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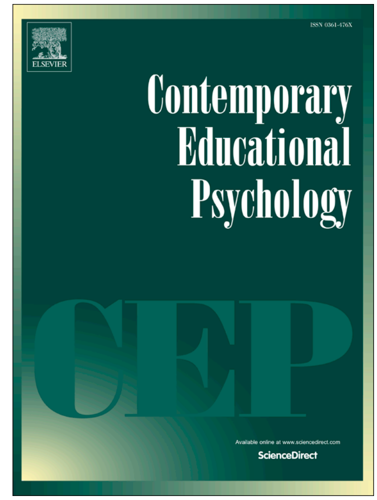

Empirical study

Covariation between Reading and Arithmetic Skills from Grade 1 to Grade 7

Heidi Korpipä ä, Tuire Koponen, Mikko Aro, Asko Tolvanen, Kaisa Aunola, Anna-Maija Poikkeus, Marja-Kristiina Lerkkanen, Jari-Erik Nurmi

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Covariation between Reading and Arithmetic Skills from Grade 1 to Grade 7

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Covariation between Reading and Arithmetic Skills from Grade 1 to Grade 7

Abstract

This study examined the extent to which reading and arithmetic skills show covariation at Grade 1 and at Grade 7, to what extent this covariation is time-invariant or time-specific, and to what extent different antecedents will predict these time-invariant and time-specific portions of the covariation. The reading and arithmetic skills of a total of 1,335 Finnish children were assessed at the end of Grade 1 and then again at the end of Grade 7. Phonological awareness, letter knowledge, rapid automatized naming (RAN), counting, and parental education levels were measured in kindergarten; working memory at Grade 1 and nonverbal reasoning at Grade 3. The results showed that reading and arithmetic had a substantial amount of covariation at grades 1 and 7, and that most of the covariation between these grades was time-invariant and could be predicted by RAN, counting, letter knowledge, working memory, and nonverbal reasoning. The time-specific portion of the covariation between reading and arithmetic in Grade 1 was predicted by phonological awareness, letter knowledge, and counting; while time-specific covariation in Grade 7 was predicted by parental education level and nonverbal reasoning.

Keywords: Reading, arithmetic, covariation, comorbidity, development

Covariation between Reading and Arithmetic Skills from Grade 1 to Grade 7

1. Introduction

Research on the development of different components of reading and math skills has traditionally focused on each skill domain separately. During the last ten years, however, there has been increasing interest in examining the covariation between reading and math (Koponen, Aunola, Ahonen, & Nurmi, 2007) and their joint antecedents (e.g., Durand, Hulme, Larking, Snowling, 2005; Koponen, Salmi, Eklund, & Aro, 2013; Koponen et al., 2016). Similarly, the coexistence of reading and math difficulties (Landerl & Moll, 2010; Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014) and the possible shared and unique cognitive backgrounds to these difficulties have been investigated (Landerl, Fussenegger, Moll, & Willburger, 2009; Slot, van Viersen, de Bree, & Kroesbergen, 2016). Although previous studies have confirmed the association between reading and math skills among both population-based (Davis et al., 2014; Koponen et al., 2007; Rutherford-Becker & Vanderwood, 2009) and clinical samples (Landerl & Moll, 2010; Moll et al., 2014), several fundamental questions still remain unclear. First, because most of the earlier studies have been cross-sectional, little is known about the extent to which the covariation between reading and math skills is based on similar processes across time or whether this covariation is specific to certain grade levels (i.e., varies according to the phase of skill development). Second, there are conflicting views concerning the cognitive antecedents of covariation between reading and math skills. On the one hand, it has been suggested that reading and math skills partially share underlying cognitive processes (Hecht, Torgesen, Wagner, & Rashotte, 2001; Koponen et al., 2013; Koponen et al., 2016). On the other, reading and math difficulties have been seen to result from two different cognitive core problems, that is, problems in phonological processing and in number sense, respectively (Landerl et al., 2009). To shed more light on these questions, longitudinal research on the time invariance and time specificity of the shared variation between reading and math is needed – as well as the key cognitive antecedents of this variation. The present study thus aims to examine the extent to which reading and arithmetic skills show shared variation at Grade 1 and Grade 7; to what extent this shared variation is time-invariant or time-specific; and to what extent parental education, general cognitive abilities, and pre-skills in both subjects predict the time invariant and time-specific portions of covariation between reading and arithmetic skills across Grades 1 and 7.

1.1 Covariation of Reading and Arithmetic Skills

A growing body of research has shown that there are substantial intercorrelations (i.e., covariation) between reading and math skills among unselected populations during the primary (Chen & Chalhoub-Deville, 2016; Davis et al., 2014; Koponen et al., 2007; Rutherford-Becker & Vanderwood, 2009) and lower secondary school years (Chen & Chalhoub-Deville, 2016; Codding, Petscher, & Truckenmiller, 2015). Correlations in the moderate to high range, of up to .60 (Davis et al., 2014), have been observed for all grades examined, regardless of gender, family socioeconomic status (SES), and race/ethnicity (Chen & Chalhoub-Deville, 2016). Difficulties in one academic domain have also been found to clearly increase the risk of difficulties in the other in studies specifically looking at their co-occurrence (Jordan, Wylie, & Mulhern, 2010; Landerl & Moll, 2010).

In previous research focusing on the comorbidity of math and reading difficulties, or on the covariation of reading and math skills, various kinds of operationalization of these skills have been used some studies focusing on accuracy and some others on speed, for example. With respect to reading, Share (2008) suggested that the irregular orthography of the English language has led to an emphasis on the accuracy of oral reading as a measure of reading skill, at the expense of silent reading, reading speed, and comprehension. However, in most alphabetic orthographies, accuracy of reading is generally achieved rather rapidly, after which the individual variation is mostly only observable in reading fluency – that is, combined measures of accuracy and speed (e.g., Seymour, Aro, & Erskine, 2003). Speed problems have been shown to be characteristic of problems in reading development in both irregular and regular orthographies (Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Equally, the speed at which math problems are solved has proved indicative of problems in the development of different components of math skills – especially in arithmetic skills (Geary, 1993). Thus, in order to better understand the relation between math and reading development, it seems relevant to focus on outcome measures which take into account both the accuracy and speed of performance. Consequently, the terms 'reading and arithmetic skills' are used in the present study to refer to fluency in them (accuracy and speed combined). Because these skills are better conceived as continuous rather than discrete variables (Branum-Martin, Fletcher, & Stuebing, 2012), a dimensional approach will be used to examine the covariation between reading and arithmetic skills among an unselected population.

