _?; 6 × 4 + 1 = _ – 21?*). In total, 28 items increasing in difficulty were presented. In terms of performance, the test requires both accuracy and speed (automatization of basic calculation routines). The sum score represents the total number of correct items and was calculated separately for each grade (maximum = 28). The Cronbach's alpha reliabilities for arithmetic skills in the current sample were 0.70 at Grade 1 and 0.94 at Grade 7.

2.2.3. Background variables

2.2.3.1. Working memory and short-term memory. Working memory and short-term memory were assessed individually at the end of Grade 1, using the Digit Span subtest of the WISC-III (Wechsler, 1991). There are two parts in this test: *digits forward* and *digits backward*. As it has been suggested that Digit Span Forward captures verbal short-term memory while Digit Span Backward is an index of working memory, two different variables were created (Alloway, Gathercole, & Pickering, 2006). The maximum score for the working memory measure was 14 points. In the short-term memory measure, the maximum score was 16 points. According to the manual (Wechsler, 2012), the Cronbach's alpha reliabilities for Digit Span subtests vary from 0.55 to 0.70 for different age groups.

2.2.3.2. Nonverbal reasoning. The students' nonverbal reasoning was tested at the end of Grade 3 in classrooms using the shortened version of the Raven's Colored Progressive Matrices test (Raven, Court, & Raven, 1992). The maximum score was 18. In the current sample, the Guttman split-half reliability of the test was 0.66 and Cronbach's alpha reliability 0.64.

2.2.3.3. Parental education level. Of the students' parents, 1,574 mothers (92.1%) and 1,569 fathers (91.8%) filled in the

Table 1
Correlations, means, and standard deviations of the study variables in a sample of 1710 children.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Reading skills T1	1.00												
2. Arithmetic skills T1	0.46***	1.00											
3. Reading skills T2	0.54***	0.27***	1.00										
4. Arithmetic skills T2	0.36***	0.52***	0.36***	1.00									
5. Phonological awareness	0.40***	0.24***	0.22***	0.21***	1.00								
6. Letter knowledge	0.49***	0.35***	0.30***	0.30***	0.56***	1.00							
7. Rapid automatized naming	−0.36***	−0.29***	−0.29***	−0.24***	−0.26***	−0.34***	1.00						
8. Counting sequence knowledge.	0.43***	0.47***	0.27***	0.40***	0.41***	0.59***	−0.28***	1.00					
9. Short-term memory	0.24***	0.17***	0.25***	0.12*	0.24***	0.21***	−0.19***	0.23***	1.00				
10. Working memory	0.31***	0.28***	0.18**	0.22***	0.24***	0.23***	−0.15***	0.32***	0.27***	1.00			
11. Inattention / hyperactivity	−0.04	−0.01	−0.09	0.02	−0.07	−0.34***	0.12*	−0.03	−0.06	−0.10*	1.00		
12. Nonverbal reasoning	0.21***	0.22***	0.22***	0.28***	0.23***	0.20***	−0.20***	0.21***	0.20***	0.25***	−0.19***	1.00	
13. Parental education level	0.14***	0.14***	0.13***	0.21***	0.21***	0.24***	−0.13***	0.16***	0.05	0.06	−0.05	0.11***	1.00
M	18.32	10.60	33.59	13.88	7.54	17.32	69.79	4.53	5.84	3.04	9.34	16.65	4.47
SD	8.03	4.09	7.41	3.80	2.40	8.89	16.98	2.81	1.32	1.15	1.48	1.73	1.49

Note. T1 = March/April of Grade 1, T2 = March/April of Grade 7. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Rapid automatized naming was scored as reaction time (low scores representing high performance and high scores representing low performance).

questionnaires reporting their vocational education on a 7-point scale (1 = *no education beyond comprehensive school,* 2 = *vocational courses,* 3 = *vocational school degree,* 4 = *vocational college degree,* 5 = *polytechnic degree or Bachelor's degree,* 6 = *Master's degree,* and 7 = *licentiate or doctoral degree*). The education level of the parent with a higher education was used as an indicator of parental education level.

2.2.3.4. Inattention/hyperactivity. Teacher-ratings of inattention and hyperactivity were collected at the end of Grade 1, using the inattention/hyperactivity subscale of the Strengths and Difficulties Questionnaire for 4–16-year-olds (SDQ 4–16; Goodman, 1997). The questionnaire consists of five questions that are rated on a 3-point scale (1 = *not true,* 2 = *somewhat true,* and 3 = *true*). Cronbach's alpha reliability for the inattention/hyperactivity subscale was 0.90.

2.3. Analysis strategy

First, latent profile analysis (LPA) was used for identifying homogeneous subgroups (i.e., profiles) of children that show similar response patterns in variables related to linguistic and basic number skills (phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge). The goal of LPA is to identify the fewest number of latent profiles that adequately explain the unobserved heterogeneity of the relationships between indicators within a population (Orri et al., 2007). Estimation was performed step-by-step, starting with a one-class solution and continuing to estimate the parameters for two-, three-, and further k-class solutions. To ensure the validity of each class solution, several different starting values were used for the parameters (see Muthén & Muthén, 1998–2011).

