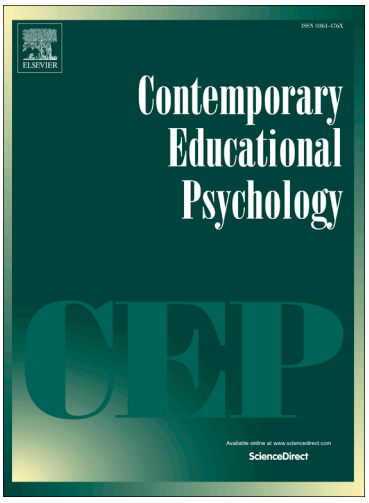

Prematurity and Overlap Between Reading and Arithmetic: The Cognitive Mechanisms Behind the Association

Heidi Korpipä ä, Pekka Niemi, Kaisa Aunola, Tuire Koponen, Minna Hannula-Sormunen, Suvi Stolt, Mikko Aro, Jari-Erik Nurmi, Päivi Rautava, the PIPARI Study Group,

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Authors' Note

Heidi Korpipää (corresponding author), Department of Psychology, P.O.Box 35, FI-40014 University of Jyväskylä, Finland; phone: +358505356678, fax: +358142601021, email: heidi.m.korpipaa@jyu.fi.

Pekka Niemi, Department of Behavioural Sciences and Philosophy, Psychology & Centre for Learning Research, FI-20014 University of Turku, Finland; phone: +35823335058, email: peknie@utu.fi.

Kaisa Aunola, Department of Psychology, P.O.Box 35, FI-40014 University of Jyväskylä, Finland; phone: +358408053481, email: kaisa.aunola@jyu.fi.

Tuire Koponen, Department of Education, University of Jyväskylä, Finland; phone: +358408054629, email: tuire.k.koponen@jyu.fi.

Minna Hannula-Sormunen, Department of Teacher Education, FI-20014 University of Turku, Finland; phone: +358503378740, email: Minna.Hannula-Sormunen@utu.fi.

Suvi Stolt, Department of Psychology and Speech-Language Pathology (Logopedigs), University of Helsinki, Finland; phone: +358294129480, email: suvi.stolt@helsinki.fi.

Mikko Aro, Department of Education, University of Jyväskylä, Finland; phone: +358408053632, email: mikko.t.aro@jyu.fi

Jari-Erik Nurmi (†), Department of Psychology, University of Jyväskylä, Finland.

Päivi Rautava, Turku University Hospital/Research Services and University of Turku, Public Health, Turku, Finland; phone: +358503005846, email: paivi.rautava@tyks.fi

† Deceased 9 October 2017

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Abstract

It is well-known that very preterm children perform at lower levels than full-term children in reading and arithmetic at school. Whether the lower performance levels of preterm children in these two separate domains have the same or different origins, however, is not clear. The present study examined the extent to which prematurity is associated with the overlap (i.e., common variance) of reading and arithmetic among Finnish school beginners. We also examined the extent to which the association of prematurity with the overlap between reading and arithmetic is due to different prereading skills, basic number skills, and general cognitive abilities. The participants (age 6–7) consisted of 193 very preterm children (<32 weeks of gestation or birth weight <1,501 g) and 175 full-term control children assessed at the beginning of Grade 1. The results showed that about 40% of the variation in reading and arithmetic skills was common to these two domains and thus, represented the overlap between reading and arithmetic. Prematurity was found to be negatively associated with the overlapping part of reading and arithmetic skills. This association was explained particularly by differences between very preterm and full-term children in prereading (letter knowledge, phonological awareness, and rapid automatized naming) and basic number skills (counting sequence knowledge): Very preterm children showed lower levels of phonological awareness, letter knowledge, counting, and rapid serial naming than full-term children and thus, also demonstrated lower skill level common for reading and arithmetic. Early screening of very preterm children according to the cognitive antecedents that predict the overlap between reading and arithmetic is needed to prevent comorbid difficulties in these domains.

Keywords: reading, arithmetic, prematurity, overlap, first grade

Prematurity and Overlap Between Reading and Arithmetic:

The Cognitive Mechanisms Behind the Association

Prematurity has been shown to be associated with learning outcomes at school (Dempsey et al., 2015; Keller-Margulis, Dempsey, & Llorens, 2011; Taylor et al., 2016). The risk of academic failure is statistically significantly higher among very preterm compared to full-term children, particularly in math (Aarnoudse-Moens, Oosterlaan, Duivenvoorden, van Goudoever, & Weisglas-Kuperus, 2011; Pritchard et al., 2009) but also in reading (for a review, see Kovachy, Adams, Tamaresis, & Feldman, 2014). Thus far, research on such differences between very preterm and full-term children has focused on each skill domain separately, ignoring the evidence that reading and math are highly correlated skills in population-based samples (Hecht, Torgesen, Wagner, & Rashotte, 2001; Koponen, Aunola, Ahonen, & Nurmi, 2007), and difficulties in these domains co-occur more often than would be expected by chance (Kovas et al., 2007; Landerl & Moll, 2010; Willcutt et al., 2013). The strong overlap between reading and math skills is thought to be caused by a common set of cognitive processes underlying both skills (Hecht et al., 2001; Koponen, Salmi, Eklund, & Aro, 2013; Koponen et al., 2016; Korpipää et al., 2017). Because research on the role of prematurity in learning outcomes has thus far focused on only one domain at time (i.e., reading or math separately), the extent to which prematurity is related to domain-general variation in basic academic skills (i.e., variation that is common for reading and math) rather than domain-specific variation is far from clear. Consequently, the aim of the present study was to examine the extent to which prematurity is associated with the overlap between reading and arithmetic. Moreover, the cognitive mechanisms mediating this association were investigated. Because learning difficulties occurring both in reading and math domains are more severe and persistent over time than difficulties evident only in one domain (Jordan, Hanich, & Kaplan, 2003, see also Koponen et al., 2018; Willcutt et al., 2013), the question is

vitally important from the educational point of view. Understanding the role of prematurity in the overlap between reading and arithmetic may give useful insights not only into the shared background of reading and arithmetic but also into how one should take prematurity into account when supporting children's school learning.