1.2 Interindividual Stability of Reading and Arithmetic Skills

Both reading skills (Hulslander, Olson, Willcutt, & Wadsworth, 2010; Landerl & Wimmer, 2008; Parrila, Aunola, Leskinen, Nurmi, & Kirby, 2005) and arithmetic skills (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Bailey, Watts, Littlefield, & Geary, 2014; Watts, Duncan, Siegler, & Davis-Kean, 2014) have been found to show moderate to high interindividual stability across school years, suggesting that a substantial portion of skill variation is time-invariant. For example, in the longitudinal study by Landerl and Wimmer (2008), the stability of individual differences in reading fluency (in a regular orthography) was observed to be high from Grade 1 to Grade 8. Similarly, Watts et al. (2014) found high stability in mathematical achievement across school grades even if the variance increased (see also, Aunola et al., 2004). Overall, these studies indicate that an individual's relative skill-level in reading and arithmetic might be established in the early years of school and remain rather invariant after that.

1.3 Time-Invariance and Time-Specificity in the Covariation of Reading and Arithmetic Skills across School Grades

Although much is known about the inter-individual stability of reading and arithmetic skills across school grades, less is known about whether the covariation of these skills is time-invariant (i.e., shared over time) or time-specific (i.e., unique for different grades). Similarly, although previous research has shown a substantial amount of covariation between reading and arithmetic skills among unselected populations during the primary (Chen & Chalhoub-Deville, 2016; Koponen et al., 2007) and secondary (Chen & Chalhoub-Deville, 2016; Codding et al., 2015) school years, little is known about whether this covariation is common over different grades or, alternatively, whether it is unique for a particular grade only. The present study thus examined the extent to which reading and arithmetic skills show shared variation at grades 1 and 7, and whether it was time-invariant or time-specific to them. To do this, the covariation between reading and arithmetic skills at grades 1 and 7 was divided into three parts: the time-invariant part common to both, and time-specific parts typical only to either Grade 1 or Grade 7.

It is commonly accepted that, when children start school, both reading and arithmetic skills are acquired via serial processing: reading is based on phonemic assembly, whereas arithmetic is based counting-based calculation strategies (Koponen et al., 2016). After this initial stage, there is a gradual shift towards the processing and retrieving of larger units, such as syllables or words in reading, and arithmetic facts in math. As reading and arithmetic fluency become automatized (Koponen et al., 2007; Koponen et al., 2016), however, it is possible that the covariation between reading and arithmetic is not constant; rather it varies according to the different phase of skill development (i.e., serial decoding / counting at the early stage of skill development vs. automatized phase relying strongly on direct retrieval at later stage of skill development). Another possibility is that reading and arithmetic skills have a persistent relationship across grade levels as suggested by Chen and Chalhoub-Deville (2016). Studies showing that there is a significant genetic overlap in reading and math skills (Hart, Petrill, Thompson, & Plomin, 2009) also support this.

1.4 Antecedents of Covariation between Reading and Arithmetic Skills

It has been suggested that the covariation of reading and arithmetic skills (Hecht et al., 2001; Koponen et al., 2007), as well as the comorbidity of related difficulties (Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; Peng & Fuchs, 2016; Willcutt et al., 2013), are partly due to same cognitive processes being involved in the development of both domains. In previous studies, suggested cognitive predictors for both have included linguistic skills (Hecht et al., 2001; Koponen et al., 2007; Koponen et al., 2016; Simmons, Singleton, & Horne, 2008), basic number skills (Koponen et al., 2007; Koponen et al., 2016), and general cognitive abilities (Alloway & Alloway, 2010; Clair-Thompson & Gathercole, 2006; Gathercole, Pickering, Knight, & Stegmann, 2004; Rohde & Thompson, 2007).

Empirical research in reading and arithmetic has supported the notion that many linguistic skills are related to both academic domains. For example, phonological awareness, i.e., the ability to analyze the sound structure of oral language, has been shown to be a strong predictor of both reading (de Jong & van der Leij, 1999, 2002; Leppänen, Aunola, Niemi, & Nurmi, 2008) and arithmetic skills (De Smedt, Taylor, Archibald, & Ansari, 2010; Hecht et al., 2001; Simmons et al., 2008) especially in the early phases of skill development. There are, however, some studies where this association has not been found with respect to arithmetic skills (Durand et al., 2005; Passolunghi & Lanfranchi, 2012). The double-deficit hypothesis presented by Wolf and Bowers (1999) proposes that problems with phonological processing and naming speed are separable sources of dysfunction. This has been confirmed in children with reading difficulty or comorbid reading and arithmetic difficulty (Heikkilä, Torppa, Aro, Närhi, & Ahonen, 2016). In line with this suggestion, the ability (RAN) to name sequentially presented familiar symbols (e.g., objects, colors, letters, or digits), has been shown to be an important indicator of fluency not only in reading (Kirby, Georgiou, Martinussen, & Parrila, 2010), but also in arithmetic (Koponen et al., 2013; Koponen et al., 2016). Koponen et al. (2016) found too that RAN was a strong predictor of both reading and arithmetic fluency development, even after controlling for a number of other underlying skills, such as phonological awareness and memory. During primary school, letter knowledge – as a basis for understanding the alphabetic principle – has also been shown to be a powerful predictor of both reading (Leppänen et al., 2008; Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2004) and arithmetic fluency development (Zhang et al., 2014). According to Koponen et al. (2007) the ability to learn and retrieve the phonological representations of visual symbols could be a process needed both in learning letters and number words, and thus it could be a common prerequisite for learning to both read and calculate. Up to now, only a few studies have examined the predictors of covariation in reading and arithmetic (Hecht et al., 2001; Koponen et al., 2007); and these have found that all three linguistic skills – phonological awareness, RAN and letter knowledge – are positively related to covariation in reading and calculation from grades 2 to 5 (Hecht, 2001; Koponen et al., 2007).

In addition to linguistic skills, basic number skills might also be associated with the covariation of reading and arithmetic skills. Previous findings from separate studies on reading and arithmetic suggest, for example, that the ability to count number words (forwards, backwards, and in steps) at age six and seven predicts the later development in primary school of both arithmetic (Aunola et al., 2004; Zhang et al., 2014) and reading skills (Koponen et al., 2013). Studies on the covariation of reading and arithmetic have also shown that a shared skill level in reading and calculation fluency at Grade 4 is strongly predicted by the counting ability shown at kindergarten (Koponen et al., 2007). One possible explanation for the relationship between counting and fluency in both reading and arithmetic is the ability to grasp rules describing the relations between elements repeatedly within a sequence (Koponen et al., 2013; 2016). In most alphabetic orthographies grapheme-phoneme correspondences are regular and predictable. For early reading, this means that the pronunciation of written words is achieved reliably by serial assembly of phonemic representations of single graphemes. Thus, at the early stages of development of both reading and arithmetic, letters and numbers are processed one by one [i.e., A-U-T-O (car); 1, 2, 3, 4, …] after which processing becomes more automatized following practice (i.e., recognizing syllables AU-TO and whole words AUTO or skip counting 5, 10, 15, and fact retrieval).

