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Running head: PREDICTORS OF FLUENCY IN ARITHMETIC AND READING

Counting and Rapid Naming Predict the Fluency of Arithmetic and Reading Skills

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HIGHLIGHTS

- This study examined the predictors of later arithmetic and reading fluency.

- Both counting and RAN were strong predictors of arithmetic and reading fluency.

- Controlling for phonological awareness, vocabulary and memory had little impact on those effects.

- Counting and RAN are not skill-specific but general predictors of arithmetic and reading fluency.

Abstract

Understanding of the factors that underlie the development of fluency in reading and arithmetic is limited. This longitudinal study examined whether verbal counting and rapid naming (RAN) were predictors of arithmetic and reading fluency in a population-based sample and to what extent related early emerging cognitive abilities and socioeconomic background accounted for the predictive power of counting and RAN. In addition, in order to examine the uniqueness of counting as a numerical predictor of reading fluency, the influence of another early number skill—number concept—was controlled. Three hundred and seventy-eight Finnish children were followed from kindergarten to Grade 3 (from 6 to 10 years). The results demonstrated that counting and RAN were powerful predictors of arithmetic and reading fluency. Controlling for phonological awareness, vocabulary, memory, and mother's education had little impact on the predictive relation of counting and RAN to fluency in arithmetic and reading. The number concept skill did not remove the predictive relation of counting with reading or arithmetic and had only a predictive relation to arithmetic fluency after controlling for cognitive skills. Findings suggest that the strong predictive relation counting had with reading and arithmetic fluency does not exist with all number skills. This finding supports the view that there is something specific in the verbal counting skill related to the development of fluency, which should be studied in the future.

Keywords: counting, RAN, arithmetic calculation fluency, reading fluency, longitudinal study

1.   Counting and Rapid Naming: General or Skill-Specific Predictors of Arithmetic and Reading Fluency

Fluency in reading and arithmetic calculation is crucial for later development of academic skills. Fluent reading skill serves as a tool for learning other school subjects, such as biology or history. Development of reading fluency at the beginning of one's school career has also been shown to be a strong predictor of later reading comprehension (Kim, Petscher, Scahtschneider, & Foorman, 2010). Similarly, basic arithmetic calculation skill serves as a tool needed in mathematical problem solving as well as in other subjects, such as science. Fluent calculation skill supports learning, because it frees up the individual's resources from use for low-level computation for use in more complex problem solving and reasoning (Meyer, Salimpoor, Wu, Geary, & Menon, 2010). Dysfluency in these two basic skills hampers the later academic learning and it's important to support the adequate development of these skills.

Despite the importance of fluent mastery of these basic skills, explicit attention to joint fluency in reading and arithmetical calculation has been rare. Thus, an understanding of the factors underlying the development of fluency in reading and arithmetic is as of yet limited. Knowledge of the cognitive factors underlying the development of fluency is theoretically important and necessary for the development of more efficient instructional practices. Knowledge of early predictors could also help teachers to identify and provide support for children at risk of later dysfluency in reading and arithmetic.

There is strong evidence for a close connection between arithmetic and reading skills in both population-based samples (e.g., Koponen, Aunola, Ahonen, & Nurmi, 2007) and samples including children with difficulties in reading and arithmetic (Räsänen & Ahonen, 1995; von Aster & Shalev, 2007). Furthermore, a meta-analysis by Duncan and colleagues (2007) showed that early math skills were as predictive of later reading achievement as early

reading skills, suggesting a close relationship between math and reading. However, there are few studies examining joint predictors of fluency in reading and arithmetic. Consequently, the aim of the present study was to add to the knowledge base on the predictors of fluency both in reading and in arithmetic skills. We focused on two cognitive skills due to their demonstrated links to fluency: rapid automatized naming (RAN) and verbal counting. RAN has been shown to be the strongest predictors of reading fluency (e.g., Landerl & Wimmer, 2008). Moreover, there is also evidence that RAN is related to arithmetic fluency (e.g., Georgiou, Tziraki, Manolitsis, & Fella, 2013; Koponen et al., 2007). Similarly, verbal counting, the ability to recite number words forward and backward, was found to be a strong predictor of arithmetic fluency (Koponen, Salmi, Eklund, & Aro, 2013; Zhang et al., 2014), and there are also a few empirical findings suggesting that counting is a predictor of reading fluency (Koponen et al., 2013; Leppänen, 2006). However, in previous studies investigating joint predictors of reading and arithmetic fluency, there are limitations that should be taken into account. The studies have typically been cross-sectional, have not modeled predictors of reading and arithmetic fluency within the same sample, and have not examined the relation between counting and reading in population-based samples (see an exception in Leppänen, 2006). Moreover, the studies have not taken into account other cognitive predictors, such as working memory.

This longitudinal study examined whether verbal counting and RAN are predictors of arithmetic and reading fluency. We also controlled for the predictive relations of phonological awareness, verbal short-term memory, working memory, and vocabulary measured at kindergarten, as well as mother's education in order to determine whether these related, early emerging cognitive abilities and/or socio-economic background explained the predictive power of counting and RAN. Previous studies on the topic have not explicitly examined the role of working memory and vocabulary as potential underlying factors that

could explain the possible predictive relations between counting and reading fluency or RAN and arithmetic fluency. In this study, the aim was to try to confirm the previous findings of counting as a predictor of reading fluency (Koponen et al., 2013; Leppänen, 2006), as well as to examine whether the domain-general relation of counting and fluency (both with reading and arithmetic) is specific or whether counting skill is a proxy for a more general relation between early number processing skills and fluency. For that purpose, we also included the measure of number concept skill in the study.

1.1.   *Development of fluency in reading and arithmetic and their relation to counting and RAN*

In the current study, fluency in reading was operationalized as the rate and accuracy of word reading, and fluency in calculation is operationalized as the rate and accuracy of solving basic arithmetical problems with single and multi-digit numbers. Reading and calculation skills share similar developmental steps. In the early stage of acquisition, both skills are based on one-by-one coding. Calculation is based on serially reciting number words (Ostad, 1999; Siegler & Shrager, 1984), and reading is based on the serial phonemic assembly of letter sounds (Share, 1995). At later stages of skill development, there is a shift toward processing and retrieving larger units, such as arithmetic facts in calculation (Ostad, 1999; Siegler & Shrager, 1984) or larger orthographic units in reading. In the present study, calculation and reading fluency were assessed at the age of 9 and 10 years, meaning that children had at least two years of instruction in basic reading and arithmetic. At that age, fluent reading reflects direct recognition of words or word parts and retrieval of corresponding phonological output from long-term memory. Dysfluent reading still requires the serial decoding of single graphemes. Similarly, in arithmetic, fluent calculation reflects the fast retrieval of arithmetical facts or the ability to derive calculations on the basis of some known arithmetical facts. Dysfluent calculation is manifested as counting-based strategies

(e.g., 6+5 counted as "*six*, then *seven, eight, nine, ten, eleven*"). To summarize, the development and fluent mastery of both reading and arithmetic skills are preceded by the serial processing of information, and there is a developmental shift toward retrieval of information directly from long-term memory as a main processing strategy. Thus, the ability to effortlessly process serial information and to retrieve verbal information rapidly from long-term memory are skills required for learning to read and calculate fluently. We suggest that verbal counting ability can be seen as an indicator of the ability to process sequential information (in this case, number words and their correct order). RAN, on the other hand, has been defined as the ability to access phonological information related to visual stimuli from long-term memory. Thus, it could be related to the retrieval of the phonological code for both words and arithmetical facts from memory.

1.2.   RAN and counting as a predictors of reading and arithmetic

        The relation between RAN and reading fluency has been well established (e.g., Landerl & Wimmer, 2008; Norton & Wolf, 2012). For example, Wolf, Bowers, and Biddle (2000) suggested that reading and rapid serial naming share many cognitive and linguistic subprocesses, such as attentional, visual, perceptual, lexical, and rapid serial processing, which could explain the identified predictive relations. Similarly, it has been reported that verbal counting is a strong predictor of later arithmetic fluency (e.g., Koponen et al., 2007; Zhang et al., 2014). The ability to recite number words (i.e., counting forward and backward from a given number) is an essential skill for the development of later arithmetic skills, because the use of memory-based retrieval strategies is based on a preceding developmental stage where counting-based strategies are used (Barrouillet & Fayol, 1998).