The following statistical criteria were used to evaluate the fit of the model in order to find the optimal number of latent profiles regarding linguistic and basic number skills: (a) log likelihood (Log L); (b) Akaike's information criterion (AIC); (c) the sample-size adjusted Bayesian information criterion (aBIC); (d) the Vuong-Lo-Mendel-Rubin test (VLMR); (e) the Lo-Mendel-Rubin test (LMR); (f) the parametric bootstrapped likelihood ratio test (BLRT; Muthén & Muthén, 1998–2007); (g) the reliability of classification by entropy; and (h) average latent class posterior probabilities (AvePP; Muthén & Muthén, 1998–2007). The lower the absolute value of the Log L, AIC, and aBIC, the better the model fit. The likelihood ratio tests (VLMR, LMR, and BLRT) compare solutions with different numbers of latent profiles. A low *p* value ($p < .05$) suggests that a solution with k latent profiles fits the data better than a solution with k-1 profiles. The entropy and AvePP indices assess the statistical quality of the classification (i.e., how well the model classifies individuals into subgroups), with possible values ranging from 0 to 1. As a rule of thumb, values > 0.70 indicate that the found solution is interpretable using the mean trajectories (Nagin, 2005).

Second, in order to examine potential differences between the domain-general cognitive profiles and parental education, we included working memory, short-term memory, nonverbal reasoning, inattention/hyperactivity, and parental education level into the previous model as auxiliary indicator variables in line with the auxiliary measurement-error-weighted method (BCH; Muthén & Asparouhov, 2015). This method enables the testing of differences between the latent groups in some external variables (so-called auxiliary variables) with a Chi-square test, without letting these external variables affect the formation of the latent profiles. Finally, to examine the extent to which the identified cognitive profiles predict subsequent reading and arithmetic skills in Grades 1 and 7, reading in Grade 1, arithmetic in Grade 1, reading in Grade 7, and arithmetic in Grade 7 were included in the model as auxiliary indicator variables, and differences between the latent profiles on these were tested using a Chi-square test. In this context, the overlap of the levels of reading and arithmetic skills within groups was investigated by comparing the 95% confidence intervals of the mean values of reading and arithmetic skills within each group, both for Grade 1 and Grade 7 separately.

When considering the magnitude of the studied effects, mean differences between the subgroups of children showing different latent profiles divided by the standard deviation of the whole sample were used as indicators of effect size. Mean differences over 0.80 were considered large, mean differences between 0.50 and 0.80 were considered medium, and values between 0.20 and 0.50 were considered small (Cohen, 1992).

All analyses were performed using the Mplus statistical software program (Version 7.0) and the standard missing-at-random (MAR) approach, which supposes that any data missing would be missing at random (Muthén & Muthén, 1998–2010). The parameters of the models were estimated using full information maximum likelihood (FIML) estimation with standard errors robust to non-normality (MLR estimator; Muthén & Muthén, 1998–2010). Means *(M)*, standard deviations *(SD)*, and the correlations between all variables are shown in Table 1.

3. Results

3.1. Cognitive profiles based on linguistic and basic number skills

First, we aimed to identify the cognitive profiles with regard to linguistic and basic number skills (phonological awareness, letter knowledge, rapid automatized naming, and counting sequence

Table 2
Comparison of the latent profile analysis solutions with one to seven classes (selected solution in bold).

Classes	Log L	AIC	aBIC	VLMR (*p*)	LMR (*p*)	BLRT (*p*)	Entropy	AvePP	*n*
1	−9680.902		19377.803	19395.942					1710
2	−8834.622	17695.244	17724.720	0.0000	0.0000	0.0000	0.82	0.94–0.95	735/ 975
3	−8654.747	17345.494	17386.307	0.0000	0.0000	0.0000	0.84	0.88–0.95	463/531/716
4	**−8518.578**	**17083.156**	**17135.305**	**0.0000**	**0.0000**	**0.0000**	**0.83**	**0.82–0.95**	**671/434/262/343**
5	−8434.284	16924.567	16988.053	0.0771	0.0813	0.0000	0.85	0.82–0.95	426/20/261/332/671
6	−8383.752	16833.505	16908.328	0.0031	0.0036	0.0000	0.82	0.81–0.94	21/142/298/315/663/271
7	−8318.643	16713.287	16799.447	0.3191	0.3274	0.0000	0.83	0.79–0.94	21/157/211/238/311/129/643

Note. Log L = log-likelihood value; AIC = Akaike's information criterion; aBIC = adjusted Bayesian information criterion; VLMR = Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR = Lo-Mendell-Rubin adjusted likelihood test; BLRT = Bootstrapped likelihood ratio test; AvePP = Average Latent Class Posterior Probabilities.

knowledge) assessed in kindergarten using LPA. The model fit indices and class sizes of the one- to seven-class solutions are shown in Table 2. A comparison of the statistical fit information suggested that the four-class solution was the best for further analysis. Although the fit indices regarding the absolute Log L, AIC, and aBIC decreased even after the four-class solution, the changes in values beyond the four-class solution were only small, suggesting that the improvement of the fit was not remarkable. Furthermore, most of the likelihood ratio tests (VLMR, LMR) indicated that the four-class solution fit the data better than the five-class solution. Finally, the class sizes were taken into account. The solutions with more than four classes included a class consisting of only 20–21 individuals, which makes it difficult to generalize the findings. The statistical quality of the classification based on entropy and AvePP values was acceptable concerning all class solutions, from 1 to 7.