In addition to linguistic and basic number skills, more general cognitive learning skills have been identified as potential predictors of covariation in reading and arithmetic. A study by Alloway and Alloway (2010), for example, showed that children's working memory at age five predicted their academic attainment in both domains six years later (after controlling for IQ). Working memory, that is the ability to retain information in the correct order while processing it, requires control of attention, retrieval of information from long-term memory and temporary storage of verbal and visuospatial information (Baddeley, 2000). The phonological aspects of working memory (Alloway & Alloway, 2010; Gathercole et al., 2004; Stevenson, Bergwerff, Heiser, & Resing, 2014) and central executive ability (Clair-Thompson & Gathercole, 2006) have been found to be closely associated with both reading and math skills. Nonverbal reasoning is also a good predictor of school achievement in both academic domains (Karbach, Gottschling, Spengler, Hegewald, & Spinath, 2013; Rohde & Thompson, 2007; Spinath, Spinath, Harlaar, & Plomin, 2006). Of these general cognitive skills, limitations in working memory is the most typical among children with reading and math (including arithmetic) difficulties (Cirino et al., 2015; Moll, Göbel, Gooch, Landerl, & Snowling, 2016; Peng & Fuchs, 2016; Willcutt et al., 2013).

Parental education may also play a role in the covariation of reading and arithmetic skills, as it has been shown to be one of the best predictors of children's educational achievement (Davis-Kean, 2005; Eccles, 2005; Sharma & Jha, 2014). For example, in a study by Larson, Shirley, Bergen, Olson, and Halfon (2015), family SES (i.e., a composite of parents' education, occupational status, and household income) explained over half the individual differences in early reading and math skills. It has been shown that SES directly relates to a child's academic achievement; not only through heritable traits (Kraphol & Plomin, 2016), but also indirectly through the parents' beliefs about achievement and stimulating behaviors (Davis-Kean, 2005; see also Eccles, 2005).

Although different antecedents have been suggested for the covariation between reading and arithmetic skills, this covariation has rarely been examined over several grades. Consequently, little is known about the antecedents of the time invariant and time-specific portions of that covariation across school grades. The second aim here is thus to examine the extent to which the known antecedents of reading and arithmetic skills (i.e., phonological awareness, RAN, letter knowledge, counting skills); general cognitive abilities (nonverbal reasoning, working memory); and parental education predict the time invariant and time-specific portions of covariation between reading and arithmetic skills from grades 1 to 7.

1.5 Research Questions

The present study examined the following research questions:

1) Given that reading and arithmetic skills show covariation (shared variance) at grades 1 and 7, to what extent is this invariant (shared at two grades), and to what extent is it time-specific (unique to a particular grade)?

Two alternative hypotheses were proposed: (1a) Because it has been suggested that both reading and arithmetic skills are based on similar cognitive processes at different grades (Hecht et al., 2001; Koponen et al., 2013; Koponen et al., 2016), we expected that a large part of the covariation between these two skills would be time-invariant. (1b) Our alternative hypothesis was that part of the covariation between reading and arithmetic is time-specific, as the acquisition of both reading and arithmetic skills is known to include not only serial processing at the early stages (Koponen et al., 2016), but also the processing and retrieving of larger units later on, such as syllables or words in reading, and arithmetic facts in math. Covariation thus represents the association here between reading and arithmetic skills, which we were then differentiated into time-invariant and time-specific parts.

2) To what extent do reading and arithmetic pre-skills, general cognitive abilities, and parental education in kindergarten predict the time invariant and time-specific portions of covariation between reading and arithmetic skills at grades 1 and 7?

Our two hypotheses to this research question were that: (2a) kindergarten pre-skills of reading and arithmetic (phonological awareness, letter knowledge, and counting) would predict time-specific covariation between reading and arithmetic skills in Grade 1 (Holopainen, Ahonen, Lyytinen, 2001; Krajewski & Schneider, 2009; Silvén, Poskiparta, Niemi, & Voeten, 2007); and that (2b) more general cognitive processes (rapid automatized naming, working memory, and nonverbal reasoning) would predict the time invariant part of the covariation between these skills.

2. Method

2.1 Participants and Procedure

This study is part of an extensive longitudinal age cohort study (authors removed for reviewing purposes, 2006), which follows up a community sample of children (n = 1880) from one rural and three urban municipalities in Finland from kindergarten entry (age *M* =

74.0 ± 3.6 months) to the end of lower secondary (age 15). All of the age cohort in the rural and two of the urban municipalities, plus about a half of the age cohort from the remaining urban municipality were used in this study. Parents were asked for written consent for their child to participate. Most of the children (80%) came from nuclear families, 10% from single parent families, 8% from blended families, and 2% from families where the parents were divorced and the child lived in two homes.

There was a total of 1,335 children (47.1% girls) participating in the present study that had performance data available for reading and arithmetic in both grades 1 and 7. These children showed a higher skill-level in reading (M = 18.73, SD = 7.80) and arithmetic (M = 11.01, SD = 3.94) at Grade 1 than those in the larger population of 1,880 who participated only at Grade 1 (M = 16.76, SD = 8.38, t (2030) = -5.27, $p < .001$ for reading; and M = 9.59, SD = 4.17, t (2049) = -7.61, $p < .001$ for arithmetic). Similarly, children who participated at both grades showed a higher skill-level of reading (M = 33.64, SD = 7.29) and arithmetic (M = 13.93, SD = 3.71) at Grade 7 than those in the larger population who participated only at Grade 7 (M = 31.56, SD = 7.57, t (1762) = -5.08, $p < .001$ for reading and M = 12.97, SD = 3.83, t (1743) = -4.56, $p < .001$ for arithmetic). The children were either 7 years old on entering school, or they turned 7 during the first term of Grade 1 (M = 85.77 months old, SD = 3.44 months). Among their parents, 27.4% of mothers had a Master's degree or higher, 32.5% a Bachelor's or vocational college degree, 25.3% a vocational school degree, and 5.7% had no education beyond lower secondary school. Meanwhile, 22.5 % of the children's fathers had a Master's degree or higher, 30.7% a Bachelor's or vocational college degree, 29.8% a vocational school degree, and 7.6% had no education beyond lower secondary. This is relatively representative of average family background characteristics in Finland (Statistics Finland, 2013).