Differences Between Very Preterm and Full-Term Children in Academic Skills and Related Cognitive Correlates

According to the meta-analysis by Kovachy et al. (2014), preterm birth is associated with both fundamental components of reading, decoding and comprehension. It has been shown that between the ages of 5 and 20, very preterm children score 0.48 SD lower in reading tests than their full-term peers (for a review, see Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009). There are also statistically significant differences between the groups regarding many antecedents of reading, such as phonological awareness and letter knowledge (Schneider, Wolke, Schlagmuller, & Meyer, 2004), as well as rapid automatized naming (RAN; Alanko et al., 2017; Saavalainen et al., 2006), which is highly predictive of fluency in reading (Kirby, Georgiou, Martinussen, & Parrila, 2010).

In addition to reading skills, very preterm children between the ages of 5 and 20 years have been found to score 0.60 SD lower than their full-term peers on math tests (for a review, see Aarnoudse-Moens et al., 2009). Evidence indicates that very preterm birth is negatively associated with basic number skills, as well as math skills at school age, such as arithmetic. For example, statistically significant differences between very preterm and full-term children have been found in skills related to number sense (i.e., knowledge of numbers and their relations), and counting sequence knowledge (i.e., the ability to count number words forward, backward, and in steps; Alanko et al., 2017; Guarini et al., 2014). These skills have been shown to be strongly related to arithmetical fluency (Koponen et al., 2013, 2016; Locuniak & Jordan, 2008).

Overall, the findings suggest that despite advances in neonatal intensive care, many very preterm children have subtle cognitive deficiencies that become evident when the children reach school age (for a review, see Aylward, 2005; Roberts, Lim, Doyle, & Anderson, 2011; Taylor et al., 2016). The severity of impairment in cognitive functioning is related to the degree of maturity at birth (Anderson, 2014) but also to parental education and perinatal medical complications (Stålnacke, Lundequist, Böhm, Forssberg, & Smedler, 2015). The cut-offs of 32 gestational weeks referred to as "very low gestational age" or "very preterm" and birthweight below 1,500 g referred to as "very low birthweight" are associated with an increased risk of neurodevelopmental problems (Aylward, 2014). Therefore, in the present study we focus on very preterm children who were born before 32 gestational weeks and/or weighed less than 1,500 g at birth.

Overlap Between Reading and Arithmetic Skills

Studies have shown that reading and math skills are strongly related in population-based (Davis et al., 2014; Koponen et al., 2007; Rutherford-Becker & Vanderwood, 2009) and clinical samples—specifically in children with learning disabilities (Landerl & Moll, 2010; Moll, Bruder, Kunze, Neuhoff, & Schulte-Körne, 2014). The intercorrelation between these skills varies from moderate up to .60 (Davis et al., 2014), regardless of gender, family socioeconomic status, or race/ethnicity (Chen & Chalhoub-Deville, 2016). Korpipää et al. (2017) also found among an unselected sample that the overlap between reading and arithmetic skills (i.e., common variation in reading and arithmetic) demonstrates substantial stability across grade levels. This finding indicates that individual differences in performance level common to reading and arithmetic are fairly well established already at the beginning of primary school. The present study adds to this previous research by examining how prematurity is associated with the overlap between reading and arithmetic. In the present study, we use the term *overlap* to refer to that part of variation in reading and arithmetic that

is common to these two domains (i.e., domain-general variation; see also Cirino, Child, & MacDonald, 2018; Harlaar, Kovas, Dale, Petrill, & Plomin, 2012). The term *domain-specific variation*, in turn, is used to refer to that part of variation in reading and arithmetic that is unique to a particular skill. In previous research, very preterm children have been shown to have a lower skill level in both reading and arithmetic compared to full-term children (Aarnoudse-Moens et al., 2009; Taylor et al., 2016). This previous research did not, however, shed light on the question to what extent differences between preterm and full-term children in reading and arithmetic are due to the common variation in these skills. Consequently, the first aim of the present study was to examine the extent to which children's prematurity is associated with the overlap (i.e., common variance) between reading and arithmetic at the beginning of Grade 1.

Scholars have suggested that the overlap between reading and arithmetic skills (Hecht et al., 2001; Koponen et al., 2007; Simmons, Singleton, & Horne, 2008) and the comorbidity of related difficulties (Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; Peng & Fuchs, 2016; Willcutt et al., 2013) are partly a result of similar cognitive processes involved in the development of both domains. Based on previous findings, common cognitive predictors of reading and arithmetic include prereading skills (Hecht et al., 2001; Koponen et al., 2007; Simmons et al., 2008), basic number skills (Koponen et al., 2007; Koponen et al., 2016), and general cognitive abilities (Alloway & Alloway, 2010; Rohde & Thompson, 2007).

Regarding prereading skills, researchers have found that phonological awareness (i.e., the ability to analyze the sound structure of oral language; Hecht et al., 2001; Korpipää et al., 2017) and rapid naming skill (i.e., the ability to name sequentially presented familiar symbols, such as objects, colors, letters, or digits; Hecht et al., 2001; Koponen et al., 2007; Korpipää et al., 2017) are important indicators of overlap between reading and arithmetic. According to the double-deficit hypothesis (Wolf & Bowers, 1999), deficits in phonological

processing and naming speed are separable sources of dysfunction, and this has been confirmed in children with comorbid difficulties in reading and arithmetic (Heikkilä, Torppa, Aro, Närhi, & Ahonen, 2016). In addition, letter knowledge, as the basis for understanding the alphabetic principle, has been shown to be a powerful predictor of overlap between reading and arithmetic (Koponen et al., 2007).

In addition to prereading skills, the overlap between reading and arithmetic skills is strongly predicted by basic number skills, such as counting ability (i.e., the ability to count number words forward, backward, and in steps; Koponen et al., 2007; Korpipää et al., 2017). Research has suggested that counting ability predicts the overlap between reading and arithmetic because fluency in both domains requires effortless processing of serial information in addition to rapid retrieval of visual-verbal associations from long-term memory (Koponen et al., 2016). Furthermore, scholars have found that general cognitive abilities that are essential for learning, as indexed by IQ, are associated with the overlap between reading and arithmetic skills (Korpipää et al., 2017).