The standardized means and estimated class probabilities for the selected four-class solution are listed in Table 3. The four identified latent profiles are shown in Fig. 1: (1) high linguistic and high counting skills, (2) low linguistic and low counting skills, (3) high counting skills in relation to linguistic skills, and (4) low counting skills in relation to linguistic skills. The given labels were based on the relation between linguistic and counting skills within profiles. Accordingly, the "high linguistic and high counting skills" children were performing above average in phonological awareness, letter knowledge, rapid automatized naming, and also counting, whereas the "low linguistic and low counting skills" children were performing below average across these skills. Children in the "high counting skills in relation to linguistic skills" and "low counting skills in relation to linguistic skills" profiles showed a discrepancy between linguistic and counting skills. The children with "high counting skills in relation to linguistic skills" performed at or below the average level in phonological awareness, letter knowledge, and rapid automatized naming but above average in counting. Children with "low counting skills in relation to linguistic skills," on the other hand, performed at the average level across linguistic skills but below average in counting.

The effect sizes (i.e., group differences in standardized values of criteria variables; see standardized mean values in Table 3) of group differences in criteria variables varied from small to large. When comparing profiles showing either consistent high or consistent low skill level—that is, profiles 1 and 2—the effect sizes were large (> 0.80) across all criteria variables. Regarding the differences between the two more discrepant profiles, that is, profiles 3 and 4, the effect sizes were large (> 0.80) for counting and letter knowledge, and small (> 0.20) for the other variables. Regarding the differences between profiles 1 and 4, as well as the differences between profiles 2 and 3, the effect size was large (> 0.80) for counting and from small (> 0.20) to medium (> 0.50) for the other variables. The effect sizes between profiles 1 and 3 and between profiles 2 and 4 were large (> 0.80) for phonological awareness and letter knowledge and from small to medium (< 0.80) for the other variables.

Next, the differences between the four cognitive profiles in general cognitive variables—that is, nonverbal reasoning ($\chi^2(3) = 75.00$, $p < .001$), short-term memory ($\chi^2(3) = 25.54$, $p < .001$), working memory ($\chi^2(3) = 23.64$, $p < .001$), and inattention/hyperactivity ($\chi^2(3) = 1.46$, $p > .05$), as well as in parental education level ($\chi^2(3) = 84.07$, $p < .001$)—were investigated. Statistically significant group differences were found in all of the external variables with effect sizes ranging from small to medium, except for inattention/hyperactivity, in which the variable group differences were not evident. The differences between the profile groups in these variables are shown in Table 4 and Fig. 2. Children characterized by high linguistic and high counting skills (Profile 1) and those characterized by high counting skills in relation to linguistic skills (Profile 3) performed significantly better in short-term memory and working memory than the children in the other two groups. Regarding nonverbal reasoning, children showing high linguistic and high counting skills (Profile 1) performed significantly better, and children showing low linguistic and low counting skills (Profile 2) performed significantly poorer than the other groups, whereas the children belonging to the other two profiles performed at the average level and did not differ from each other. The level of parental education was significantly highest among children characterized

Table 3
The results of the four-class solution: standardized means (M), standard errors (S.E.), and average posterior probabilities (AvePP) for each latent cognitive profile regarding linguistic and basic number skills.

Cognitive profiles	1 *M (S.E.)*	2 *M (S.E.)*	3 *M (S.E.)*	4 *M (S.E.)*
Phonological awareness	0.63 (0.03)[a]	−0.78 (0.06)[b]	−0.35 (0.07)[c]	0.03 (0.07)[d]
Letter knowledge	0.92 (0.02)[a]	−1.24 (0.04)[b]	−0.62 (0.06)[c]	0.25 (0.06)[d]
Counting sequence knowledge	0.84 (0.03)[a]	−1.16 (0.03)[b]	0.59 (0.05)[c]	−0.70 (0.06)[d]
Rapid automatized naming	0.38 (0.03)[a]	−0.50 (0.06)[b]	−0.17 (0.08)[c]	0.01 (0.06)[c]
AvePP	0.95	0.93	0.86	0.82

Note. 1 = High linguistic and high counting skills; 2 = Low linguistic and low counting skills; 3 = High counting skills in relation to linguistic skills; 4 = Low counting skills in relation to linguistic skills; AvePP = Average Latent Class Posterior Probabilities.
Subscripts: Means with the same subscript do not differ significantly from each other.