The Finnish basic compulsory education is from grades 1 to 6 at primary, and grades 7 to 9 at lower secondary. Children start primary at age seven, and before this there is a year of kindergarten for 6-year-olds, to consolidate the pre-skills required for reading and arithmetic, which are then formally taught from Grade 1 onwards. The data concerning reading and arithmetic skills was collected from a group setting in the March/April of grades 1 and 7. Phonological awareness, letter knowledge, RAN, and counting were tested individually during the kindergarten year, while working memory was tested at Grade 1, and nonverbal reasoning at Grade 3. All tests were carried out by researchers or students in psychology/education that had been trained accordingly.

2.2 Measurements

2.2.1 Reading

In March/April of Grade 1, a Finnish adaptation of TOSREC (the Test of Silent Reading Efficiency and Comprehension; Wagner, Torgesen, Rashotte, & Pearson, 2009) was used as a sentence verification task to measure reading fluency. This Finnish version (Lerkkanen & Poikkeus, 2008) is very similar to measures used in previous studies examining the comorbidity of fluency problems in reading and arithmetic (see Landerl & Moll, 2010). It required students to read out 60 semantically simple sentences (such as "an apple is blue"; or "candy is usually sweet"), and decide whether the sentences were true or not. The score was based on the number of correct responses made within three minutes (at a max. of 60 per minute). According to Lerkkanen (2003), it has been confirmed that, on average, Finnish students can read whole sentences by the December of Grade 1.

At Grade 7, another Finnish version of the TOSREC was used (Lerkkanen, Löytynoja, Poikkeus, Aro, & Eklund, 2016). This time it consisted of reading 70 sentences silently in their heads and deciding whether they were true or not within two minutes (i.e., "*Monday is a season*", " *An irreversible damage is easy to repair*"). The sum score (min./max. = 0/70) was based on the number of items they had got correct. The Cronbach's alpha reliabilities for the test were .89 at Grade 1 and .94 at Grade 7.

2.2.2 Arithmetic skills

Students' arithmetic skills were assessed using the Basic Arithmetic Test (Aunola & Räsänen, 2007) in March/April of grades 1 and 7. Performance in the test requires both accuracy and speed (automatization of basic calculation routines). At Grade 1, the test consisted of completing 14 addition sentences (e.g., *2 + 1 =* __, *3 + 4 + 6 =* __), and 14 subtraction (e.g., *4 - 1=* __, *20 - 2 - 4 =* __). At Grade 7 the test also consisted of 28 items in total, but they were a mix of addition, subtraction, multiplication and division tasks (e.g., *40 : 8 – 3 =* __, __ *– 18 = 45 – 12, 11 × 3,2 =* __, *6 × 4 + 1 =* __ *- 21*). Students were given 3 minutes to complete as many items as possible, and this time limit, combined the increasing difficulty of items towards the end meant the test was challenging even for the older students. The total number of correct items at grades 1 and 7 was then calculated to provide a sum score (maximum value of 28). The Cronbach's alpha reliabilities for arithmetic skills were .70 at Grade 1 and .94 at Grade 7.

2.2.3 Phonological awareness

Phonological awareness was assessed individually during the fall of kindergarten using an initial phoneme identification task containing 10 items (Lerkkanen, Poikkeus, & Ketonen, 2006). For each item (phoneme), the student was shown the pictures of four objects at the same time and told their names. The student was then asked to indicate which of the pictures began with the same phoneme (e.g., "*At the beginning of which word do you hear* ____*?*"). The score was the total number of correct items (maximum value of 10). The Cronbach's alpha reliability was .78.

2.2.4 Letter knowledge

Letter knowledge was assessed individually during the fall of kindergarten using the Letter Knowledge Test (Lerkkanen et al., 2006), consisting of all 29 uppercase letters in the Finnish alphabet arranged along three rows in a random order. The student was shown one row at a time and asked to name the letters. The sum score was based on the number of correct items (maximum value of 29). The Cronbach's alpha reliability for the test was .95.

2.2.5 Rapid automatized naming (RAN)

The rapid naming of objects was assessed in March/April of kindergarten using a standard procedure (see Denckla & Rudel, 1974) in which the student was asked to name, as rapidly as possible, a series of five familiar visual stimuli replicated 10 times on a matrix in random order. Documented errors and self-corrections were few and they were not used in the analysis. The completion time in seconds of the total matrix (five rows of 10) was used as the score. According to the manual, the test-retest reliability coefficients ranged from .84 to .92 for all age groups (Wolf & Denckla, 2005).

2.2.6 Counting sequence knowledge

Counting sequence knowledge was assessed individually during the fall of kindergarten using the (forward and backward) Number Sequences Test (Salonen et al., 1994). This consists of four tasks in which the student is asked to count out loud (i) forwards from 1 to 31; (ii) forwards from 6 to 13; (iii) backwards from 12 to 7; and (iv) backwards from 23 to 1. For each of the four tasks, two points were given for completing it without a mistake; one point for up to two mistakes; and zero for any more than that, or if the task could not be completed. The total maximum score for the test was therefore 8, and the Cronbach's alpha reliability for the test was .74.

2.2.7 Working memory

Working memory was assessed individually in March/April of Grade 1 using the WISC-III (Wechsler, 1991) digit span subtest. The student was asked to repeat an identical string of digits after the tester, and then again so that there were two identical spans per section. The span was then increased by 1 in each section, so that eventually there were 8 forward, and 7 backward digit spans. Two points were given for repeating both spans correctly, 1 for only one, and 0 for none, whereupon the test was discontinued. The maximum possible score was therefore 16 points for forward digit spans and 14 for backward, giving a total of 30. According to the manual, the average reliability for all age groups was .75 (Wechsler, 1991).

2.2.8 Nonverbal reasoning

The shortened version of Raven's Colored Progressive Matrices (Raven, Court, & Raven, 1992) was used to assess the students' nonverbal reasoning in March/April of Grade 3. The test contains 18 items, in each of which the student was asked to identify the missing element to complete a pattern (from 6 choices). One point was scored for each correctly answered item, so that the maximum total score was 18. Guttman's split-half reliability for the test was found to be .66 and Cronbach's alpha reliability .64.

2.2.9 Parental education level

A total of 1,214 mothers (90.7%) and 1,212 fathers (90.6%) filled in and returned the questionnaires reporting on their education level using a 7-point scale (1 = *no education beyond secondary 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*). Parental education score was then determined by education score of the most highly educated parent.