The reading and mathematics performance of very preterm children has been shown to be linked with general cognitive abilities indexed by IQ (Schneider et al., 2004; see also Wolke, Samara, Bracewell, & Marlow, 2008). However, linguistic skills, such as rapid automatized naming, have also been related to very preterm children's underachievement in both domains independently of intelligence (Wocadlo & Rieger, 2007). Because previous studies found statistically significant differences between very preterm and full-term children in early linguistic skills (Guarini et al., 2009; Saavalainen et al., 2006; Schneider et al., 2004), basic number skills (Alanko et al., 2017; Guarini et al., 2014), and general cognitive abilities (Anderson, 2014; Johnson, 2007), and all these variables have been found to be associated with the overlap between reading and arithmetic (Korpipää et al., 2017), the second aim of the present study was to investigate the extent to which the association of prematurity with

the overlap between reading and arithmetic is accounted for by prereading and basic number skills and general cognitive abilities in terms of performance and verbal IQ.

Research Questions

The present study examined the following research questions.

Research question 1. To what extent is children's prematurity (very preterm vs. full-term children) associated with the overlap (i.e., common variance) of reading and arithmetic at the beginning of Grade 1? Very preterm children have been shown to have a lower skill level than full-term children in reading and arithmetic (Aarnoudse-Moens et al., 2009; Pritchard et al., 2009; Taylor et al., 2016), and reading and arithmetic have been shown to substantially overlap (Cirino et al., 2018; Korpipää et al., 2017). Therefore, we hypothesized that prematurity is negatively associated with the overlap between reading and arithmetic (hypothesis 1).

Research question 2. To what extent is the association of prematurity with the overlap between reading and arithmetic at the beginning of Grade 1 mediated by linguistic skills (letter knowledge, phonological awareness, and rapid automatized naming), basic number skills (digit knowledge and counting sequence knowledge), and general cognitive abilities (nonverbal and verbal IQ)? Several studies have demonstrated that very preterm children perform at lower levels than full-term children in these indicators (Aarnoudse-Moens et al., 2011; Guarini et al., 2009; Wocadlo & Rieger, 2007). Therefore, we assumed that the association of prematurity with the overlap between reading and arithmetic is accounted for by differences between very preterm and full-term children in linguistic skills, basic number skills, and general cognitive abilities (hypothesis 2).

Method

Participants

The present study is part of the multidisciplinary project Development and Functioning in Very Low Birth Weight Infants from Infancy to School Age (PIPARI) which followed very preterm children and healthy full-term control children from infancy to Grade 1. Inclusion criteria were based on World Health Organization (International Classification of Diseases; ICD-10) definitions of very preterm birth (< 32 weeks of gestation), and very low birth weight (< 1,500 g). The targeted sample consisted of all preterm children born in 2001–2004 at the Turku University Hospital, the only facility that provides neonatal intensive care in the hospital's catchment area. All eligible families were asked to participate in the study, and 95% gave their informed consent. The total attrition rate was 26.7%, with early death being the major cause (see Setänen et al., 2013). The very preterm group consisted of 193 (43.0% girls) children. Of them, 153 were born weighing less than 1,501 g and at less than 32 weeks of gestation; 15 met only the gestational age criterion, and 25 met only the birth weight criterion. The control group (n = 175; 49.7% girls) was recruited by a research psychologist who asked the parents of the first full-term girl or boy born on each Monday to participate in the study. In the case of refusal, the parents of the next boy or girl were contacted. The inclusion criteria were a birth weight higher than –2 SD according to Finnish growth charts, a gestational age of 37 weeks or longer, and no neonatal care during the first week of life. All the families in the control group lived in the Turku University Hospital catchment area and understood Finnish or Swedish. Table 1 presents additional participant characteristics (for a more detailed description, see Alanko et al., 2017).

The participants were either 7 years of age upon entering school or turned 7 during the fall semester of Grade 1. Mothers' level of education at the time of birth did not differ between very preterm and full-term children while fathers with higher education were overrepresented in the full-term children's group. Cranial ultrasounds were carried out on the

very preterm children (at 3 to 5 days of age, 7 to 10 days of age, 1 month, and each month thereafter until discharge), as well as brain magnetic resonance imaging (MRI; for 190 infants at term on the same day as the ultrasound). For a detailed description of the examinations and classification of the degree of brain pathology, see Maunu et al. (2006, pp. 58–59). The PIPARI Study protocol was approved by the Ethics Review Committee of the Hospital District of Southwest Finland. Parents of all the children participating were informed about the study and gave their written consent.

Measures

Data were collected at the beginning of first grade during a 6-week period over August and September. As an exception, data concerning the children's general cognitive ability were gathered at age 5 by the research unit at the university hospital. All the tests were administered either individually or in group situations and carried out by trained testers at school.

Criterion validity (defined as predictive validity) and concurrent validity of all the measures used in the present study have been shown to be good in previous studies (Koponen et al., 2007; Korpipää et al., 2017; Leppänen, Niemi, Aunola, & Nurmi, 2004; Torppa et al., 2016). More specifically, correlations between cognitive antecedents measured at kindergarten age and subsequent reading and arithmetic skills at school age have been shown to vary depending on the study, on average, in the moderate range (.20 to .70). Concurrent validity between the measures used is also good, with intercorrelations varying within the moderate range (.30 to .70).

Reading skills. Reading skills were assessed individually at the beginning of Grade 1 with two subtests. (a) *Word reading accuracy* was assessed with a word list reading test containing two-syllable (seven words), three-syllable (two words), and five-syllable (one word) words (subtest of the ARMI – A tool for assessing reading and writing skills in Grade

1; Lerkkanen, Poikkeus, & Ketonen, 2006). The words were presented one at a time, and the child was asked to read them out loud without a time limit. Meanwhile, (b) *word reading fluency* was assessed using a list of 90 words arranged on a sheet of paper into three columns in order of increasing difficulty (Lukilasse Graded Fluency Test; Häyrinen, Serenius-Sirve, & Korkman, 1999). The child was asked to read as many words out loud as possible within a time limit of 45 s.