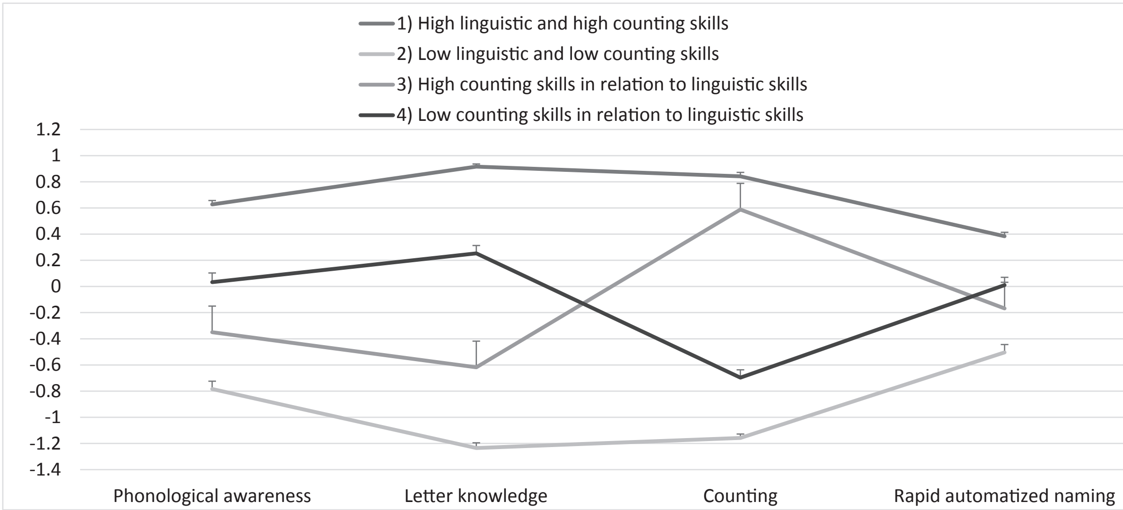

Fig. 1. Cognitive profiles based on linguistic and basic number skills. Lines represent different patterns of performance across phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge (i.e., cognitive profiles).

by high linguistic and high counting skills (Profile 1) and lowest among children characterized by low linguistic and low counting skills (Profile 2) together with children showing high counting skills in relation to linguistic skills (Profile 3).

3.2. The association between cognitive profiles and reading and arithmetic skills in Grades 1 and 7

Next, we analyzed to what extent the identified cognitive profiles are associated with children's subsequent reading and arithmetic skills in Grades 1 and 7. The results showed statistically significant group differences between the latent cognitive profiles in reading and arithmetic skills both in Grade 1 [$\chi^2(3) = 567.68, p < .001$ for reading; $\chi^2(3) = 402.64, p < .001$ for arithmetic] and Grade 7 [$\chi^2(3) = 123.42, p < .001$ for reading; $\chi^2(3) = 212.87, p < .001$ for arithmetic]. The differences between the profile groups are shown in Table 5 and Fig. 3.

The results showed that, both in Grades 1 and 7, children characterized by high linguistic and high counting skills (Profile 1) performed significantly highest, whereas children characterized by low linguistic and low counting skills (Profile 2) performed significantly lowest both in reading and arithmetic. The 95% confidence intervals revealed further that, in the case of profile 1, performance in reading and in arithmetic were on the same level (i.e., demonstrated overlap) in Grade 1 (CI [0.53, 0.69] for reading, CI [0.43, 0.59] for arithmetic) and in Grade 7 (CI [0.26, 0.46] for reading, CI [0.37, 0.53] for arithmetic). Similarly, in the case of profile 2, performance in reading and in arithmetic were on the same level in Grade 1 (CI [–0.78, –0.62] for reading, CI [–0.67, –0.51] for arithmetic) and in Grade 7 (CI [–0.64, –0.36] for reading, CI [–0.69, –0.41] for arithmetic). Overall, these results suggest that in the case of profiles showing either consistent high or low levels of linguistic and counting skills—that is, profiles 1 (high linguistic and high counting skills) and 2 (low linguistic and low counting skills)—reading and arithmetic skills were on the same level, demonstrating overlap from primary to lower secondary school.

The other two profiles—high counting skills in relation to linguistic skills (Profile 3) and low counting skills in relation to linguistic skills (Profile 4)—were associated with somewhat discrepant reading and arithmetic performances in Grades 1 and 7, and the overlap between reading and arithmetic skills was less evident. Children characterized by high counting skills in relation to linguistic skills (Profile 3) performed in between the ones with "high linguistic and high counting skills" and those with "low linguistic and low counting skills" in reading and arithmetic across both grades. Furthermore, they scored significantly higher in arithmetic (CI [0.01, 0.29]) than in reading (CI [–0.32, –0.08]) in Grade 1, but they showed overlap between reading (CI [–0.34, –0.06]) and arithmetic (CI [–0.12, 0.20]) skills in Grade 7. Children characterized by low counting skills in relation to linguistic skills (Profile 4) in turn performed similarly in between the children with "high linguistic and high counting skills" and those with "low linguistic and low counting skills" in reading at Grades 1 and 7. In arithmetic, they performed at a level between the children with "high counting skills in relation to linguistic skills" and those with "low linguistic and low counting skills" in Grade 1, and they performed lowest together with those with "low linguistic and low counting skills" in Grade 7. In Grade 1, their skills in arithmetic (CI [–0.50, –0.30]) and in

Table 4
Means (M) and standard errors (S.E.) of the children's general cognitive abilities and parental education level in each cognitive profile, and statistically significant differences between the four patterns.