2.3 Analysis Strategy

The research questions were examined using SEM (structural equation modeling). The SEM models were conducted through two steps. First, we constructed a model in which reading and arithmetic skills were modeled with three latent factors at grades 1 and 7 (times 1 and 2 respectively). The first factor modeled the covariation (shared variance) of reading and arithmetic skills across time, i.e., *time-invariant covariation* (see figure 1); for which the loadings of indicators (i.e., standardized reading and arithmetic skills at time 1, and at time 2) were estimated as equal. Meanwhile, the second latent factor described the time-specific covariation of reading and arithmetic at time 1 (that was no longer evident at time 2). This latent factor had two indicators—reading skills and arithmetic skills at time 1—for which loadings were estimated as equal. Finally, the third latent factor described the time-specific covariation of reading and arithmetic at time 2 (that was not evident at time 1). This latent factor consisted of two indicators—reading at time 2 and arithmetic at time 2—for which loadings were estimated as equal. In the model, the residual of the observed reading skills at time 1 was allowed to correlate with the residual of the same at time 2, and the residual of the observed arithmetic skills at time 1 was allowed to correlate with the residual of the same at time 2.

The second step in the analysis was to predict the time-invariant covariation in the level of skills shared by reading and arithmetic at both times 1 and 2 by adding the antecedent variables to the previous model. Then, we examined the model fit and modification indices to see whether the paths from antecedents should be estimated also to time-specific covariation factors between reading and arithmetic skills at times 1 and 2. Large modification indices (over the value of 10) were taken to suggest that the fit would improve if the paths from predictor variable to latent time-specific covariation factor was added to the model (Figure 2).

All of the statistical analyses were performed using Mplus statistical software and the standard missing-at-random (MAR) approach–which supposes that any data missing would be at random (Muthén & Muthén, 1998–2010). The parameters of the models were estimated using full information maximum likelihood (FIML) estimation with standard errors that are robust to non-normality (MLR estimator; Muthén & Muthén, 1998–2010). This method allowed us to use all of the observations in the dataset to estimate the parameters of the models.

With both a nonsignificant χ^2-test value and comparative fit index (*CFI*) of greater than .95; and a root mean square error of approximation (*RMSEA*) of lower than .06, the model seemed to fit the data well (Muthén, & Muthén, 1998–2010). Several fit indices were used since, as Bollen and Long (1993) have suggested, they provide different information about the model fit (RMSEA might measure absolute fit, but CFI and TLI measure relative fit). The correlations, means (*M*), and standard deviations (*SD*) of study variables are shown in table 1.

------Insert Table 1 about here-----

3. Results

As we have seen, to examine the first research question of how much covariation between reading and arithmetic skills is shared (invariant) between grades 1 and 7, and how much is unique (time-specific) to each grade, we modeled the latent factors for time-invariance and time-specificity. The fit of the model was: χ^2 (3) = 7.59, p = .06; CFI = 1.00; $RMSEA$ = 0.03. The model is shown in figure 1.

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

Figure 1 shows that reading and arithmetic skills shared 47% of their variance at Grade 1 and 33% at Grade 7. The results showed further that the majority of this covariation between reading and arithmetic was time-invariant: the shared variance between reading and arithmetic was common for both times 1 and 2. However, part of the covariation between reading and arithmetic was also time-specific: some pertaining only to time 1, and some of it only to time 2.

To answer the second research question of how phonological awareness, letter knowledge, RAN, counting skills, working memory, nonverbal reasoning, and parental education (predictor variables) would predict time-invariant and time-specific covariation between reading and arithmetic skills at grades 1 and 7, they were first added to the model to predict the time-invariant portion of covariation. The fit of the model was: χ^2 (26) = 206.35, *p* < .001; *CFI* = .93; *RMSEA* = 0.05. However, the inspection of modification indices suggested that the fit would improve if the paths were estimated (i) from letter knowledge, phonological awareness, and counting to time-specific covariation at time 1; and (ii) from nonverbal reasoning and parental education level to time-specific covariation at time 2. After these modifications, the model fitted the data well (χ^2 (21) = 137.67, *p* = < .001; *CFI* = .95; *RMSEA* = 0.05), and no more modification indices were over 10. This final model is shown directly below in figure 2.

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

To begin with, the results showed that *time-invariant* covariation between reading and arithmetic was predicted by *letter knowledge*, *counting skills*, *RAN*, *working memory*, and *nonverbal reasoning*; the higher these predictor variables were, the higher the levels of both reading and arithmetic in grades 1 and 7. Secondly, *time-specific* covariation between reading and arithmetic at Grade 1 (time 1) was predicted by *letter knowledge*, *phonological awareness*, and *counting skills* in kindergarten; the higher these three antecedent variables were, the higher the levels of both reading and arithmetic in Grade 1 (i.e., level of performance shared by reading and arithmetic at Grade 1 that is no longer evident at Grade 7). Finally, time-specific covariation between reading and arithmetic in Grade 7 (time 2) was predicted by nonverbal reasoning and the level of parental education; the higher these two antecedent variables were, the higher the levels of both reading and arithmetic in Grade 7 (i.e., skill level shared by reading and arithmetic at Grade 7 that was not evident at Grade 1) 1.

4. Discussion

The present study was an attempt to complement current understanding of the cross-domain development of reading and math skills using an unselected population from the beginning of primary school (Grade 1) to lower secondary school (Grade 7), and to define the antecedents of this development. The results showed that reading and arithmetic skills shared about half of their variance at Grade 1 and one third of their variance at Grade 7. It was also clear that a large proportion of this covariation was common (time-invariant) to both grades 1 and 7. Moreover, this time-invariant part of the shared variation between reading and arithmetic was found to be predicted by RAN and counting, as well as by early letter knowledge, working memory, and nonverbal reasoning. Time-specific part of the shared skill level of reading and arithmetic evident at Grade 1 was predicted by phonological awareness, letter knowledge, and counting. Time-specific part of the shared skill level at Grade 7, in turn, was predicted by parental education level and nonverbal reasoning.

4.1 Covariation between Reading and Arithmetic From Primary to Lower Secondary

The first aim of the present study was to investigate to what extent there is covariation between reading and arithmetic skills in Grade 1 and Grade7 in an unselected population, and to what extent this covariation is invariant (shared across the two grades) from primary school (Grade 1) to lower secondary school (Grade 7). The results showed that reading and arithmetic skills were associated both at grades 1 and 7. Overall, this result is consistent with previous studies that also indicate substantial covariation between reading and math skills among an unselected population in primary (Chen & Chalhoub-Deville, 2016; Davis et al., 2014; Hecht et al., 2001; Koponen et al., 2007; Rutherford-Becker & Vanderwood, 2009) and lower secondary school (Chen & Chalhoub-Deville, 2016; Codding et al., 2015), suggesting that reading and arithmetic skills develop in tandem across grade levels.