        Recent findings have suggested that RAN and counting are not skill-specific predictors for either reading or arithmetic but that RAN can predict arithmetic fluency and that counting can predict reading fluency. A recent study on RAN demonstrated that the

RAN–math relationship was similar to RAN's relationship to reading, where pause time rather than articulation speed was the critical component (Georgiou et al., 2013). Thus, the retrieval process itself seems to be critical in relation to both reading and mathematics.

In contrast to the relation between RAN and reading fluency, the relation between counting and reading has been much less studied. Both counting and reading are serial processes requiring monitoring and holding information in one's memory while processing. One-by-one processing is a central feature in counting (1, 2, 3, 4..) as well as in the early developmental phase of reading (e.g., A-U-T-O). However, these skills become more automatized following practice with, for example, skip counting (2, 4, 6 or 5, 10, 15), and direct retrieval of verbal output corresponding to a letter sequence (recognizing syllables AU-TO or whole word AUTO) becomes possible. Leppänen's study (2006) was the first to report the predictive relation between counting and reading fluency. Leppänen suggested that working memory could be the common factor underlying the relation but did not examine the issue. Koponen et al. (2013) recently examined the relation between counting and reading fluency by controlling for phonological awareness and verbal-short-term memory, but not working memory. They found that counting and RAN were strong predictors of both reading and arithmetic fluency even after controlling for phonological awareness and verbal short-term memory. However, their findings were based on a sample containing a substantial proportion (23.5%) of children with dyslexia, which could have influenced the identified predictive relations. Moreover, they did not examine whether the predictive role of counting was unique and how the controlling for other early number skills could effect on the results. Recent findings of the relation between linguistic and numerical skills with reading and arithmetic skills have revealed that quantity skills (magnitude comparisons) are significantly related to arithmetic skills but not to reading after linguistic skills are taken into account (Sowinski et al., 2015). This is in line with the theories suggesting that magnitude

comparison relies strongly on numerical cognition (e.g., Dehaene & Cohen, 1997), which is not required in reading. However, there are other basic number skills which require the processing of written and verbal symbols, analogous to the processing requirements of reading. For example, number concept tasks require mapping the number words or written numbers to corresponding quantities (e.g., 2, 5, *two* and *five*). Number concept skill is known to predict arithmetic skills (e.g., Krajewski & Schneider, 2009), and thus it is important to investigate whether it could also predict reading development. Thus, controlling for the number concept skill can shed light on the observed relation between counting and reading.

The present study provides an important extension to previous studies. First, it is an investigation of the predictors of both arithmetic and reading fluency based on a large population-based sample that has been followed-up from kindergarten (age 6) to Grade 3 (age 9). Second, by controlling for phonological awareness, verbal short-term memory, and, importantly, also for vocabulary and working memory (measured at kindergarten and first grade), the study aimed at increasing the current understanding of the cognitive mechanisms that account for the predictive relations of RAN and counting with reading and arithmetic fluency. Third, socio-economic background was also taken into account by controlling for mother's education. Fourth, the specificity of counting as a number-related predictor of reading was also assessed by taking into account another relevant early number skill: number concept. Fifth, RAN with letters and digits was not used in this study so as to avoid any confounding effects of using shared stimuli with reading and arithmetic skills.

1.3. Phonological awareness, vocabulary, memory, and mother's education as predictors of reading and arithmetic fluency

At present, there is no theoretical consensus on the subprocesses in counting and RAN that would explain their relation to fluency in reading and arithmetic. An interesting question is whether they have unique predictive power or whether other cognitive skills measured

concurrently with RAN and counting can explain their relations with reading and arithmetic fluency. It is possible that other early emerging skills, such as language skills and memory, that are shown to predict reading and arithmetic skills may also explain the observed predictive relations between RAN and counting on fluency in reading and arithmetic. If this is the case, the predictive utility of counting and RAN is not unique but shared with the other predictors. To shed light on the predictive relationships of RAN and counting with reading and arithmetic fluency, basic cognitive abilities, measured at kindergarten concurrently with RAN and counting and at first grade (memory), were taken into account in this study.

Awareness of the phonological structure of a language is one of the early language skills that plays an important role in the development of reading, particularly in the development of basic word-decoding skill (e.g., Hogan, Catts, & Little, 2005; Holopainen, Ahonen, & Lyytinen, 2001; Silvén, Poskiparta, Niemi, & Voeten, 2007). Phonological awareness starts to develop years before school entry (Goswami, 2001) and has been shown to be among the best early predictors of decoding (Puolakanaho, Ahonen, Aro, et al., 2008). In addition to reading, a recent study has shown that phonological awareness is linked to arithmetic fluency (De Smedt, Taylor, Archibald, & Ansari, 2010). One possible mechanism for the association of phonological skills and arithmetic calculations is that number words and arithmetical facts are phonologically coded in memory (e.g., Stanescu-Cosson et al., 2000; Simmons & Singleton, 2008). The weakness of phonological representations for number words (and number facts) in long-term memory is likely to make it more difficult to retrieve them quickly and accurately (Simmons & Singleton, 2008). Supporting this notion, previous studies have demonstrated a moderate association between phonological awareness and counting skill (Koponen et al., 2007; Krajewski & Schneider, 2009), as well as between RAN and phonological awareness (e.g., Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997).

Of the language skills, vocabulary has been shown to be an important predictor of reading (for a meta-analysis, see Swanson, Trainin, Necoechea, & Hammill, 2003). In addition to reading accuracy, early vocabulary has been shown to predict reading fluency (Speece, Mills, Ritchey, & Hillman, 2003), as well as arithmetic skills (LeFevre et al., 2010) and calculation fluency (Georgiou et al., 2013). Growth in word knowledge supposedly results in greater availability of information in one's memory (Nippold, 1992). Gradual expansion of the lexicon provides a speaker with a richer database from which to select and retrieve words, and this could foster the development of reading, and arithmetic and counting. LeFevre et al. (2010) argued that the breadth of receptive vocabulary might reflect children's abilities to acquire vocabulary in the number system. Mastery of number words was shown to be critical for the ability to perform arithmetic calculations with numbers larger than 4 or 5 (Pica, Lemer, Izard, & Dehaene, 2004). As vocabulary is linked to reading, arithmetic, and to verbal counting and RAN, vocabulary skill could provide at least a partial explanation for the predictive relation of counting and RAN with reading fluency.

Reading and arithmetic fluency involve holding information in the memory while simultaneously processing new information. Therefore, it is not surprising that working memory and verbal short-term memory (i.e., the domain-specific storage of verbal information) have been found to be related to reading (Alloway & Alloway, 2010; de Jong, 1998; Swanson & Howell, 2001; Swanson & Jerman, 2007; Swanson, Trainin, Necoechea, & Hammill, 2003) and arithmetic fluency (Raghubar, Barnes, & Hecht, 2010; Swanson & Kim, 2007), as well as to difficulties in reading and arithmetic (Willcutt et al., 2013). Studies have also shown that memory components are related to the predictors of reading and arithmetic fluency, that is, counting (Cowan et al., 2011) and RAN (e.g., Wagner et al., 1997; Amtmann et al., 2007). Therefore, it is possible that memory functions contribute to the cognitive basis of reading and arithmetic fluency and, at least partially, explain the predictive relation of

RAN with counting. Verbal short-term memory is required for storing problem information, whereas working memory is needed for arithmetic calculations, especially those requiring counting-based calculation or carrying strategies (Fürst & Hitch, 2000; Hecht, 2002). Counting requires holding in mind the current place in sequence and how many number words should be counted while retrieving what number word comes next according to the rule which to count (forward, backward, skip counting by two, etc.). In reading, working memory is assumed to be responsible for coordinating orthographic and phonological processing (Amtmann, Abbot, & Berninger, 2007). Thus, working memory may contribute to the automatic coordination and sustained mental effort required for controlled searches involved in mapping orthographic codes (letters) onto phonological codes. A similar kind of coordination is required in counting. Interestingly, Amtmann et al. (2007) showed that working memory was associated with RAN and reading and explained the relations between RAN and reading fluency. No previous studies examined the extent to which working memory could explain the predictive relation between counting and reading fluency.