Cognitive profiles	1 *M (S.E.)*	2 *M (S.E.)*	3 *M (S.E.)*	4 *M (S.E.)*
Short-term memory	0.38 (0.09)[a]	−0.20 (0.09)[b]	0.35 (0.15)[ac]	0.02 (0.12)[bc]
Working memory	0.41 (0.09)[a]	−0.09 (0.10)[b]	0.43 (0.17)[a]	−0.17 (0.12)[b]
Inattention /hyperactivity	−0.01 (0.09)[a]	−0.04 (0.12)[a]	0.06 (0.23)[a]	−0.22 (0.15)[a]
Nonverbal reasoning	0.25 (0.03)[a]	−0.34 (0.07)[b]	0.03 (0.07)[c]	−0.11 (0.07)[c]
Parental education level	0.27 (0.04)[a]	−0.30 (0.05)[b]	−0.22 (0.07)[b]	−0.00 (0.07)[c]

Note. 1 = High linguistic and high counting skills; 2 = Low linguistic and low counting skills; 3 = High counting skills in relation to linguistic skills; 4 = Low counting skills in relation to linguistic skills. Subscripts: Means with the same subscript do not differ significantly from each other.

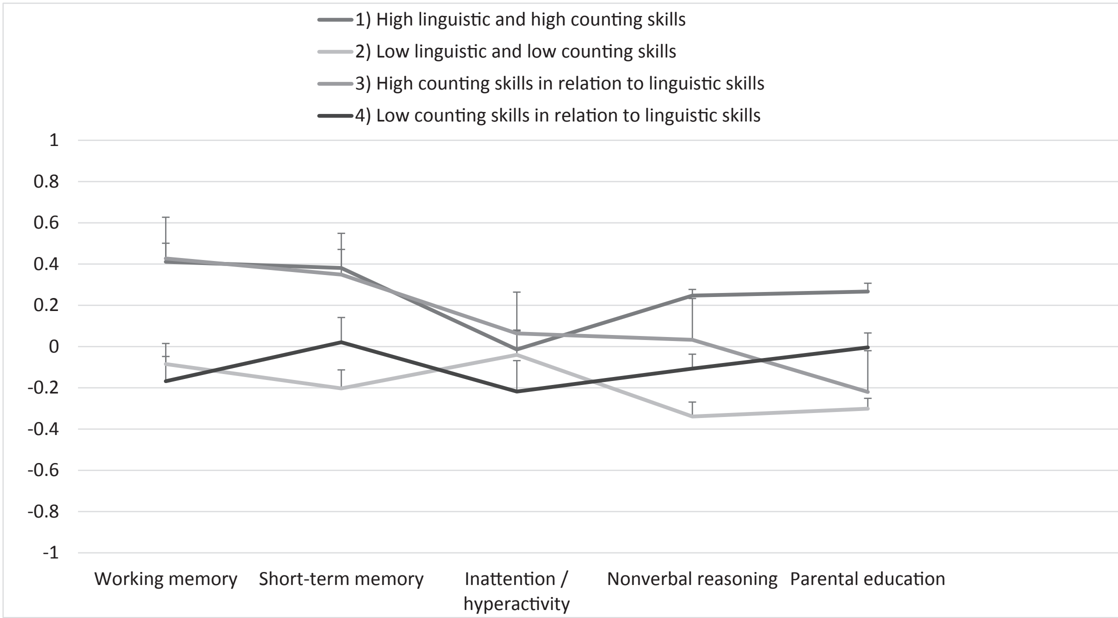

Fig. 2. Differences between the cognitive profiles in control variables. Lines represent differences between the profiles in general cognitive abilities and parental education.

reading (CI [–0.32, –0.08]) were on the same level, indicating overlap between these skills. However, in Grade 7, their skills in reading (CI [–0.21, 0.07]) were at a higher level than their skills in arithmetic (CI [–0.57, –0.29]), demonstrating a discrepancy rather than an overlap between reading and arithmetic.

The effect sizes (i.e., group differences in standardized values of dependent variables; see standardized mean values in Table 5) between the two consistent profiles, that is, profiles 1 and 2, were large (> 0.80) across all dependent variables (reading Grade 1, arithmetic Grade 1, reading Grade 7, arithmetic Grade 7). The two discrepant profiles—that is, profiles 3 and 4—differed from each other only in arithmetic: the effect size ranging from small (> .20) (Grade 7) to medium (> .50) (Grade 1). Differences between the profiles 1 and 4 were large (> .80) in arithmetic (Grade 1 and 7) and from small (> .20) (Grade 7) to large (> .80) (Grade 1) in reading, and differences between the profiles 1 and 3 were from medium (> .50) (Grade 7) to large (> .80) (Grade 1) in reading and small (> .20) in arithmetic (Grade 1 and 7). Finally, differences between the profiles 2 and 3 varied from small (> .20) (reading Grade 7) to medium (> .50) (reading Grade 1 and arithmetic Grade 1 and Grade 7), and differences between the profiles 2 and 4 varied from small (> .20) (arithmetic Grade 1 and reading Grade 7) to medium (> .50) (reading Grade 1).