For both tests, the score was based on the total number of words read out correctly. The Cronbach alphas for the tests were .97 and .97, respectively. In the present study, the sum score of standardized *word reading accuracy* and *word reading fluency* was used as the measure of reading skills.

Arithmetic skills. Arithmetic skills were tested in a group situation at the beginning of Grade 1 using the Basic Arithmetic Test (Aunola & Räsänen, 2007). The test consisted of 28 items in total—14 items of addition (e.g., 2+1=_, 7+_=14) and 14 items of subtraction (e.g., 4-1=_, _–3=10)—which gradually increased in difficulty. Participants were given a 3 min time limit to complete as many items as possible. Performance on the test required accuracy and speed (automatization of basic calculation routines). The sum score was based on the total number of correct items (maximum value of 28), and the Cronbach alpha for the test was .85.

Prereading Skills

Letter knowledge. The children were asked to name all 29 uppercase letters of the Finnish alphabet arranged in three rows in random order and shown one row at a time (Lerkkanen et al., 2006). The sum score was based on the number of correct responses (maximum value of 29), and the Cronbach alpha for the test was .95.

Phonological awareness. Three- to seven-letter words were presented phoneme by phoneme in a small group session (Poskiparta, 1995). The participants were told to figure out

the resulting word and on an answer sheet with four alternative pictures, mark the one they thought best matched the word. There were nine trials in total, preceded by one practice trial. The sum score was based on the number of correct items (maximum value of 9). The Cronbach alpha for the test was .73.

Rapid automatized naming. The standardized Finnish version by Ahonen, Tuovinen, and Leppäsaari (1999) of an object naming task (Denckla & Rudel, 1976) was used to assess rapid automatized naming. Participants were asked to name as rapidly as possible a series of familiar visual stimuli. The task consisted of five familiar objects replicated 10 times on a matrix in pseudorandom order. Documented errors and self-corrections were few, and they were not included in the analysis. The time taken (in seconds) to complete the total matrix (five rows of 10) was then used as the RAN score. According to the manual, the test-retest reliability coefficients ranged from .84 to .92 for all age groups (Wolf & Denckla, 2005).

Basic Number Skills

Digit knowledge. The test consisted of 12 one- to six-digit numbers that were presented to the participants in numerical order, starting with 9 and ending with 627,003. The children were asked to name the numbers one at a time without a time limit, but once a child had made two consecutive mistakes, the test was stopped. The Cronbach alpha for the test was .82.

Counting sequence knowledge. Counting sequence knowledge was assessed with the following seven subtasks using the Number Sequences Test (Salonen et al., 1994): (a) counting forward from 1 to 51, (b) 6 to 13, and (c) 18 to 25; (d) counting backward from 12 to 7, (e) 23 to 1, and (f) 33 to 17; and finally, (g) counting 5 numbers backward from 23. Two points were given for each task correctly completed, one point for a task completed with two errors or fewer, and zero points if there were more than two errors or participants failed to

complete the task. The maximum total score for the test was the sum of the scores for these seven tasks (14), and the Cronbach alpha for the test was .82.

General Cognitive Ability

Cognitive level. A short Finnish version of the Wechsler Primary and Preschool Scales of Intelligence–Revised (WPPSI–R) was used to assess the cognitive level, and two sum scores were created. (a) Verbal IQ was estimated based on the WPPSI–R subtests information, sentences, and arithmetic, and (b) performance IQ was estimated based on block design, geometric design, and picture completion subtests.

Parental education. Parents were asked about their education in years at the time of the child's birth with questionnaire with a 3-point scale (1 = < 9 years, 2 = 9–12 years, 3 = > 12 years). The parental education score was determined by the education score of the more educated parent. The information concerning parental education was gathered from 368 (92.7%) parents.

Analysis Strategy

Analyses were carried out using structural equation modeling (SEM). This modeling approach made it possible to model the dependent variable, that is, the overlap between reading and arithmetic, via a latent variable (latent factor accounting for the intercorrelation of reading and arithmetic) and then explain the individual variation in this latent factor (overlap) with other variables. By using this approach, we were able to divide the variation in reading and arithmetic into two parts: domain-general variation representing overlap between reading and arithmetic and domain-specific variation representing variation that is not related with the other skill domain. The analyses were carried out in the following steps. First, a model was constructed to examine the extent to which prematurity (very preterm vs. full-term children) would account for the overlap between reading and arithmetic skills at first grade in primary school. In this model, the overlap between reading and arithmetic skills (i.e., the

intercorrelation of these skills) was modeled using a latent variable that represented the variance common to the measures assessing reading and arithmetic skills, and variation in this latent overlap variable was predicted by prematurity status. In the model, the factor loadings of the indicators of the latent factor—standardized reading and arithmetic skills—were estimated as equal. The paths from prematurity to the residuals of the indicators of the latent variable (i.e., reading and arithmetic) were first constrained to be zero. Inspection of model fit and modification indices were then used to investigate the extent to which prematurity is also associated with the unique (i.e., domain-specific variation not common for reading and arithmetic) variance of reading or arithmetic (see also, Korpipää et al., 2017; Koponen et al., 2007).

Second, to examine the extent to which the association of prematurity with the overlap between reading and arithmetic is the result of shared deficits in prereading skills (letter knowledge, phonological awareness, and rapid automatized naming), basic number skills (counting sequence knowledge and digit knowledge), and general cognitive abilities (verbal IQ and performance IQ), these variables were included in the previous model. Indirect paths from prematurity to the latent variable representing the overlap between reading and arithmetic skills through these variables were estimated. Child's gender (girl vs. boy) and parental level of education were included in the model as covariates. The schematic mediation model is shown in Figure 1.