Finally, the role of SES in explaining the predictive relation of RAN and counting in reading and arithmetic fluency should also be taken into account because SES has been shown to be related to reading and arithmetic fluency as well as to counting and rapid naming (Koponen et al., 2007). Thus, the effect of mother's educational level was controlled. There are several possible reasons why parents' educational level predicts later reading and arithmetic skills. One possible explanation of the link between parents' education and their children's academic achievement is based on the assumption that parents learn something during schooling that influences the ways in which parents interact with their children in learning activities in the home (Eccles, 2005). Other views suggest that education influences parents' skills, values and knowledge of the educational system, and methods for educational practices at home and the children's skills (Eccles, 2005).

1.4 The present study

The present study focused on the prediction of fluency in arithmetic and reading with a particular focus on the roles of RAN and verbal counting. To analyze the extent to which they contribute independently to fluency in arithmetic and reading, related cognitive abilities, such as phonological awareness, vocabulary, verbal short-term memory and working memory were controlled for. Moreover, we aimed to clarify whether verbal counting has a unique relation to reading or whether controlling for another early number skill that requires processing both verbal and written symbolic information (number concept skill) would remove this predictive relation.

The present study addressed three research questions:

1) Are counting and RAN domain-general predictors of fluency in arithmetic and reading in a population-based sample? Due to a lack of previous studies with population-based samples investigating the predictive power of RAN and counting on reading and arithmetic fluency with the same children using a single model, strong hypotheses cannot be made. However, based on earlier studies of the relation between RAN and arithmetic fluency (Berg, 2008; Cirino, 2011; Koponen et al., 2007; Koponen et al., 2013), as well as the relations between counting and reading fluency (Koponen et al., 2013; Leppänen, 2006), we assumed that counting ability and RAN would predict both arithmetic and reading fluency during early school years.

2) To what extent is the predictive power of counting and RAN accounted for by other early predictors of reading and arithmetic including cognitive abilities, such as phonological awareness, vocabulary and memory skills, and socio-economic background (mother's education) (Model 2)? A previous study conducted by Koponen and colleagues (2013) demonstrated that in a sample in which 23.5% of the children had dyslexia, counting and RAN predicted both arithmetic and reading fluency after controlling for phonological

awareness and verbal short-term memory. Consequently, we expected these findings to be replicated using the current population-based sample. With the inclusion of vocabulary and working memory, we aimed to investigate whether these variables could, at least partially, explain the predictive power of RAN and counting. Although it has been suggested that working memory could underlie the predictive relation between counting and reading (Leppänen, 2006), this has never been explicitly examined. Similarly, vocabulary has been suggested as a possible underlying skill in both reading and arithmetic development (LeFevre et al., 2010; Speece et al., 2003), as well as in counting and RAN (LeFevre et al., 2010; Wolf, Bowers & Biddle, 2000). If counting and RAN are unique predictors of reading and arithmetic fluency, controlling for abilities, such as identifying and manipulating speech sounds (phonological awareness), storing and manipulating verbal information in the memory, (short-term memory and working memory), or vocabulary (receptive vocabulary) should not eliminate the observed predictive relationships.

3) Does controlling for number concept skill (early number skill requiring both verbal and visual processing of number symbols) remove the predictive relation of counting with reading fluency? The aim of this analysis was to clarify whether the previous findings with regard to counting skill reflect its role as a proxy for a more general relation between number skills and reading or whether counting has unique predictive effect?

2. Method

2.1 Participants and procedure

This study is part of an extensive longitudinal study conducted in Finland (authors removed for reviewing purposes, 2006), in which 1,880 children were followed from kindergarten to Grade 3. The sample was recruited from four municipalities in Finland: two in central Finland, one in western Finland, and one in eastern Finland. The children

comprised about half of the age cohort from one municipality and the entire age cohort from the other three. Parental written consent was obtained for all participants. The sample was representative with regard to average family background characteristics in Finland—for example, parents' educational level (Statistics Finland, 2007).

To facilitate a more thorough evaluation of children skills, a target sample of 642 children was drawn from the larger sample of 1,880 children for a more detailed individual follow-up. The target sample represents (a) children at high risk of developing reading difficulties (at risk for RD; n = 321) and (b) a random sampling of not-at-risk children as controls. A child was identified as being at risk for RD if the child demonstrated low phonological awareness skills and poor letter knowledge and/or slow naming speed at the end of kindergarten (i.e., scored clearly below age level using the lowest 15th percentile as a cut-off criterion; see Lerkkanen, Ahonen, & Poikkeus, 2011). In addition, parental reports on familial risk were also taken into account.

For the purposes of the present paper, we selected all the randomly selected controls (not at risk for RD, n = 321) participating in the individual follow-up and added a random sample of 57 high-risk children (15% of the participants) to create a representative sample of the population. The participants in this study were thus a subsample of 378 children (182 girls, 196 boys; age at kindergarten entry: $M = 74.0$ months, $SD = 3.4$ months). They came from 76 schools and 147 classrooms (there were 51 classrooms with only one participant and 96 with two to four participants). The vast majority (77.6%) of the children came from nuclear families, 11.5% from single-parent families, 9.6% from blended families, and 1.3% from families where the parents were divorced and the child had two homes. A total of 26.8% of the children's mothers had a master's degree or higher, 36.3% had a bachelor's degree or vocational college degree, 30.2% had a vocational school degree, and 6.7% had no education

beyond comprehensive school. The participants were all native Finnish speakers with no

documented intellectual or sensory deficits.

2.2. Measures

In the present study, we used data from assessments conducted in kindergarten (September

2006, April 2007), Grade 1 (September 2007, April 2008), Grade 2 (April 2009), and Grade 3

(April 2010). RAN, counting skill, phonological awareness, memory, arithmetic fluency, and

reading fluency were assessed by trained testers (researchers or students of psychology and

education).

2.2.1. Verbal counting

      Forward and backward counting were assessed twice, in the kindergarten spring and

Grade 1 fall. In kindergarten, the following four items were used: counting forward from

number 1 (counting was stopped after 31 in kindergarten and 51 in Grade 1), counting

forward from number 6 to 13, counting backward from number 12 (counting was stopped

after 7), and counting backward from number 23 to 1 (for similar tasks, see Aunola, Nurmi,

Lerkkanen, & Rasku-Puttonen, 2003; Koponen et al., 2007; Räsänen, Salminen, Wilson,

Aunio, & Dehaene, 2009). In the Grade 1 fall, three additional items were added: counting

forward from number 18 to 25, counting backward from number 33 (counting was stopped

after 17), and counting five items backward from 23. For each task, two points were awarded

for the correct outcome, one point for completing the task with up to two errors, and zero

points were awarded if the child made more than two errors or failed to complete the task.

Because of the ceiling effect of forward counting in kindergarten, only backward counting

was used in the analyses for kindergarten, while both forward and backward counting were

used for Grade 1 (the maximum score was four points in backward counting in kindergarten

and six points in forward and eight points in backward counting in Grade 1). Cronbach's

alpha for total scale was .63 in kindergarten and .79 in Grade 1.

2.2.2 Number concept

Number concept skill is a combined measure of ordinal and cardinal number

knowledge as well as knowledge of basic mathematical concepts. The child saw a number

and was asked to draw a corresponding number of balls or, alternatively, was shown balls and

was asked to select the corresponding number from five choices. The child was asked to draw

balls according the instructions "*as many,*" "*one more,*" and "*one less*" and mark the "*first,*"

"*fourth,*" and "*seventh*" ball. Number concept was assessed in the kindergarten spring. The

sum score was based on the number of correct items (a maximum score of nine). The

Cronbach α coefficient was .66.