4. Discussion

In the present study, we applied a person-oriented approach in order to improve our understanding of the cognitive antecedents related to the overlap between reading and arithmetic skills from primary to lower secondary school. Specifically, we investigated the extent to which different patterns of performance across linguistic and basic number skills predict the overall performance level in reading and arithmetic. Subgroups of children showing distinct cognitive profiles in kindergarten with regard to phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge were identified. Furthermore, the relations of these cognitive profiles to reading and arithmetic skills assessed at Grades 1 and 7 were examined. Four distinct cognitive profiles emerged: (1) high linguistic and high counting skills, (2) low linguistic and low counting skills, (3) high counting skills in relation to linguistic skills, and (4) low counting skills in relation to linguistic skills. These profiles differentially predicted subsequent reading and arithmetic development as well as the overlap between the two academic skills at Grades 1 and 7.

First, the results showed that the majority of the children (about 65%) demonstrated overall either high or low linguistic and counting skills, and, accordingly, either high or low levels in both reading and arithmetic skills, tested in Grades 1 and 7. These two profiles thus demonstrated overlap not only between early linguistic and basic number skills but also between reading and arithmetic skills across school

Table 5
Means (M) and standard errors (S.E.) of the children's reading and arithmetic skills in grades 1 and 7 for latent cognitive profiles and statistically significant differences between the patterns.

Cognitive profiles	1 *M (S.E.)*	2 *M (S.E.)*	3 *M (S.E.)*	4 *M (S.E.)*
Reading skills, Grade 1	0.61 (0.04)[a]	−0.70 (0.04)[b]	−0.20 (0.06)[c]	−0.20 (0.06)[c]
Arithmetic skills, Grade 1	0.51 (0.04)[a]	−0.59 (0.04)[b]	0.15 (0.07)[c]	−0.40 (0.05)[d]
Reading skills, Grade 7	0.36 (0.05)[a]	−0.50 (0.07)[b]	−0.20 (0.07)[c]	−0.07 (0.07)[c]
Arithmetic skills, Grade 7	0.45 (0.04)[a]	−0.55 (0.07)[b]	0.04 (0.08)[c]	−0.43 (0.07)[b]

Note. 1 = High linguistic and high counting skills; 2 = Low linguistic and low counting skills; 3 = High counting skills in relation to linguistic skills; 4 = Low counting skills in relation to linguistic skills. Subscripts: Means with the same subscript do not differ significantly from each other.

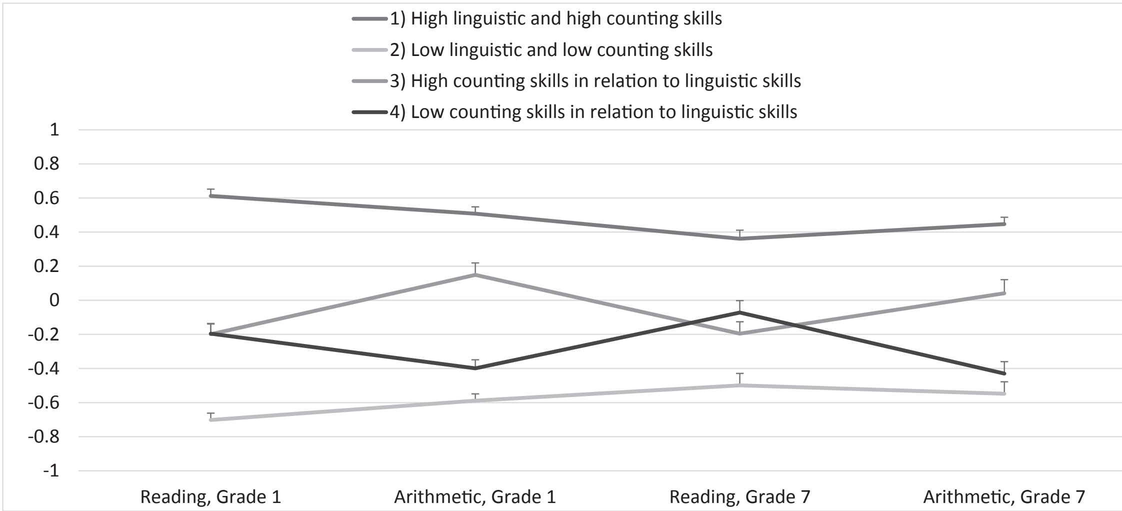

Fig. 3. Differences between the cognitive profiles in reading and arithmetic skills in Grades 1 and 7. Lines represent outcomes in reading and arithmetic skills in Grades 1 and 7 by different cognitive profiles.

grades. The differences between these two profiles in the levels of subsequent reading and arithmetic skills were notable. Taking into account the fact that the studied linguistic and basic number skills have previously been shown to have additive impacts (i.e., an increase in each independent variable adds independently to the predicted value) on the overlap of reading and arithmetic skills in studies using a variable-oriented approach (Korpipää et al., 2017, 2019), it is not surprising that children demonstrating high levels in all of these cognitive antecedents also show high skill levels in both reading and arithmetic, whereas children with low levels in all of these cognitive antecedents show the lowest performance levels in reading and arithmetic. In previous research, fluency in both reading and arithmetic has been shown to build on the ability to form and retrieve phonological representations corresponding to visually presented symbols, such as letters and digits, as well as on the ability to process serial information (Koponen et al., 2007, 2016). Furthermore, the central manifestation of both difficulties in reading (Fuchs, Fuchs, Hosp, & Jenkins, 2001) and math (Geary, 2004) relates to a lack of fluency. As such, these two cognitive profiles represent the high and low end of reading and arithmetic skills, supporting the idea that the attributes of learning difficulties in reading and math are dimensional and represent a correlated continua of severity (Branum-Martin, Fletcher, & Stuebing, 2013).