------Insert Figure 1 about here-----

The analyses were carried out using the Mplus statistical software program (Version 7.0) and the standard missing at random (MAR) approach–supposing that data would be missing at random (Muthén & Muthén, 1998–2010). The frequency of children having missing data ranged (depending on the variable) from 0 to 19 among preterm children and between 0 and 14 among full-term children. The parameters of the models were estimated

using full information maximum likelihood (FIML) estimation with standard errors robust to nonnormality (MLR estimator; Muthén & Muthén, 1998–2010). This method allowed us to use all of the observations in the data sets to estimate parameters in the models. The following outcomes were taken to indicate that the model fitted the data well: a nonsignificant χ^2 test value, a comparative fit index (CFI) and Tucker-Lewis index (TLI) of greater than .95, and a root mean square error of approximation (RMSEA) of lower than .06 (Muthén, & Muthén, 1998–2010).

Results

Descriptive Statistics

The means and standard deviations of the study variables, as well as the results of independent samples *t*-tests comparing the means between very preterm and full-term children, are shown in Table 2. The correlations between the study variables ranged from –.42 to .73 (Table 2). Reading and arithmetic skills showed a moderate intercorrelation (.42, $p < .001$). Prematurity correlated negatively with reading (–.18, $p < .001$) and arithmetic skills (–.31, $p < .001$). Of the hypothesized mediating variables (linguistic skills, basic number skills, and general cognitive abilities), phonological awareness and letter knowledge showed the highest correlations with reading skills, whereas counting sequence knowledge and digit knowledge showed the highest correlations with arithmetic skills. Of the covariates, parental education correlated statistically significantly and positively with reading and arithmetic. However, these correlations were weaker than those for children's cognitive skills with reading and arithmetic. Child's gender did not correlate with reading or arithmetic.

Comparisons of the means between very preterm and full-term children (see Table 2) revealed that very preterm children performed less well than full-term children in reading and arithmetic. There was also a statistically significant difference between the groups in linguistic skills, basic number skills, and general cognitive abilities in favor of full-term

children. No statistically significant difference between very preterm and full-term children was found in parental education or gender.

The Association of Prematurity with the Overlap Between Reading and Arithmetic Skills

The first research question asked to what extent prematurity is associated with the overlap between reading and arithmetic skills at the beginning of school. This question was examined by estimating a model where the overlap between reading and arithmetic was modeled as a latent variable and variation in this latent overlap variable was predicted by prematurity status. The SEM (χ^2 (1) = 5.36, p = 0.02; CFI = .96; TLI = 0.87; RMSEA = .11) results showed poor fit. Inspection of the modification indices suggested that adding a direct path from prematurity to arithmetic (i.e., to domain-specific variation in arithmetic) would improve the fit of the model. After this specification was carried out, the model was saturated. The results showed, first, that 41% of the variance in reading skills and 42% of that in arithmetic, was explained by the latent common factor—overlap between reading and arithmetic—and thus, represented domain-general variation in these skills. In turn, 59% of the variation in reading skills and 58% of that in arithmetic was not explained by the common factor and thus, represented domain-specific variation of these skills. Second, the results showed that prematurity (i.e., the dummy variable *very preterm vs. full-term*) was statistically significantly and negatively associated with the common variance of reading and arithmetic skills (standardized estimate = –.29, $p < .001$): Very preterm children showed lower skill level common for reading and arithmetic at the beginning of Grade 1 than their full-term peers. Moreover, prematurity was negatively related to the domain-specific variance of arithmetic (standardized estimate = –.13, p = 0.02): Very preterm children showed slightly lower arithmetic skills than full-term children independent of their reading skill levels.

The Mediating Mechanisms

To answer the second research question whether the association of prematurity with the overlap between reading and arithmetic is mediated by various cognitive antecedents, variables representing phonological awareness, letter knowledge, rapid automatized naming, counting sequence knowledge, digit knowledge, verbal IQ, and performance IQ were added to the model. Paths from prematurity to the latent overlap variable through these variables were then estimated. Children's gender and parental level of education were included in the model as covariates. The fit of the model was poor: χ^2 (9) = 54.76, $p < .001$; CFI = 0.97; TLI = 0.78; RMSEA = 0.12. Inspection of the modification indices suggested that estimating direct paths from digit knowledge and letter knowledge to arithmetic skills (i.e., to domain-specific variation in arithmetic) would increase the fit of the model. After these modifications, the model was found to fit the data well: χ^2 (7) = 15.38, $p = .03$; CFI = 0.99; TLI = 0.95; RMSEA = 0.06. The final model including only the statistically significant paths (χ^2 (10) = 14.47, *p = 0.15*; CFI = 1.00; *TLI* = 0.98; RMSEA = 0.04) is shown in Figure 2.

------Insert Figure 2 about here-----

The results (see Figure 2) showed, first, that the overlap between reading and arithmetic skills was associated with letter knowledge, phonological awareness, RAN, counting sequence knowledge, and—to smaller extent—performance IQ. The higher the level of these linguistic and basic number skills, as well as performance IQ, the higher the skill level common for reading and arithmetic at the beginning of Grade 1. Second, the association of prematurity with the overlap between reading and arithmetic was fully accounted for by the five antecedents: Very preterm children showed lower letter knowledge (standardized indirect effect = –.05, $p < .01$), phonological awareness (standardized indirect effect = –.07, $p < .01$), RAN (standardized indirect effect = –.04, $p < .01$), counting sequence knowledge (standardized indirect effect = –.07, $p < .001$), and performance IQ (standardized indirect effect = –.06, $p < .01$) than full-term children and, consequently, they also demonstrated a

lower skill level common for reading and arithmetic (i.e., domain-general part of the skill level) than full-term children. Third, the results showed that prematurity was associated with the domain-specific variation in arithmetic skills through digit knowledge (standardized indirect effect = –.08, $p < .001$) and letter knowledge (standardized indirect effect = .05, $p = 0.01$). These indirect effects, however, partly compensated each other: Very preterm children showed lower digit and letter knowledge than full-term children but whereas digit knowledge was positively associated with domain-specific variation in arithmetic, letter knowledge demonstrated a negative association with it.