2.2.3. Rapid automatized naming (RAN)

The rapid naming of objects was assessed using a standard procedure (see Denckla &

Rudel, 1974) in which the child was asked to name as rapidly as possible a series of visual

stimuli with which they had become familiar. Matrices of 50 items (five stimuli 10 times)

were used. The child's performance was timed, and errors and self-corrections were

documented. The errors were few, and they were not used in the analysis. Object naming was

assessed in the kindergarten spring and Grade 1 spring. The total matrix (five rows of 10)

completion time in seconds was used as the score. The test-retest correlation was .62.

2.2.4. Phonological awareness (PA)

The initial phoneme identification test from the ARMI test material (Lerkkanen,

Poikkeus, & Ketonen, 2006) was used to assess PA in the kindergarten fall. Each child was

shown four pictures of objects, which were named by the experimenter. The child was then asked to select the correct picture on the basis of the oral presentation of the initial phoneme relating to one target (e.g., "At the beginning of which word do you hear ____?"). PA was assessed in the kindergarten fall. The sum score was based on the number of correct items (a maximum score of 10). Cronbach's alpha for phoneme identification was .73.

2.2.5. Vocabulary

Receptive vocabulary was assessed in the kindergarten spring using a 30-item shortened version of the Peabody Picture Vocabulary Test-Revised (PPVT-R, Form L; Dunn & Dunn, 1981) (a maximum score of 30). The PPVT requires the child to select from four alternatives the picture that correctly depicts a spoken word (e.g., "group," "cooperation"). The items for the shortened version were selected based on the data from the full-scale administration of the PPVT-R to the control group in another Finnish study, the Jyväskylä Longitudinal Study of Dyslexia (see Lyytinen et al., 2004). The Cronbach α coefficient was 0.61.

2.2.6. Memory

Memory was assessed in the Grade 1 spring using the WISC-III (Wechsler, 1991) digit span subtest with the standard assessment procedure. Forward digit recall was used as a measure of verbal short-term memory and backward digit recall as a measure of verbal working memory, as suggested by Gathercole and Adams (1994). In the digit recall task, the child hears a sequence of digits and is asked to recall each sequence in the correct order. In the backward digit recall task, the child is required to recall a sequence of spoken digits in the reverse order. Test trials begin with two numbers and increase by one number in each block. Scores for both verbal short-term memory and verbal working memory were the number of

correctly repeated number sequences. The maximum score was 16 points for the verbal short-term memory task and 14 points for the working memory task. According to the manual, the average reliability for all age groups was .75 (Wechsler, 1991).

2.2.7. Arithmetic fluency

Arithmetic fluency was assessed in the Grade 2 spring and the Grade 3 spring using the Arithmetics test (Aunola & Räsänen, 2007). The test consists of a maximum of 28 items containing 14 additional items (e.g., *2 + 1 = ; 3 + 4 + 6 = *) and 14 subtraction items (e.g., *4 - 1 = ; 20 - 2 - 4 = *) that can be attempted within a time limit. The task difficulty increases across the test. In this study, a three-minute time limit was used. The test was administered on a group basis. The score was the total number of correct answers (the maximum score was 28 points). The Cronbach's alphas for arithmetic fluency were .86 in Grade 2 and .68 in Grade 3.

2.2.8. Reading fluency

A speeded word list reading test from *Lukilasse* (Häyrinen, Serenius-Sirve, & Korkman, 1999) was administered in the Grade 2 spring and Grade 3 spring. The children were asked to read aloud a list of words, which gradually increased in length and difficulty. The measure was the total number of words read correctly within two minutes (a maximum score of 105). Cronbach's alpha was .97 for both Grade 2 and Grade 3 (Häyrinen et al., 1999).

2.3. Data analysis

The preliminary analyses included an analysis of missing data and an examination of variable distributions. The amount of attrition was low: 4.2% (362 of the 378 children who were assessed in kindergarten were still participating in the spring of Grade 3). Attrition was

not found to be systematically related to any of the measures used in this study: The mean

levels of children with and without missing data did not differ significantly in any of the

measures. The maximum available data for each child was used in each analysis.

The examination of distributions showed ceiling effects for kindergarten phonological

awareness (PA), number concept and counting, as well as for the Grade 1 counting measures.

Therefore, Spearman correlation coefficients were calculated for these measures. In the

structural equation models (SEMs), we used maximum likelihood with robust estimation

(MLR), a recommended estimation method for such data (Muthén & Muthén, 1998–2010).

Before the analyses, the few outlier scores (more than three SDs from the average) were

relocated to the tails of the distributions. Because the data were selected from classrooms

with children nested in classrooms, the effect of being a member of a classroom was

examined using the COMPLEX option provided by Mplus (Muthén & Muthén, 1998–2010),

which corrects standard errors according to the nested data structure. For this analysis, we

had to drop 51 participants who were the sole representatives of their classrooms to avoid

relying on single individuals as representatives of their classrooms. The models with (N =

327) and without COMPLEX (N = 378) were almost identical, so we will report only on

models without COMPLEX that include all the participants.

In the SEM models, the latent factors were created first for counting, RAN, arithmetic

fluency, and reading fluency. Second, arithmetic fluency and reading fluency were predicted

first by counting ability (Model 1a), then by RAN (Model 1b), and finally by both counting

and RAN (Model 1c). Third, we built a model controlling for the contribution of

phonological awareness, verbal short-term memory, vocabulary, and mother's education to

predicting arithmetic fluency and reading fluency (Model 2). Fourth, we replaced short-term

memory with working memory (Model 3). Fifth, we re-ran Model 1c after replacing RAN

with number concept skill (Model 4) as well as added number knowledge to Model 3 (Model

5). In all models, the goodness of fit was evaluated using five indicators: the χ^2 test, the

comparative fit index (CFI), the Tucker–Lewis fit index (TLI), the root mean square error of

approximation (RMSEA), and the standardized root mean residual (SRMR). All error

variances were estimated freely.

3. Results

3.1. Descriptive statistics

The means and standard deviations of the predictors and outcome measures are

presented in Table 1, while the correlations are presented in Table 2. All correlations between

predictors (counting and RAN) and outcome variables (arithmetic and reading fluency) as

well as between covariates (phonological awareness, vocabulary, verbal short-term memory,

and working memory) and outcome variables were significant. The only exception was

mother's education, which did not correlate significantly with the reading variables.

3.2. Longitudinal models for counting, RAN, reading fluency, and arithmetic fluency

The first aim of the study was to examine the extent to which counting and RAN

would predict arithmetic fluency and reading fluency. Three models were built to examine

this research question (see Figure 1, Models 1a, 1b, and 1c). First, a prediction model in

which arithmetic and reading fluency were predicted by counting (Model 1a) and RAN

(Model 1b) was constructed. In addition, a combined model (Model 1c) was constructed to

analyze the relation between counting and RAN. The model fit indices varied from

acceptable to very good depending on which predictor(s) were included in the model (see

Figure 1).

Model 1a revealed that counting alone predicted 46% of the subsequent arithmetic

fluency variance and 28% of the subsequent reading fluency variance. RAN, on the other

hand, predicted 21% of the subsequent arithmetic fluency variance and 17% of the

subsequent reading fluency variance (Model 1b). In the model with both counting and RAN

as predictors (Model 1c), 55% of the arithmetic fluency variance and 36% of the reading fluency variance were predicted.

3.3. Longitudinal model with phonological awareness and verbal short-term memory

The second aim of this study was to examine the extent to which RAN and counting predict arithmetic fluency and reading fluency when the phonological awareness, verbal short-term memory, vocabulary, and mother's education are controlled for. Model 2 included counting, RAN, phonological awareness, verbal short-term memory, vocabulary, mother's education, arithmetic fluency, and reading fluency. The model fit indices indicated that the model fit the data well (see Figure 2). For arithmetic fluency variance, Model 2 predicted 55%, while it predicted 41% of the reading fluency variance. Both phonological awareness and verbal short-term memory were significantly correlated with counting and RAN, and both were significant predictors of reading fluency (both directly added approximately 3% to the prediction of reading fluency) but not of arithmetic fluency. Mother's education significantly predicted arithmetic fluency but not reading fluency (added approximately 1.4% to the prediction of arithmetic fluency). In addition, vocabulary had small negative association with arithmetic fluency. Both counting and RAN were significant predictors of arithmetic fluency and reading fluency even after adding phonological awareness, verbal short-term memory, vocabulary, and mother's education to the model.