On the other hand, the results of the present study also showed that one-third of the sample (35.4%) demonstrated discrepant linguistic and basic number skills and, accordingly, somewhat discrepant levels of reading and arithmetic skills in Grades 1 and 7. The first discrepant group comprised children with high counting skills in relation to linguistic skills. As expected, children with this profile performed higher in arithmetic than in reading in Grade 1. Interestingly, in Grade 7, these differences between reading and arithmetic skills were somewhat less evident. This result may reflect a slower development of reading skills in the early phase of skill development in this group of children. As a result, the reading skills of children with high counting skills in relation to linguistic skills were not, during the transition stage to primary school, at the same level. The awareness of letters and sounds has been shown to be particularly important in the development of basic word decoding skills (Hogan, Catts, & Little, 2005; Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012), whereas rapid automated naming is a predictor of later growth in reading fluency (Lervåg & Hulme, 2009; see also Landerl et al., 2019). However, once children have acquired all the needed subskills to learn to read (Hulme & Snowling, 2013), there is a rapid increase in their reading performance and decrease in inter-individual variation (Leppänen, Niemi, Aunola, & Nurmi, 2004). In line with this, phonological awareness and letter-sound knowledge have been shown to predict the overlap between reading and arithmetic mainly in the early phase of skill development (Korpipää et al., 2017). The strengths in cognitive antecedents that are strongly related to developing fluency in both domains, such as rapid automatized naming and counting sequence knowledge (Koponen et al., 2013; 2016), are likely to explain the overlap between reading and arithmetic especially in Grade 7.

The other discrepant group included children with low counting skills in relation to linguistic skills. Children with this profile showed an overlap between reading and arithmetic skills in Grade 1, but they performed higher in reading than in arithmetic in Grade 7. This pattern may also be due to different developmental trajectories of reading and arithmetic skills: whereas individual differences in reading ability decrease across school years (Leppänen et al., 2004; Parrila, Aunola, Leskinen, & Nurmi, 2005), differences in arithmetic ability rather increase (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004). Kindergarten counting has been shown to be the strongest predictor of this cumulative development of arithmetic skills (Aunola et al., 2004; Zhang et al., 2014). Counting is related to developing memory representations of arithmetic facts and more mature strategies of retrieving these facts from long-term memory (Geary, 2004; Siegler & Shranger, 1984). Consequently, counting sequence knowledge continues to exert its influence on arithmetic ability until higher grades (Koponen et al., 2016). Following this line of reasoning, poor basic number skills in kindergarten may lead the child to lag behind his or her peers, particularly concerning arithmetic ability. Furthermore, children in this group had more strengths regarding the shared cognitive antecedents of reading and arithmetic skills at an early rather than later phase of skill development, such as phonological awareness and letter knowledge (Korpipää et al., 2017). It is likely that the overlap between reading and arithmetic is therefore more evident in Grade 1 than in Grade 7.

In the present study, children who showed high counting skills in relation to linguistic skills performed lower in arithmetic across the grades than did the children who showed high linguistic and high counting skills (the effect was, however, small). This result can be interpreted to stem from the children's weaknesses in linguistic skills. It has been shown that weaknesses in linguistic skills have a negative impact on developing arithmetic skills (Geary, 1993; Jordan, Hanich, & Kaplan, 2003; Simmons & Singleton, 2008), and this negative effect seems to be independent of the effect of counting skills. Children showing low counting skills in relation to linguistic skills, in turn, performed low in arithmetic in Grades 1 and 7 despite their average linguistic skills. It is likely that, in this profile, low arithmetic skills derive mainly from weaknesses in number-specific skills rather than from weaknesses in representing and accessing semantic information (Locuniak & Jordan, 2008). However, further research is needed to clarify the issue. Overall, having strengths in one of the skill domains seems to be somewhat advantageous (effect sizes ranging from small to medium) over having weaknesses in both domains. Particularly, a high level of counting skills may function as a compensator for poor letter knowledge and phonological awareness. It has been previously reported that deficits in both domains can lead to more severe and stable impairments in academic functioning (Koponen et al., 2018; see also Willcutt et al., 2013). The results of our study point toward the importance of both shared and nonshared influences of linguistic and basic number skills on reading and arithmetic skill development, supporting the findings by Cirino et al. (2018).