Discussion

The present study aimed to add our understanding of the role of prematurity in the overlap between reading and arithmetic skills at the beginning of school. The results showed that about 40% of the variation in reading and arithmetic skills was common to these two domains and represented the overlap between reading and arithmetic, whereas 60% of the variation in these skills was domain-specific, that is, not shared by reading and arithmetic. Previous literature has shown that prematurity is associated with lower skill levels in both reading (Kovachy et al., 2014) and arithmetic (Taylor, Espy, & Anderson, 2009). The results of the present study suggest that these associations are mainly due to domain-general variation of these skills. The association of prematurity with the overlap between reading and arithmetic skills was further found to be accounted for particularly by prereading (letter knowledge, phonological awareness, and rapid automatized naming) and basic number skills (counting sequence knowledge) which have been shown to be important indicators of the overlap between reading and arithmetic (Korpipää et al., 2017).

Because beginning reading and arithmetic skills are strongly related (Korpipää et al., 2017), the question arises whether the poor performance of very preterm children in reading and arithmetic is due to processes that are common to these domains. The results of the

present study confirmed our hypothesis by demonstrating that prematurity was negatively associated with the overlap between reading and arithmetic: The skill level common to reading and arithmetic was lower among very preterm children than among full-term children. After taking into account the domain-general variation in reading and arithmetic skills, no differences between the groups were evident in levels of reading skills, contrary to arithmetic skills which still showed a slight difference. Overall, the results suggest that differences between very preterm and full-term children in reading and arithmetic skills are, in large part, related to the factors or processes common to reading and arithmetic. Because learning difficulties that are related to both reading and math domains are more severe and persistent over time than difficulties evident only in one domain (Jordan et al., 2003; see also Koponen et al., 2018; Willcutt et al., 2013), it is important to acknowledge the risk very preterm children have for overlapping learning difficulties.

The second aim was to examine the extent to which different cognitive antecedents, including letter knowledge, phonological awareness, rapid automatized naming, digit knowledge, counting sequence knowledge, and general cognitive level, mediate the association of prematurity with the overlap between reading and arithmetic. In line with the hypothesis, the results showed that differences between the two groups in the skill level common to reading and arithmetic skills were fully accounted for by these cognitive antecedents previously shown to predict the overlap between reading and arithmetic (Korpipää et al., 2017). The most powerful mediators were phonological awareness and counting sequence knowledge, which have been found to be the strongest predictors of the overlap between reading and arithmetic in the early phase of skill development (Korpipää et al., 2017) when both skills are based on serial one-by-one processing (i.e., serial decoding in reading and counting-based strategies in arithmetic; see Koponen et al., 2016).

Group differences were also mediated through rapid automatized naming, which has been found to be related to development of fluency both in reading and arithmetic (i.e., direct retrieval of larger units following practice or retrieving arithmetical facts; Koponen et al., 2013, 2016), as well as to the overlap between these skills across grade levels (Korpipää et al., 2017). In previous studies, counting ability has proved to be a good predictor of the overlap between reading and arithmetic in initial and more automatized phases of skill development in these domains (Korpipää et al., 2017). Therefore, the lower performance of very preterm children in counting and rapid automatized naming at the beginning of school predicts an elevated risk of learning difficulties through lower primary school, including the fluency aspect of both skills. Obviously, this finding calls for early support and close monitoring of skill development through the early grades both in reading and in arithmetic.

Overall, the results of the present study suggest that the association of prematurity with the overlap between reading and arithmetic skills is related to linguistic and basic number skills, such as letter knowledge, phonological awareness, rapid automatized naming, and counting, more than to intelligence, supporting the findings by Wocadlo and Rieger (2007). These results may be explained by the fact that reading and arithmetic skills require the ability to learn and retrieve phonological representations of visual symbols (Koponen et al., 2007), as well as the ability to process serial information (Koponen et al., 2013, 2016). In addition, previous studies showing that very preterm children with general cognitive ability within the normal range have impairments in these prereading skills (Guarini et al., 2009; Pritchard et al., 2009; Saavalainen et al., 2006) and basic number skills (Guarini et al., 2014) support this conclusion. Thus, measures of the general cognitive level, such as IQ, are not adequate predictors of low performance levels in reading and arithmetic, and more attention should be paid to prereading and basic number skills that are related to developing fluency in both domains.

In addition to the association with the overlap between reading and arithmetic, we found that prematurity was associated with the domain-specific variation in arithmetic. However, this association was rather weak. Despite the finding that prematurity showed a unique association with arithmetic independent of the level of reading skills, difficulties in mathematical development among very preterm children seem to have, in part, a linguistic base. This finding is in line with studies underscoring the importance of reading-related skills to mathematical development (Krajewski & Schneider, 2009; Zhang et al., 2014) and supports a similar pattern of findings by Hannula-Sormunen et al. (2017).

Limitations

Four main limitations should be considered with respect to generalization of the findings. First, in the absence of relevant data, we did not include executive functions or working memory as predictors of covariation in reading and arithmetic skills. Second, one should note the transparent orthography of the Finnish language. Because Finnish has a simple and symmetrically regular phoneme-grapheme correspondence, decoding requires less advanced phonological processing skills than irregular orthographies, such as English. Third, because phoneme-to-grapheme rules are equally regular for spelling and reading in Finnish, spelling was not investigated in this study. In future studies, and with less transparent orthographies, spelling should be included as a separate outcome variable. Fourth, because the children in the present study were school beginners, their reading and arithmetic skills were skewed to low values.

