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Research Reports

Cognitive Predictors of Counting Skills

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Abstract

Rote counting skills have found to be a strong predictor of later arithmetic and reading fluency. However, knowledge of the underlying cognitive factors influencing counting skill is very limited. Present study examined to what extent language skills (phonology, vocabulary, and morphology), nonverbal reasoning skills, and memory at the age of five could explain counting skill at the beginning of first grade. Gender, parents' education level and child's persistence were included as control variables. The question was examined in a longitudinal sample (N = 101) with a structural equation model. Results showed that language skills together with memory, nonverbal reasoning skills and parent's education explained only 22% of the variance in counting at the beginning of the first grade. Vocabulary, morphology, and verbal short-term memory were found to be interchangeable predictors, each explaining approximately 7%–9%, of counting skill. These findings challenge the interpretation of counting as a strongly language-based number skill. However, additional analysis among children with dyslexia revealed that memory and language skills, together with a child's persistence and gender, had a rather strong predictive value, explaining 34%–46% of counting skill. Together these results suggest that verbal short-term memory and language skills at the age of five have not the same predictive value on counting skill at the beginning of school among a population-based sample as found in subjects with language impairment or learning difficulties, and thus, other cognitive factors should be taken into account in further research related to typical development of counting skill.

Keywords: rote counting, cognitive predictors, language, memory

Rote counting—the ability to recite number words forward and backward—is an early number skill that starts to develop around the age of two years, and remarkable developmental steps are acquired before children enter formal education. The ability to recite number words can be considered as one of the core number skills, being an essential skill for the exact enumeration of quantities larger than five and a tool for mental calculation. From a theoretical and practical point of view, counting is an important skill because it has been found to be a strong predictor of later arithmetic fluency (Koponen, Salmi, Eklund, & Aro, 2013; Koponen et al., 2016; Zhang et al., 2014) and accuracy (Koponen, Aunola, Ahonen, & Nurmi, 2007). In these studies, correlations between counting and arithmetical calculation have varied from .32 to .53, which is high even when compared to other core number skill, magnitude comparison, which has been extensively examined in recent years. Magnitude comparison has shown to have predictive relations with mental and written arithmetic, correlations varying from .28 to .38 (Schneider et al., 2016). Surprisingly, and unlike magnitude comparison, counting has also been found predict strongly later reading fluency (Durand, Hulme, Larkin, & Snowling, 2005; Koponen et al., 2016), even

when considering the classical predictors of reading skill: phonological awareness, rapid naming, verbal short-term memory, and working memory (Koponen et al., 2013, 2016; Leppänen, 2006).

Despite the importance of counting as a predictor of later fluency in reading and arithmetic, the cognitive factors underlying the development of an individual's counting skill are poorly understood. Yet only by understanding the cognitive processes and skills needed to perform well in counting tasks are we able to comprehend why counting serves as a good predictor. This, in turn, is the first critical step when trying to develop effective early support to provide good basic skills in calculation and reading. In the present study, we aimed to explore the proximal cognitive predictors of counting at school start, a time point before which no formal teaching for mathematics has been available for children. When examining cognitive correlates of counting, it's important to know how it develops during early childhood. In the following chapters we will first describe the development of counting skills and then cognitive factors that have been found to associate with counting skills.

Development of Counting Skill

Learning to count in many languages, including Finnish, means acquiring rather arbitrary sequences of number words below 20 and knowledge of the syntax and grammar for the structure of higher numbers (Fuson, 1988). Rote counting skill develops gradually, and several steps of development can be defined (Fuson, 1988). In the early phase of string-level development, which occurs around the age of 2, children count verbally by starting from the beginning and saying a string of words, but they do not necessarily even recognize counting words as separate words. Next, they separate each counting word and they learn to count up to 10, then 20, and then higher. This step is called the unbreakable list level, meaning that the child has not yet acquired the capacity to start counting from an arbitrary entry point, only from 1, allowing the counting-all strategy in arithmetic calculation. This phase of development could be compared to learning other verbal sequences, such as rhymes. According to most critical views, at this point, the number word sequence does not carry mathematical information and is not yet used as a tool for enumerating sets of objects (Negen & Sarnecka, 2012). By practicing, counting skill becomes more or less automatized, allowing counting to start from a given number. At the so-called breakable chain and the following numerable chain levels, children can produce parts of the number sequence from arbitrary entry points, which allows the use of counting as a strategy in calculation (7+5 → eight, nine…twelve). At the numerable chain level, children start using number sequences in an enumeration context with concrete objects (see Wynn, 1992; Children's acquisition of how the counting system represents numerosity). At the most advanced level, called the bidirectional chain, fluent counting forward and backward, as well as skip counting by following different rules (e.g., by two: 2, 4, 6) becomes possible.