3.4. Longitudinal model with phonological awareness and working memory controls

The third aim of this study was to examine the extent to which RAN and counting predict arithmetic and reading fluency when working memory is also controlled for. Model 3 included counting, RAN, phonological awareness, working memory, vocabulary, mother's education, arithmetic fluency, and reading fluency. The model fit indices indicated that the

model fit the data well (see Figure 3). Model 3 predicted 56% of the arithmetic fluency variance and 38% of the reading fluency variance. Phoneme identification was significantly correlated with counting and RAN, whereas working memory was correlated with counting but not with RAN. Counting, RAN, and mother's education predicted arithmetic fluency significantly, and counting, RAN, and phonological awareness predicted reading fluency. Working memory was not a significant predictor of either arithmetic fluency or of reading fluency.

In Models 2 and 3, RAN and counting were included as latent factors and the control variables were included as observed variables. Thus, Models 2 and 3 may have overestimated the predictive power of RAN and counting in comparison to the control variables. In addition, the inclusion of Grade 1 measures of counting and RAN may have further increased their relative predictive power in comparison to phonemic awareness (verbal short-term memory and working memory were also assessed in Grade 1). Therefore, we re-ran the analyses using models where RAN and counting were included as observed variables measured in the kindergarten group in the spring. In addition, we tested whether changing the kindergarten fall measure of phoneme identification to the kindergarten spring measure of phonemic awareness would change the results (the kindergarten spring measure suffered from a more severe ceiling effect than the fall measure and was thus not included in the final models). The results with any of these modifications to the models, however, remained the same as reported in Figures 2 and 3: RAN and counting predicted arithmetic and reading fluency even when we controlled for the phonological awareness and verbal short-term memory and working memory.

3.5. Longitudinal model with number knowledge as a predictor of arithmetic and reading fluency

Finally, we explored whether controlling for number concept skill would remove predictive relation of counting with reading fluency. We first estimated a model where kindergarten number concept skill (cardinal and ordinal number knowledge) was added as a predictor of reading and arithmetic fluency together with counting (Model 4). Model 4 included counting, number concept, RAN, arithmetic fluency, and reading fluency. The results demonstrated that number concept skill was a significant additional predictor of both reading (explained 4% of the variance) and arithmetic fluency (explained 6% of the variance) but it did not remove or diminished clearly the predictive relations of counting with reading and arithmetic. After including the measures of working memory, phonological awareness, vocabulary, and mother's education in the model (Model 5: see Figure 4), the predictive power of number concept skill disappeared for reading fluency and diminished for arithmetic fluency (explained 2.6% of the variance). Thus, the predictive relation of number concept skill for reading was explained by related cognitive factors, and for arithmetic, the predictive relation was clearly weaker than that of counting.

4. Discussion

The present study first examined whether verbal counting and RAN were predictors of fluency in both arithmetic and reading in a population-based sample. We then investigated the extent to which related cognitive abilities measured concurrently with RAN and counting, such as phonological awareness, vocabulary, verbal short-term memory, working memory, and socio-economic background, explained the predictive power of counting and RAN. The results indicated that counting and RAN predicted both arithmetic fluency and reading fluency. These predictive relations remained after controlling for phonological awareness, vocabulary, verbal short-term memory, working memory, number concept skill and mother's education. The results support the view that both RAN and counting are domain-general

predictors of fluency. In addition, the analyses revealed that by controlling for another early number skill we could not remove the relation between counting and reading. Moreover, in contrast to counting, number concept skill did not show a predictive relation to later reading fluency after controlling for phonological awareness, vocabulary, working memory, and mother's education. Thus, the findings support the view that the domain-general relation of counting and fluency is specific, and counting skill is not just a proxy for a more general relation between early number processing skills and fluency.

This is the first study to use a population-based sample to show that counting and RAN, when included simultaneously in a model, both independently predict fluency in arithmetic and reading. The findings of shared predictors of fluency in reading and arithmetic suggest that these two academic skills may have partially shared cognitive underpinnings. The findings also suggest that fluency both in reading and arithmetic is related to learning and automatization of sequential information, as well as rapid retrieval of phonological information (sounds or number names) from visual stimuli (numbers or letters). These associations were not explained by more general abilities, such as learning words (vocabulary),the ability to hold and manipulate verbal information in memory (working memory), and socio-economic background.

4.1. The predictors of fluency in arithmetic

First, we will discuss the findings of RAN and counting as a predictor of fluency in arithmetic. Counting and RAN together explained a total of 55% of the variance in arithmetic fluency (see Model 1c). The amount of explained variance is large considering the time between assessments (from kindergarten and Grade 1 to Grades 2 and 3) of predictors and outcome variables and formal schooling, which guarantees that all children received instructional guidance in arithmetic independent of their early experiences.

The predictive power of counting skill in later arithmetic fluency was high, as it predicted 46% of its variance (see Model 1a) and 35% when included in the same model with RAN (see Model 1c). This close relation between counting and arithmetic was expected, as the use of memory-based retrieval strategies is preceded by the use of counting-based strategies (Barrouillet & Fayol, 1998). Accurate and fluent retrieval of the number-word sequence is required to facilitate the shift from counting-based strategies to fact retrieval. Moreover, Johansson (2005) suggested that with increasing counting skill, children may detect regularities in the number-word sequence that can be used to form new and more accurate strategies in calculation. The ability to start counting from a given number word— that is, to "break the chain" of the counting string, enables children to use more advanced strategies to solve basic arithmetic skills, which in turns leads to higher levels of fluency (e.g., Fuson, 1982; Baroody, 1987). Moreover, it has been suggested that counting and arithmetic share common processes (neural mechanisms) (Dehaene & Cohen, 1997). Dehaene's triple-code model suggests that the normal route for over-learned calculations, such as single-digit multiplication and simple addition, is the so-called direct route through which the problem (e.g., 4 x 5) is converted into an internal verbal representation ("four times five"), which is then used to complete this word sequence by retrieving the answer from verbal memory ("two times four equals eight") (Dehaene & Cohen, 1997).

The results of the present study showed further that RAN predicted 21% of the variance in arithmetic fluency (see Model 1b) and 10% in the same model with counting (see Model 1c). Thus, both unique variance of RAN as well as shared variance with counting is related to arithmetic fluency. This is a substantial proportion, considering that RAN objects were used instead of RAN digits. RAN has also been previously found to predict arithmetic fluency (e.g., de Jong & van der Leij, 1999). In addition, in comorbidity studies, difficulties in arithmetic fluency have been found to be associated with slow RAN performance

(Willburger, Fussenegger, Moll, Wood, & Landerl, 2008), although this association has been suggested to be domain-specific. In other words, dyscalculic children exhibited a deficit only in the rapid naming of quantities (Willburger et al., 2008) and numbers (Landerl, Bevan, & Butterworth, 2004). This confounding effect was avoided in the present study by using objects as stimuli in RAN. Thus, the present findings offer further support to the view that the naming process, instead of shared stimuli, is a predictor of arithmetic calculation fluency. This suggests that the acquisition of fluent calculation skill requires that the arbitrary associations between visual symbolic forms (numbers) and phonological forms (number words) must be learned to a level of effortless, automatized retrieval. Interestingly, the findings from a recent twin study (Hart, Petrill, Thompson, & Plomin, 2009) demonstrated that RAN and arithmetic fluency share significant genetic overlap.

Controlling for phonological awareness, vocabulary, and memory in the models did not decrease the impact of counting or RAN on arithmetic fluency. In accordance with previous studies (Koponen et al., 2007; Koponen et al., 2013, Krajewski & Schneider, 2009), phonological awareness was related more strongly to counting skill than to arithmetic fluency. Although working memory was significantly correlated with counting and arithmetic fluency, controlling for it did not decrease the predictive power of counting on arithmetic fluency, nor did it have a direct relation to arithmetic fluency. Thus, relations of working memory with arithmetic fluency were fully mediated via counting.