Conclusion

The results of the present study add to our understanding of the association between prematurity and the overlap between reading and arithmetic, as well as the cognitive mechanisms related to lower performance levels across these two domains. Unlike in previous studies, the difference between very preterm and full-term children was investigated

in terms of the overlap between reading and arithmetic rather than in each domain separately. Focusing on the overlap between reading and arithmetic made it possible to examine to what extent the group differences in reading and arithmetic skills found previously are domain general rather than domain specific. Overall, the results indicated that the differences between very preterm children and full-term children in reading and arithmetic skills are mainly the result of the domain-general variation of these skills. An important implication is that premature children who are struggling in one domain should be closely monitored for difficulties in the other domain as well (see also Cirino et al., 2018). The results of the present study provide important insights for educators to support very preterm children's development of both reading and arithmetic skills early enough to diminish the achievement gap between them and full-term children. As the overlap between these skills is well established by the first year of school (Korpipää et al., 2017), more attention to training prereading and basic number skills among very preterm children is necessary during the kindergarten year. Such an intensive follow-up might prove valuable in later primary grades. For example, it is not known whether preterm children are overrepresented among students who after some years of typical progress at school develop so-called late-emerging reading difficulties (Catts, Compton, Tomblin, & Bridges, 2012; Torppa, Eklund, van Bergen, & Lyytinen, 2015).

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Table 1

Background Characteristics of Very Preterm (Gestational Age < 32 weeks or Birth Weight < 1,501 g) and Full-Term Control Children

	Very preterm group (*n* = 193)	Full-term group (*n* = 175)
Birth weight (g)		
Mean (*SD*) [min, max]	1126 (325) [400, 2120]	3673 (442) [2570, 4980]
Gestational age (weeks)		
Mean (*SD*) [min, max]	29 (3) [23, 35]	40 (1) [37, 42]
Male	110 (57.0)	88 (49.7)
Brain pathology in MRI		
Normal (%)	111 (57.5)	
Minor (%)	28 (14.5)	
Major (%)	50 (25.9)	
Maternal education		

≤ 9 years (%)	18 (9.6)	8 (5.3)
9–12 years (%)	45 (23.9)	54 (35.5)
> 12 years (%)	125 (66.5)	90 (59.2)
Paternal education		
≤ 9 years (%)	15 (7.9)	12 (8.2)
9–12 years (%)	107 (56.9)	62 (42.5)
> 12 years (%)	66 (35.1)	72 (49.3)

Note. For a more detailed description, see Alanko et al. (2017).

Table 2

Correlations, Means, and Standard Deviations of the Study Variables and Test of Statistically Significant Differences in the Means between Preterm and Full-Term Children

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Reading skills T1	1.00											
2. Arithmetic skills T1	.42***	1.00										
3. Phonological awareness	.60***	.38***	1.00									
4. Letter knowledge	.55***	.33***	.59***	1.00								
5. Rapid automatized naming	–.42***	–.38***	–.43***	–.32***	1.00							
6. Counting sequence knowledge	.51***	.54***	.50***	.57***	–.39***	1.00						
7. Digit knowledge	.45***	.54***	.42***	.55***	–.35***	.73***	1.00					
8. Performance IQ	.35***	.40***	.37***	.29***	–.33***	.38***	.36***	1.00				
9. Verbal IQ	.45***	.37***	.52***	.46***	–.40***	.47***	.43***	.49***	1.00			
10. Parental education	.18**	.14*	.22***	.28***	–.12*	.21***	.16**	.11	.21***	1.00		
11. Gender	.05	.10	.07	.05	–.05	.08	.03	.06	–.06	–.04	1.00	

12. Prematurity	–.18***	–.31***	–.18**	–.13*	.24***	–.29***	–.27***	–.40***	–.17**	–.00	–.07	1.00
Preterm children												
M	-0.18	2.10	6.85	23.49	76.33	6.31	4.47	98.28	103.54	2.69	1.43	
SD	0.88	1.72	2.07	6.85	21.22	3.81	2.59	17.36	15.78	0.50	0.50	
Full-term children												
M	0.17	3.48	7.54	25.06	66.89	8.55	5.87	111.54	108.68	2.69	1.50	
SD	0.97	2.47	1.70	5.40	16.98	3.72	2.45	108.68	13.46	0.52	0.50	
t	3.53***	6.11***	3.46**	2.46*	–4.70***	5.68***	5.29***	7.92***	3.20**	0.05	1.29	

Note. The variable *reading skills* is the mean of two standardized reading subtests.