The results of the present study further showed, in line with our hypothesis (1a), that the majority of covariation in reading and arithmetic skills was common to both grades 1 and

7 (i.e., time-invariant). This confirms previous findings indicating relatively high stability of individual differences both in reading (de Jong & van der Leij, 2002; Hulslander et al., 2010; Landerl & Wimmer, 2008; Parrila et al., 2005) and in arithmetic (Aunola et al., 2004; Bailey et al., 2014; Watts et al., 2014) across the school years. Our results also suggest that the development of reading and arithmetic seem to share common processes *across* the different developmental phases. Considering the importance of early reading and arithmetic skills for later academic performance (Duncan et al., 2007), these findings raise the question as to whether individual differences in the level of these skills are established already at the beginning of school. At this point, however, it should be pointed out that high invariance in the skill level shared by reading and arithmetic does not mean that children's reading and arithmetic skills are not developing; even if school does not seem to remove individual differences in skill levels, it clearly helps in improving all children's skills.

The large proportion of shared variance between reading and arithmetic from Grade 1 to Grade 7 may be explained by the fact that these skills are related to each other at many levels. For example, the 'generalist genes' hypothesis suggests that the same set of genes affect a diverse number of skills that are required in both domains (Davis, 2014; Plomin & Kovas, 2005). Due to the rather high heritability of reading and math skills (Davis et al., 2014; Kraphol et al., 2014), it is likely that this genetic overlap is one reason for our results. It has been found that there is also an overlap in cognitive processes between reading and arithmetic skills (Hecht et al., 2001; Koponen et al., 2016; Simmons et al., 2008), that can be found in studies on the comorbidity of related difficulties too (Cirino et al., 2015; Peng & Fuchs, 2016; Willcutt et al., 2016). If difficulties in reading and arithmetic are indeed caused by the same underlying cognitive factors that enable the learning of these skills (Kovas & Plomin, 2007), then the high covariation found in the entire distribution of the unselected population used in this present study would seem to confirm this.

Furthermore, and in line with hypothesis 1b, part of the covariation between reading and arithmetic was found to be time-specific (i.e., typical only to Grade 1 or Grade 7). This finding provides some evidence for a notion that the covariation between reading and arithmetic can be partly related to certain phases of skill development, such as serial decoding/counting or automatized phase with direct retrieval of larger units. Moreover, association between reading and arithmetic fluency was slightly stronger in Grade 1 than in Grade 7, suggesting that reading and arithmetic skills have more in common in the early phases of skill development.

4.2 Antecedents of Time-Invariant and Time-Specific Covariation from Grades 1 to 7

The second aim of the present study was to investigate the extent to which linguistic and basic number skills, general cognitive abilities, and parental education level predict time-invariant and time-specific covariation between reading and arithmetic from Grade 1 to Grade 7. Our results showed that the invariant part of the covariation was predicted by various reading and arithmetic pre-skills (letter knowledge, RAN, counting) and by general cognitive abilities (working memory, nonverbal reasoning). The higher the level of these pre-skills and general cognitive abilities, the higher the level of skills shared by reading and arithmetic across grade levels.

The strongest predictors of the time-invariant level of skills shared by reading and arithmetic from Grade 1 to Grade 7 were RAN and counting, which previous studies have also found to predict both reading and arithmetic fluency at Grades 2 and 3 (Koponen et al. 2013; Koponen et al., 2016), as well as their covariation at Grade 4 (Koponen et al., 2007). For the first time, however, the present study showed that both of these skills also predict the covariation of reading and arithmetic fluency over time. This finding emphasizes the role of RAN and counting as early predictors of fluency in two important academic domains. The predictive role of RAN suggests that the time-invariant part of skills used in both arithmetic and reading is not simply related to phonological awareness, but more specifically, to how quickly phonological representations can be accessed, or how automatic visual-verbal associations are.

In addition, the results are consistent with studies indicating the importance of working memory (Alloway & Alloway, 2010; Gathercole et al., 2004) and nonverbal reasoning (Karbach et al., 2013; Rohde & Thompson, 2007; Spinath et al., 2006) in overall school achievement. Of the general cognitive abilities, working memory was a stronger predictor of the level of skills shared by reading and arithmetic across grade levels than nonverbal reasoning. Alloway and Alloway (2010) also found verbal working memory, at the start of formal education, to be a better predictor than IQ of subsequent success in reading and arithmetic.

The results also showed, in line with our hypothesis (2a), that time-specific skill level shared by reading and arithmetic at Grade 1 (i.e., covariation evident in Grade 1 but not Grade 7) were predicted by phonological awareness, letter knowledge, and counting: the higher the level of these pre-skills in kindergarten, the higher the shared skill level of reading and arithmetic at Grade 1. These results may be explained by the similarity in ways both the alphabetic and numeral systems are taught at the beginning of school. This confirms previous research showing that phonological awareness (Simmons et al., 2008), letter knowledge (Koponen et al., 2007), and counting (Koponen et al., 2016) are important precursors of both reading and arithmetic skills. Awareness of the phonological structure of a language has also been shown to have an important role in the development of reading, particularly of basic word-decoding skills (e.g., Hogan, Catts, & Little, 2005; Holopainen et al., 2001; Silvén et al., 2007). In arithmetic, phonological awareness has been found to be associated with early quantity-number skills and, through those skills, to later arithmetic skills. Interestingly, Krajewski and Schneider (2009), found that phonological awareness did not directly contribute to either the prediction of higher order quantity-number skills or later arithmetic competencies but only did so indirectly, via early quantity-number skills. The strongest predictor of covariation between reading and arithmetic skills at Grade 1 was again counting ability, which seems to be a good predictor both for initial phases as well as more automatized phases of skill development in reading and arithmetic. The results regarding phonological awareness, letter knowledge, and counting being predictors of time-specific covariation at Grade 1 might also be explained by the fact that these pre-skills were all measured at the beginning of kindergarten, thus indicating how well prepared children were for school tasks before they started school. After formal instruction and practice at school, it would seem safe to assume that the variance related to early training (and non-training) will diminish over time.

Meanwhile, time-specific skill level shared by reading and arithmetic at Grade 7 (i.e., covariation that was evident in Grade 7 but not in Grade 1) was found to be predicted by the level of parental education and nonverbal reasoning: the higher the level of parental education and nonverbal reasoning, the higher the shared skill level of reading and arithmetic in Grade 7, independent of the level of these skills at Grade 1. The results of time-specific covariation at Grade 7 are in line with studies indicating the importance of the parents' education level (Davis-Kean, 2005) and the child's nonverbal reasoning abilities (Karbach et al., 2013) in overall school achievement during early adolescence. A study by von Stumm and Plomin (2015), for example, showed that the development of children's intelligence from infancy to adolescence was significantly associated with family SES. Since differences in the availability of learning opportunities, support and resources are also thought to accentuate individual differences in cognitive ability (von Stumm & Plomin, 2015), it is possible that children with high initial intelligence engage more in reading and math related activities than children with low initial intelligence due to both family environment (Davis-Kean, 2005) and their individual cognitive abilities (Trzaskowski et al., 2014). In the long-term, this engagement may then lead to higher overall performance in both reading and arithmetic skills, regardless of the level of these skills at Grade 1–thus explaining our results for the predictors of covariation in reading and arithmetic skills specific to Grade 7 only.