In the present study, RAN had a direct relation to arithmetic fluency, whereas in a previous study conducted by Koponen and colleagues (2013) using a sample with a high prevalence of children with dyslexia, the predictive power of RAN on arithmetic fluency was mediated by counting. This difference in findings of the present study and that conducted by Koponen et al. (2013) was also visible in the weaker correlation between RAN and counting in the present data. In other words, counting and RAN shared more variance in the sample

with a high prevalence of children with dyslexia than in the population-based sample. A

possible explanation for the strong association between RAN and counting in a sample with a

high prevalence of children with dyslexia could be common cognitive functions in which the

achievement of a certain ability level (a threshold) is essential for both of these predictors,

such as phonological processing or other language skills. However, in contrast to this

argument, the poor quality of phonological representations did not explain the high

association between counting and RAN in their sample with a high prevalence of children

with dyslexia: Controlling for phonological awareness did not remove the association

between RAN and counting (Koponen et al., 2013).

4.2. The predictors of fluency in reading

Second, counting and RAN together explained a total of 40% of the variance in

reading fluency. Their combined predictive power can be considered to be substantial. The

results of the present study provide further evidence that counting and RAN are general

predictors of reading fluency. RAN was associated with reading fluency even when objects

were used as stimuli and not letters. This finding is in line with those of comorbidity studies

that suggest a general deficit in RAN irrespective of stimuli in children with dyslexia

(Willburger et al., 2008). Counting was an even stronger predictor of reading fluency than

RAN was. Similar results were found in a sample with a high prevalence of children with

dyslexia (Koponen et al., 2013). Interestingly, controlling for phonological awareness,

vocabulary, verbal short-term memory, and working memory did not decrease the predictive

power of counting on reading fluency. In contrast, the number concept skill did not have a

predictive relation to reading fluency after controlling for cognitive skills. Even though

vocabulary and working memory were significantly correlated with reading fluency, they did

not have a direct relation to reading fluency but indirect via counting, RAN, and phonological awareness.

These findings suggest that there is an evident need for a refined investigation of the cognitive requirements of the counting process in order to understand its links with reading fluency and the cognitive mechanisms involved. For example, a wider battery of language skills, besides phonological awareness and vocabulary, should be included, and an examination of other possible cognitive factors, and attentive processes, should be undertaken. Moreover, it should be noted that regardless of the fact that counting speed was not measured in the present study, most of the items in the counting task required the ability to continue counting from a given number and thus a more automatized level of number sequence skills than pure rote counting beginning from number 1. Automatized sequences might be one shared property of both counting and reading skills that should be studied in the future.

In the present study, phonological processing had a direct relation to reading fluency but did not explain the association between RAN and reading fluency. This is in line with earlier suggestions that phonological processing and RAN are separable resources of reading skill (e.g., Wolf & Bowers, 1999). We also found that vocabulary did not explain the relation between RAN and reading fluency, which is in accordance with earlier findings suggesting that vocabulary skills are related more closely to reading comprehension than fluency (e.g., Torppa et al., 2007). The finding that RAN was not correlated with working memory (measured by digit span backwards) is contradictory to the findings reported by Amtmann et al. (2007) showing that working memory explained the relations between RAN and reading fluency. However, because Amtmann's findings came from a sample of children and adults with reading disabilities, they are not directly comparable to the findings of the present study with typically developing participants.

4.3. Limitations and generality

There are certain limitations of the present study that need to be considered. First, both of the memory tasks used included digits as stimuli. Consequently, further studies are needed to examine the role of working memory and short-term memory with non-numerical stimuli to better understand the role of memory in the development of fluent reading and arithmetic skills. Second, the vocabulary, phonological awareness, and memory variables included only one measure, and there is an evident need to expand the range of instruments used for examining these variables in future research. Third, besides phonological awareness, the language variables included only a receptive vocabulary measure with low reliability, and we cannot rule out the possibility that language is a possible underlying factor explaining the relation between counting and reading fluency if a more comprehensive measure of language skills is included. Fourth, the phonological awareness measure was based on only one measure with a ceiling effect. A similar kind of ceiling effect was also found in math with counting and number concept measures. Good mastery of basic skills is typical for most Finnish kindergarteners. However, as in any other country, there are also children with very weak skills. For example, about one-third of Finnish children can read before entering school (Lerkkanen, Rasku-Puttonen, Aunola, & Nurmi, 2004), and at the same time the poorest performing children know only a few letters. Phonemic awareness assessment is a challenge for readers because reading ability strongly supports phoneme awareness development. The ceiling effect means that the variance in kindergarten measures comes mainly from average and low performing children and that measures do not differentiate children with good skills. However, in a longitudinal study focusing on identifying and following the development of the children at risk for later difficulties in reading and math, avoiding the floor effect is even more critical than that of ceiling. In the present study, the ceiling effect related to

phonological awareness, number concept, and counting had been taking into account when selecting analyses. Fifth, further studies are needed to clarify the role of other number skills (e.g., number naming) and other cognitive factors, such as processing speed (Kail & Hall, 1994; Kail, Hall, & Caskey, 1999; see also Georgiou et al., 2013 and Willcutt et al., 2013). For example, Hart and colleagues (2009) suggested that the genetic overlap between RAN and arithmetic fluency might be due to the timed nature of both tasks. In a recent study conducted by Georgiou and colleagues (Georgiou et al., 2013), speed of processing (with and without other cognitive factors) explained the relation between RAN and mathematic fluency measured in kindergarten and first grade and should thus be taken into account when examining the RAN-arithmetic fluency relation later in school. At the same time, it should be noted that counting was not a speed measure, and thus processing speed is unlikely to explain its relation to either reading or arithmetic.

When generalizing these findings across countries, the transparent orthography of the Finnish language should be taken into account. Due to the simple phoneme-grapheme connection structure of Finnish, decoding requires less-advanced phonological processing skills than more opaque orthographies do, such as in English. Moreover, with regards to the transparency of orthography, the variance in reading skill comes mainly from fluency and not accuracy, even though the efficiency of reading (correctly reading words within the time limit) is used as an outcome measure.

The influence of the Finnish educational system, which is known to be rather efficient, is also relevant to discuss. Both reading and arithmetic calculation are skills that are directly taught at school but it's also possible that children have learnt basics of these skills earlier via more informal instruction at home, like parent's responses to children's questions of letters and words as well as arithmetical sums. Thus, it is possible that the association between these two skills, as well as their common predictors might differ across

countries due to differences in schooling systems and quality of instruction or in educational support provided at home. It can be assumed that the homogeneity of the Finnish educational system (PISA, OECD 2013) with its national curriculum and the requirement of a master's degree for all teachers as well as a relatively low heterogeneity in families socio-economical background, may weaken the impact of environmental effects and that the relative effects of cognitive skills are pronounced in our samples.

5. Conclusions

These findings indicate that both counting and RAN are strong predictors of fluency in both arithmetic and reading skills. Predictive power was not accounted for by related and early emerging cognitive abilities such as phonological awareness, vocabulary, and memory or mother's education. Controlling for another early number skill did not remove the found relation between counting and reading fluency. It can be stated that there is something unique in counting skill, when compared to another early number skill that requires processing both written and verbal number symbols, that makes it a strong predictor of both arithmetic and reading. Moreover, in the future, comorbidity studies of reading and arithmetic should also examine the role of counting instead of being restricted to the investigation of pure number processing skills, such as magnitude comparison. In addition to the theoretical implications, the findings of RAN and counting as two important predictors of both reading and arithmetic fluency also have practical consequences concerning the identification of children who would benefit from closer monitoring of skill development and early support as early as at kindergarten age. The fact that both counting and RAN can easily be assessed by a classroom instructor or special education teacher emphasizes the practical importance of the findings of the present study.

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Figure 1. Standardized Estimates for models 1a-c.