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

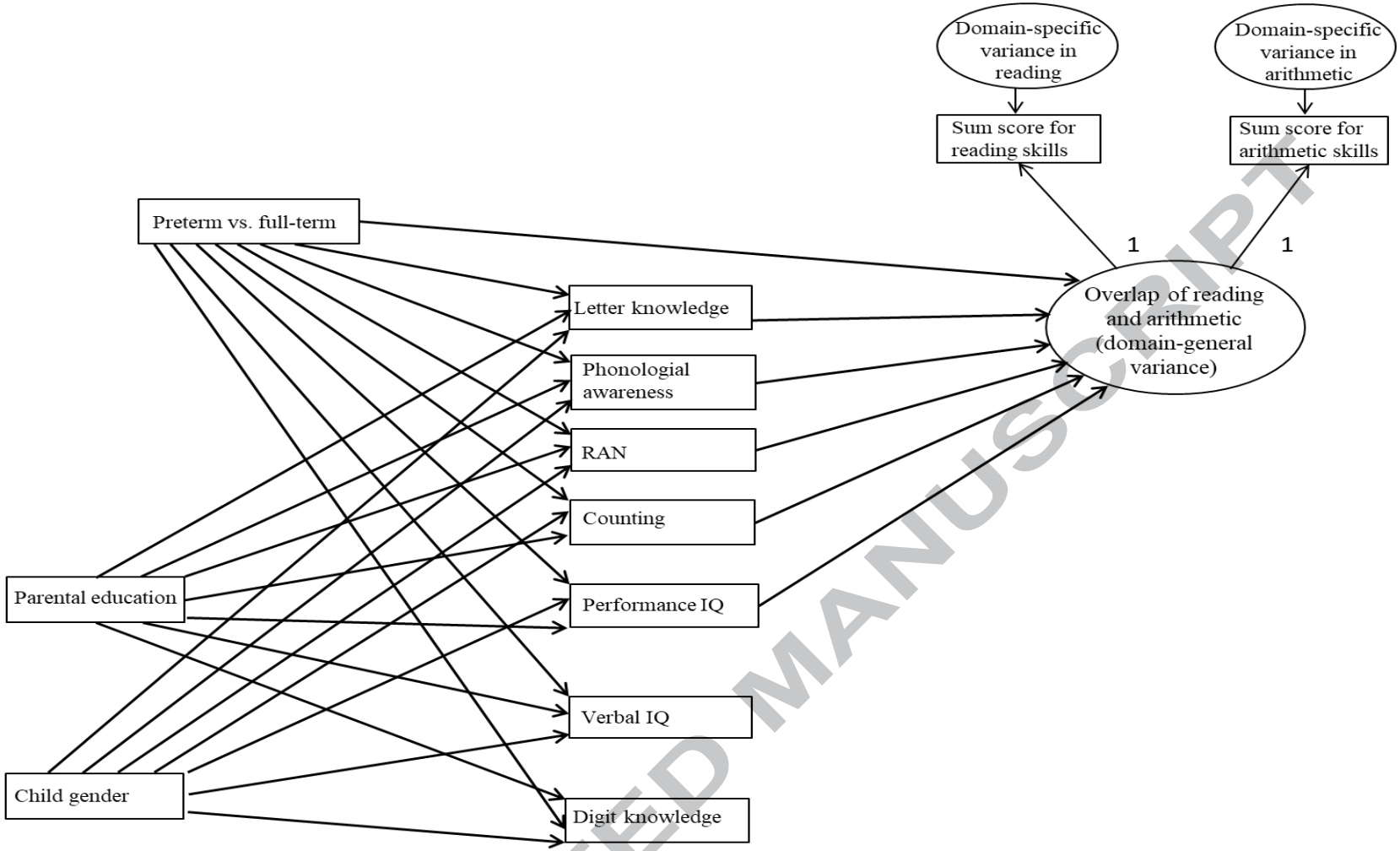

Figure 1. Schematic structural equation model.

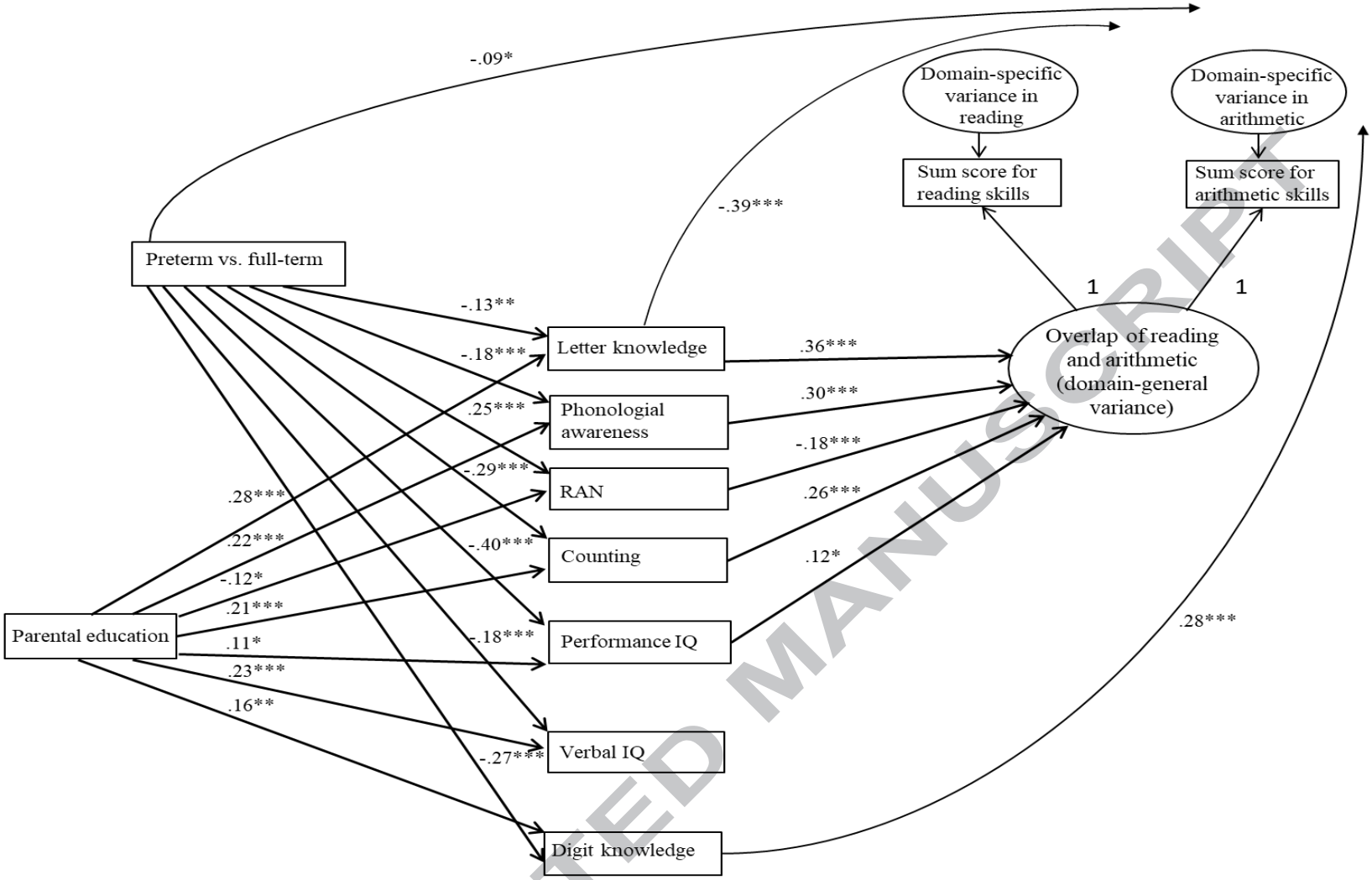

Figure 2. The structural equation model for the association of prematurity with the overlap between reading and arithmetic and mediators of this association. *$p < .05$. **$p < .01$. ***$p < .001$.

Highlights

- Prematurity is related to domain-general rather than domain-specific variation in reading and arithmetic.
- The association of prematurity with the overlap between reading and arithmetic is mediated via cognitive antecedents of both skills.
- Training both prereading and basic number skills among very preterm children is needed during the kindergarten year.