4.3 Limitations

There are at least seven limitations that should be taken into account before we can generalize any further about the findings of the present study. First, the predictor variables were measured at different points in time: counting skills, phonological awareness, and letter knowledge were measured at the fall of kindergarten, whereas RAN was measured the following spring. General cognitive abilities were also measured at different points in time: working memory in spring of Grade 1 and nonverbal reasoning in spring of Grade 3. Second, limited working memory measure with the digit span subtest of WISC-III was used. Although the digit span subtest of WISC-III has been shown to be highly reliable as a test for working memory across a range of age groups (Wechsler, 1991), no information concerning the reliability of the test for the present sample was available. Third, we did not have the necessary data to include executive functioning as a predictor variable of covariation in reading and arithmetic skills. Fourth, although the level of parental education was included as a predictor variable, it was not possible to separate genetic from environmental influences. Fifth, when generalizing these findings across languages, the transparent orthography of the Finnish language should be taken into account. Due to the simple and symmetrically regular phoneme-grapheme connection structure of Finnish, decoding requires less advanced phonological processing skills than do more opaque orthographies, such as English. Moreover, with regards to the transparency of orthography, the variance in reading skills derives mainly from fluency and not accuracy, even though reading efficiency (reading words accurately within a time limit) was used as an outcome measure. Sixth, due to the relative transparency of grapheme–phoneme correspondence being equally regular for spelling as it is for reading in Finnish, spelling was not investigated. In future studies in languages with less transparent orthographies, spelling should be included as a separate outcome variable. Finally, the amount of covariation between reading and arithmetic skills might well be dependent on the individual skill levels of the students, so this should be examined in future studies.

4.4 Conclusion

Overall, the results of the present longitudinal study showed that most of the covariation between reading and arithmetic was common to grades 1 and 7. This suggests that reading and arithmetic skills are strongly related to each other, and the association is shared across grade levels. Our results also suggest that the shared skill level of reading and arithmetic is already fairly well established at the beginning of school.

These results have at least two practical implications. Firstly, there is a substantial amount of time-invariant covariation between reading and arithmetic across the school years, and the cognitive predictors of this time-invariance suggest that these skills have the same underpinnings at different phases of skill development. As development in both reading and math requires fluency in basic skills, early identification of those children who might develop fluency problems is important already at kindergarten. Rapid serial naming and counting are easy to assess before children enter school, and can be used as diagnostic tools to detect children at risk of developing fluency difficulties in both reading and arithmetic. The high invariance in covariation between the two domains also underlines the need to develop effective tools for supporting fluency development in math and reading skills, which has received less attention in intervention research.

Secondly, unlike many other studies, we were able to differentiate the antecedents of time-invariant and time-specific covariation in reading and arithmetic skills. The results concerning time-specific covariation showed that early pre-skills, such as phonological awareness, played a particularly important role at the start of skill development, whereas the educational level of parents and more general reasoning skills were significant at a later phase in the development shared reading and arithmetic fluency. This finding suggests that intensive preventive support for those children who show impairment in phonological processing could be an efficient way to support the early phases of skill development in reading and arithmetic. However, the skill level in later grades is likely to require a more general type of support such as interventions aimed to increase students' motivation and engagement.

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Table 1

Correlations, Means (M), and Standard Deviations (SD) of the Study Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Reading skills Time 1	1.00										
2. Arithmetic skills Time 1	.44***	1.00									
3. Reading skills Time 2	.54***	.27***	1.00								
4. Arithmetic skills Time 2	.35***	.51***	.36***	1.00							
5. Phonological awareness	.39***	.19***	.23***	.21***	1.00						
6. Letter knowledge	.47***	.31***	.30***	.30***	.56***	1.00					
7. Rapid automized naming	-.35***	-.24***	-.30***	-.25***	-.24***	-.29***	1.00				
8. Counting skills	.41***	.44***	.27***	.40***	.38***	.57***	-.25***	1.00			
9. Working memory	.35***	.20***	.28***	.20***	.23***	.21***	-.10	.31***	1.00		

10. Nonverbal reasoning	.20***	.19***	.23***	.27***	.20***	.18***	-.18***	.20***	.21***	1.00	
11. Parental level of education	.13***	.12***	.13***	.22***	.19***	.21***	-.13***	.18***	.03	.11***	1.00
M	18.73	11.01	33.64	13.93	7.66	18.02	69.36	4.80	9.13	16.78	4.58
SD	7.80	3.94	7.29	3.71	2.30	8.63	16.45	2.77	1.89	1.60	1.46

Note 1. Time 1 = March/April of Grade 1, Time 2 = March/April of Grade 7

Note 2. * $p < .05$, ** $p < .01$, *** $p < .001$

Note 3. Rapid automatized naming was scored as reaction time (low scores meaning high performance and high score meaning low performance)