1a

Counting BW K   .75
Counting BW G1   .73   Counting
Counting FW G1   .79

.68*** → Arithmetic Fluency R²=.46
.83 → Ar. fluency G2
.88 → Ar. fluency G3

.52*** → Reading Fluency R²=.28
.99 → Rea. fluency G2
.88 → Rea. fluency G3

.28***

1b

RAN Obj K   .82
RAN Obj G1   .76   RAN

.46*** → Arithmetic Fluency R²=.21
.78 → Ar. fluency G2
.94 → Ar. fluency G3

.41*** → Reading Fluency R²=.17
.98 → Rea. fluency G2
.90 → Rea. fluency G3

.43***

1c

Counting BW K   .74
Counting BW G1   .74   Counting
Counting FW G1   .79

.27***

RAN Obj K   .82
RAN Obj G1   .77   RAN

.59*** → Arithmetic Fluency R²=.55
.83 → Ar. fluency G2
.88 → Ar. fluency G3

.31***
45***
.29***

Reading Fluency R²=.36
.99 → Rea. fluency G2
.88 → Rea. fluency G3

.18*

χ^2 (21) = 34.23, p=.03, RMSEA= .04 , CFI = .99, TLI = .98, SRMR = .02
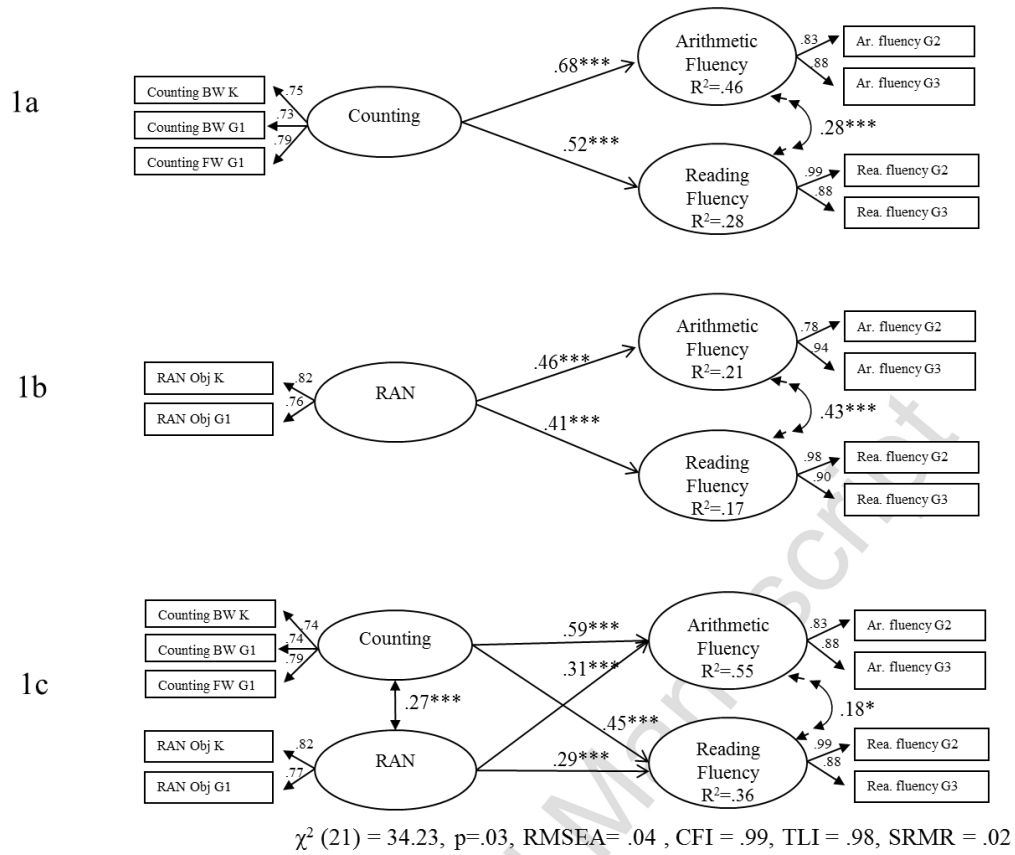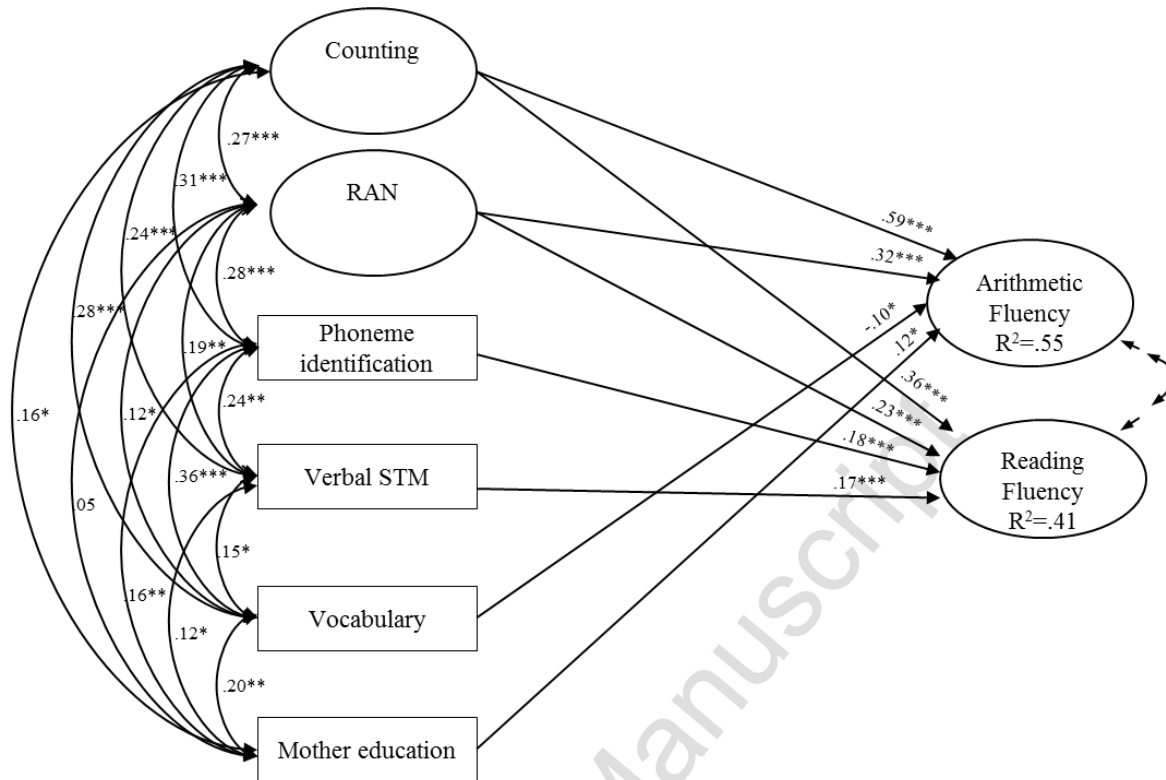
Figure 2. Standardized estimates for model 2.

$\chi^2(45)=64.78$, p=.03, RMSEA=.04, CFI = .99, TLI = .98, SRMR = .03

Figure 3. Standardized estimates for model 3.