Children with different cognitive profiles were also found to differ from each other with respect to more general cognitive factors, such as short-term memory, working memory, and nonverbal reasoning, as well as parental education (the effect sizes varying from small to medium). In the profiles of consistent linguistic and basic number skills, children differed across all of these measures: children showing high linguistic and high basic number skills performed highest, whereas children showing low linguistic and low basic number skills performed lowest. In the profiles of discrepant linguistic and basic number skills, children differed mainly in terms of memory measures. Children showing high basic number skills in relation to linguistic skills performed highest, and children showing low basic number skills in relation to linguistic skills performed lowest regarding working memory and short-term memory. These results are in line with previous findings suggesting that children with difficulties in math tend to have a weaker working memory capacity than children showing normal math achievement (Swanson & Beebe-Frankenberger, 2004). As working memory systems play an important role in arithmetic (Cragg, Richardson, Hubber, Keeble, & Gilmore, 2017; De Smedt et al., 2009), it is likely that the discrepancy between linguistic and basic number skills, as well as between subsequent reading and arithmetic skills, is at least partly related to working memory capacity. It should be noted, however, that—for all profiles—the children's performances across the measures of working memory, short-term memory, nonverbal reasoning, and inattention/hyperactivity were within the average range, and the differences between the profiles in these variables were not large in magnitude. This result is well in line with the recent findings suggesting that cognitively focused interventions (e.g., training working memory) for children with learning difficulties in reading and arithmetic are less efficient than academic or skills-based interventions focusing on improving academic performance (e.g. letter-sound correspondence) (for a review, see Kearns & Fuchs, 2013).

Overall, whereas the earlier research identified the cognitive antecedents that underlie the rather strong overlap between reading and arithmetic skills in Grades 1 and 7 (Korpipää et al., 2017), the present study identified homogeneous subgroups of children that differ qualitatively in terms of patterns of performance across these cognitive antecedents. This made it possible to investigate interactive effects of linguistic and basic number skills on the overlap between reading and arithmetic (i.e., whether these cognitive antecedents predict differently the overlap between reading and arithmetic depending on the levels of each other). As such, the results of this study provide a deeper understanding of how linguistic and basic number skills operate together in predicting reading and arithmetic skills, as well as their overlap, across grade levels.

From a practical point of view, the results provide valuable information for educators to predict the development of reading and arithmetic skills in relation to each other from primary to lower secondary school. The findings suggest that weaknesses in phonological awareness and letter knowledge in kindergarten do not yet place children at risk for low skill level shared by reading and arithmetic. Rather, the risk becomes evident when weaknesses in letter knowledge and phonological awareness show up together with weaknesses in early counting skills. Weaknesses in counting alone in turn place children at risk for difficulties in arithmetic, especially at the later phase of skill development, independently of the levels of different linguistic skills. Thus, for difficulties in arithmetic skill development, weaknesses in counting skills alone are an equal risk to weaknesses evident in both linguistic and counting skills. Another important finding of the present study is that in kindergarten, weaknesses across linguistic and basic number skills are more common than weaknesses in only one of the domains. In previous literature, weaknesses across different domains have been shown to be related to the most severe and persistent problems in both reading and arithmetic (Koponen et al., 2018). Consequently, assessing the cognitive profiles regarding the shared predictors of reading and arithmetic provide additional information concerning the broadness of difficulties at different phases of skill development in these two basic academic domains.

5. Limitations

The following limitations should be taken into account before generalizing the findings of this study. First, cognitive abilities were assessed at different time points: (1) preskills (phonological awareness, letter knowledge, rapid automatized naming, and counting sequence knowledge) in kindergarten; (2) working memory, short-term memory, and inattention/hyperactivity in Grade 1; and (3) nonverbal reasoning in Grade 3. Second, the measures of working memory, short-term memory, and inattention/hyperactivity were available only from a subsample, and we did not have the data to include executive functioning or processing speed as separate outcome variables. Third, basic number skills included only a measure of counting sequence knowledge, which taps the ability to form and access associative relations (see Fuchs et al., 2016). In future studies, it would be interesting to include other subskills of arithmetic, such as number concept (mapping between the symbolic number words and numbers with quantities) and magnitude comparisons as well. Fourth, the transparent orthography of the Finnish language should be considered when generalizing these results to other languages. Due to the highly consistent grapheme–-phoneme correspondence structure, decoding in Finnish requires less advanced phonological processing skills than in more opaque orthographies, such as English.

6. Conclusion

The results of the present study show that, among most of the children, linguistic and basic number skills (in terms of counting skills) were strongly related, which was evident as the children showed either high or low performance levels across all of these skills. This covariation of linguistic and basic number skills predicted overlapping—either high or low overall performance level—in reading and arithmetic skills during primary and lower secondary school. However, among some of the children, linguistic and basic number skills were less related, and the discrepant patterns of linguistic and basic number skills predicted somewhat discrepant levels of subsequent reading and arithmetic skills as well. Furthermore, the weaknesses in both linguistic and counting skills were a more typical pattern than weaknesses in only one of the domains. The results of this study suggest that there is individual variation in the combination of linguistic and basic number skills, and, consequently, these cognitive antecedents predict the overlap between reading and arithmetic differently at early and later phases of development, depending on each individual's cognitive profile. Therefore, individual differences in children's underlying cognitive strengths and weaknesses should be taken into account when supporting the development of these skills.

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