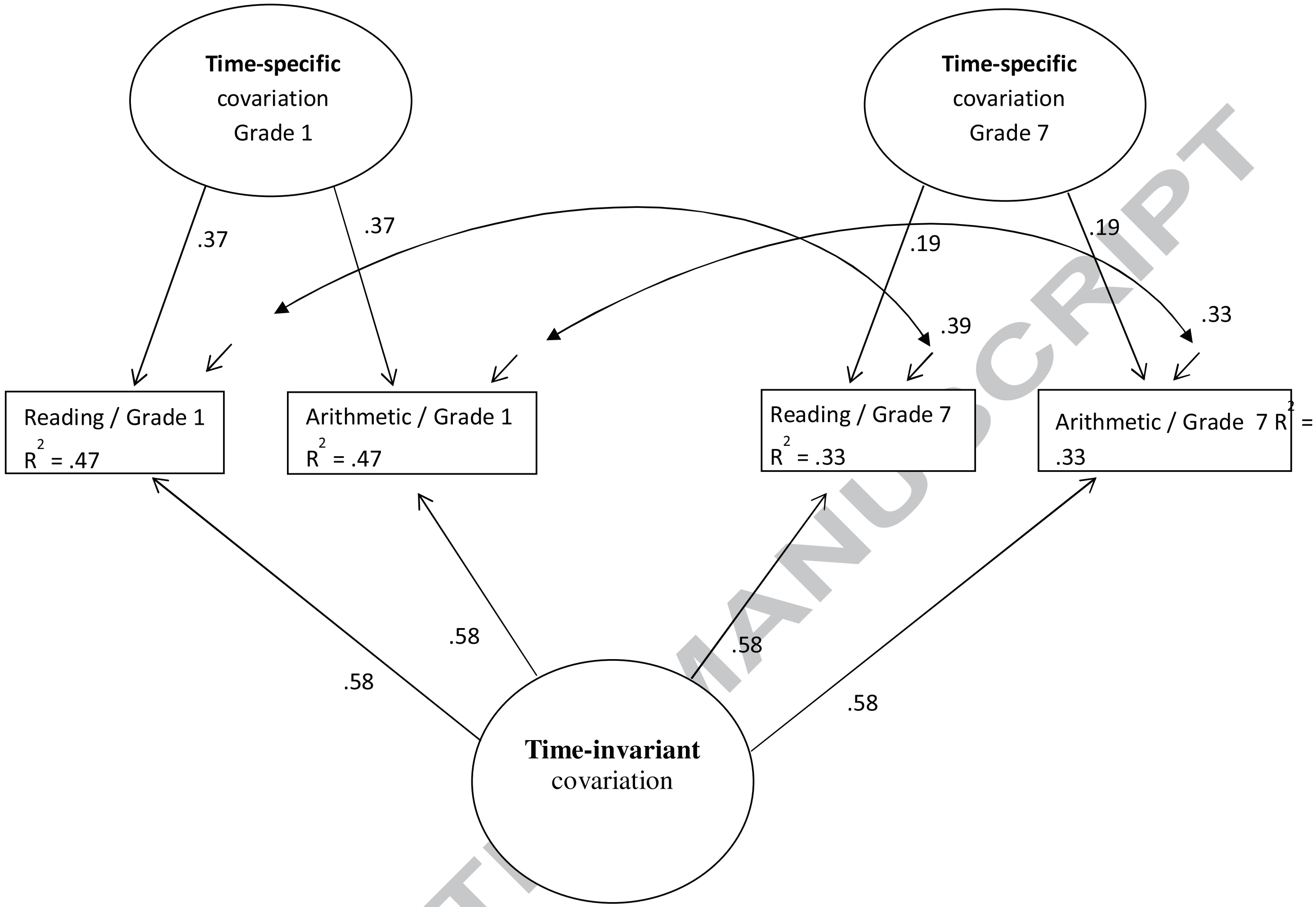

Figure 1. Time-invariant and time-specific parts of covariation between reading and arithmetic skills from Grade 1 (Time 1) to Grade 7 (Time 2).

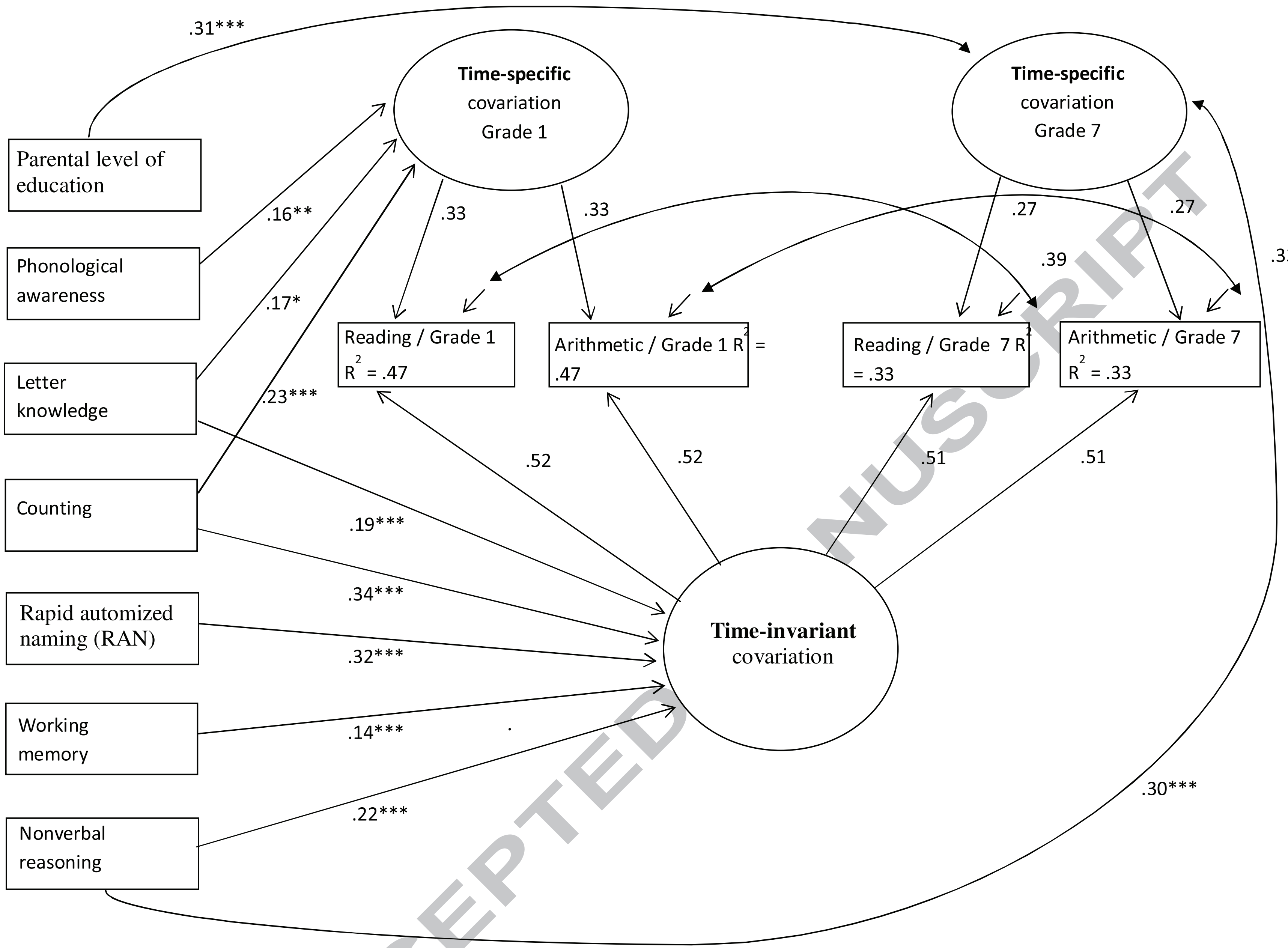

Figure 2. Predictors of the time-invariant and time-specific parts of covariation between reading and arithmetic skills (Standardized Estimates).

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