$\chi^2(46)=70.09$, p=.01, RMSEA=.04, CFI = .99, TLI = .98, SRMR = .03
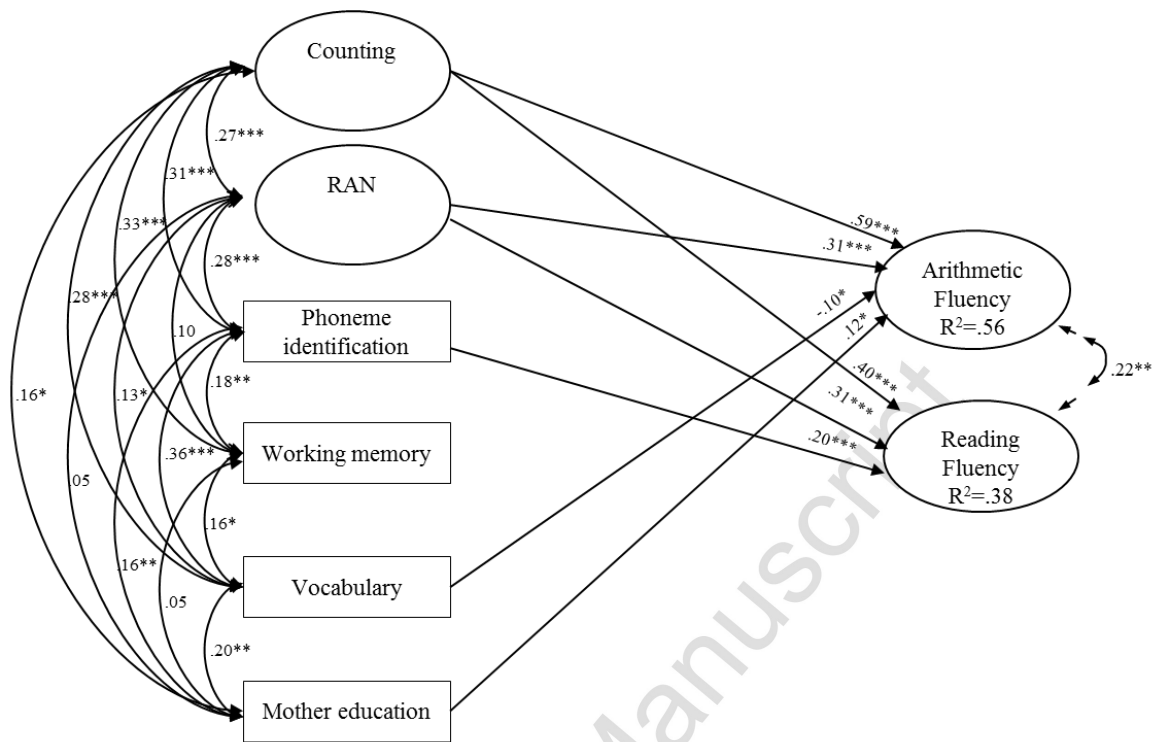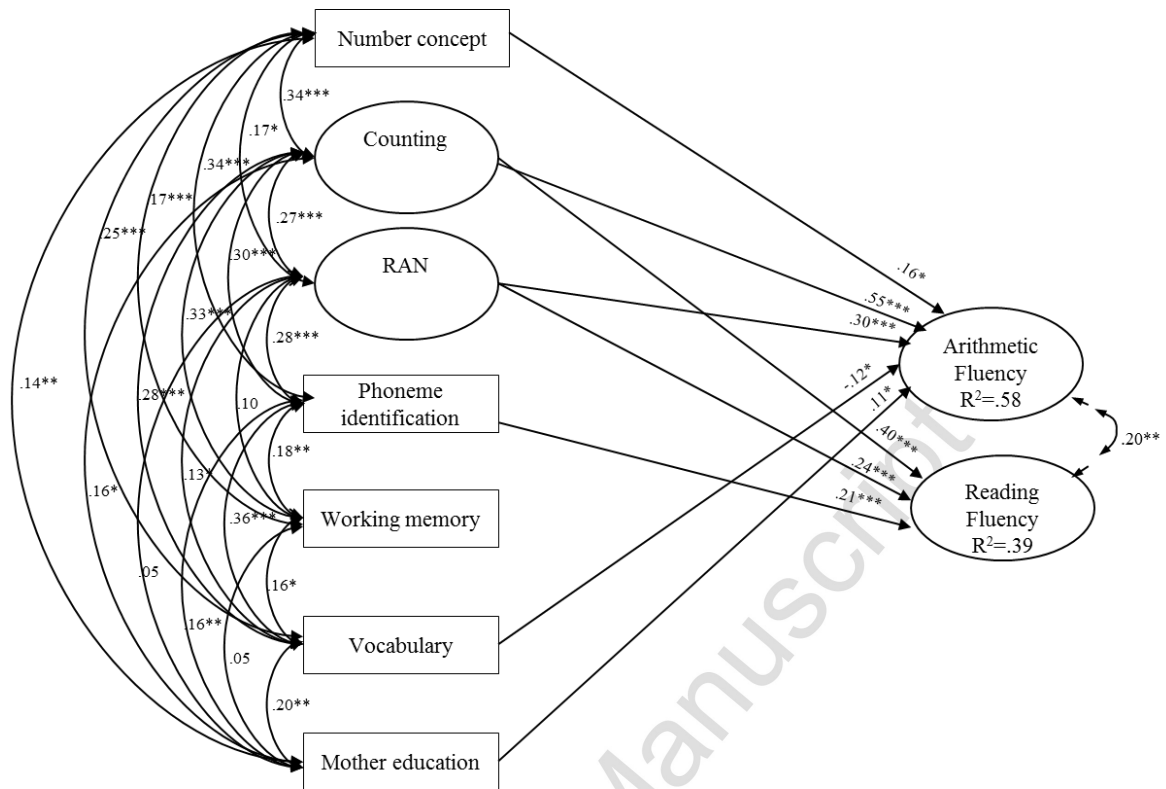
Figure 4. Standardized estimates for model 5.

$\chi^2(52)=80.91$, p=.01, RMSEA=.04, CFI = .98, TLI = .97, SRMR = .05

Table 1. *Descriptive Statistics for the Measures of Reading Fluency, and Arithmetic Fluency*

Counting, Rapid Naming, Phonological Awareness, Vocabulary, Memory and Mother's

eduaction.

	N	Min	Max	Mean	SD
Arithmetic fluency					
Grade 2 spring	364	2	28	16.29	4.92
Grade 3 spring	362	4	28	19.69	4.76
Reading fluency					
Grade 2 spring	358	2	75	40.65	9.66
Grade 3 spring	356	16	76	48.58	10.37
Counting					
Backward, Kindergarten spring	377	0	4	2.77	1.44
Forward, Grade 1 fall	360	0	6	4.69	1.55
Backward, Grade 1 fall	357	0	8	4.99	2.57
Rapid naming					
Kindergarten spring	376	40	135	68.87	16.22
Grade 1 spring	369	32	98	57.26	11.49
Phoneme identification, Kindergarten fall	376	1	10	7.63	2.34
Verbal short-term memory, Grade 1 spring	369	2	10	6.02	1.23
Working memory, Grade 1 spring	369	0	8	3.22	1.13
Vocabulary, Kindergarten spring	377	8	29	20.07	3.28
Number concept	376	2	9	8.24	1.29
Mother's education	344	1	7	4.17	1.49

Table 2. *Correlation Coefficients for the Measures of Reading Fluency, and Arithmetic Fluency Counting, Rapid Naming, Phonological Awareness, Vocabulary, Memory and Mother's education..*

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1.	Arithmetic fluency, G2															
2.	Arithmetic fluency, G3	.73***														
3.	Reading fluency, G2	.40***	.48***													
4.	Reading fluency, G3	.34***	.46***	.88***												
5.	Counting BW, K	.45***	.38***	.32***	.27***											
6.	Counting FW, G1	.40***	.35***	.35***	.33***	.49***										
7.	Counting BW,G1	.47***	.46***	.39***	.32***	.54***	.51***									
8.	RAN, K	-.31***	-.36***	-.32***	-.29***	-.23***	-.21**	-.15**								
9.	RAN, G1	-.27***	-.31***	-.33***	-.29***	-.19***	-.17**	-.10	.62***							
10.	Phoneme aw., K	.14**	.21***	.39***	.32***	.20***	.32***	.21***	-.28***	-.19***						
11.	Verbal STM, G1	.15**	.17***	.34***	.32***	.19***	.21***	.19***	-.14**	-.16***	.25***					
12.	Working memory, G1	.20***	.20***	.26***	.25***	.29***	.22***	.20***	-.07	-.07	.19***	.22***				
13.	Vocabulary, K	.11*	.11*	.21***	.20***	.22***	.16	.24***	-.11*	-.07	.33***	.15*	.16**			
14.	Number concept, K	.32***	.35***	.30***	.26***	.30***	.24***	.22***	-.16**	-.09	.34***	.18**	.17**	.25***		
15.	Mother's education	.13*	.21***	.07	.09	.08	.11	.18**	-.05	-.03	.16**	.12*	.05	.19**	.13*	

Note. Coefficients involving counting measures, number concepts and phoneme awareness are Spearman correlation coefficients, otherwise Pearson correlation coefficients. K = Kindergarten, G1= Grade 1, G2= Grade 2, G3= Grade 3, STM = short-term memory
p < .05. **p* < .01. ***p* < .001.