Counting and Language

Despite the importance of counting as a predictor of later reading and arithmetic skill, only a few previous studies focused on the underlying cognitive skills required for counting (Cowan, Donlan, Newton, & Llyod, 2005; Liu, Lin, & Zhang, 2016). However, in many studies, counting has been proposed as being tightly related to language and so-called verbal number skill (Donlan, Cowan, Newton, & Lloyd, 2007; Koponen, Mononen, Räsänen, & Ahonen, 2006). The evidence comes mainly from research concerning children with language impairment (SLI) showing systematically that children with language impairment, varying in age from 3.5 years old to 11 years old, lack behind their peers in counting skills (e.g., Arvedson, 2002; Cowan et al., 2005; Fazio, 1994, 1996). However, these studies in children with language impairment have not been able to specify which

subskills of language are related to the development of counting. This is an important question because language consists of several subskills, such as phonology, morphology, lexicon, speech perception, syntax, and articulation (e.g., Pennington, 2006), which are related but independent in the sense that they can be impaired independently of each other.

There are several reasonable hypotheses for the possible links between counting and language that explain why deficiencies in language skills would result in a compromised counting skill. One possibility is phonology: the number words are phonologically coded in memory (e.g., Simmons & Singleton, 2008; Stanescu-Cosson et al., 2000), and the weakness of phonological representations for number words in long-term memory is likely to make it more difficult to retrieve number words quickly and accurately (Simmons & Singleton, 2008). Krajewski and Schneider (2009) suggested that shifting from the string level to the unbreakable list level in counting requires phonological awareness to be able to separate number words from each other. Supporting these views, previous studies have shown moderate to strong associations between phonological awareness and counting skill correlations, varying between 0.23 and 0.58 (Koponen et al., 2007; Krajewski & Schneider, 2009; Zhang et al., 2014).

Another reasonable hypothesis of underlying language-based factors are lexical skills, that is, receptive and productive vocabulary. LeFevre et al. (2010) argued that the breadth of receptive vocabulary might reflect children's abilities to acquire vocabulary in the number system. Negen and Sarnecka (2012) showed that a strong correlation was found between number–word knowledge and vocabulary: both receptive and expressive vocabulary were related to number–word knowledge in children between 30 and 60 months old. However, number–word knowledge was assessed by using a 'give a number' task and thus did not assess rote counting directly.

The third and fourth possible relevant language skills in counting are language comprehension and morphology. In a study by Cowan et al. (2005), the correlation between counting and language comprehension was higher than those between counting and working memory or nonverbal reasoning in a sample consisting of children with language impairment and their age peers and language-matched controls. In the multiple regressions, oral language comprehension made a unique contribution (standardised β = 0.23) in explaining this variation in counting skill. The association between counting and language comprehension was interpreted in a way that, in addition to knowing the words needed in counting, counting also was shown to require mastery of compounding rules (Skwarchuk & Anglin, 2002). This is analogous to the case in sentence comprehension, where processing of morphology and syntax information in addition to lexical information is needed. In a recent study in Chinese kindergarteners, morphology was found to be related to counting, especially to counting forward (Liu et al., 2016). Children with better knowledge of compounding morphology in Chinese developed higher counting ability 1 year later. It was suggested that the strength of this association could be related to the children's experiences using compounding morphology in their language because in Chinese, compound words are dominant. Finnish language also consists of compound words, but it is above all a highly inflected language that may contain thousands of different word forms of the same root (Hirsimäki et al., 2006). Therefore, inflectional morphology (which involves grammatical transformations in words) is highly common in the Finnish language (Hirsimäki et al., 2006), and rather long words, that is, nouns, adjectives, and verbs with complex meaning, can be formed when adding several suffixes, such as case endings, plural markers, and person markers after the root of a word (e.g., *kahdeksastakymmenestä* means "from eighty…"; Lyytinen & Lyytinen, 2004; Nieminen, 2007).

Therefore, it is reasonable to expect that morphology predicts later counting skills in Finnish, with rather long number words and irregular number names in 11–19.

Counting and Memory

Rote counting is a serial process requiring holding information in one's memory while articulating items and retrieving the next; thus, verbal memory should be examined as a potential underlying factor influencing counting skill. According to Fazio (1994), counting requires auditory memory of the number terms, as well as auditory sequential memory of the correct order of number words. Fazio (1994) proposed that SLI children's counting is impaired, at least in part, because of poor language-processing abilities associated with the auditory, sequential nature of counting and could be explained by short-term memory deficits of phonological storage. This suggestion is in line with findings in population-based samples where verbal short-term memory, requiring the recalling of the name of the digits in correct order, was found to be related to counting (e.g., Cowan et al., 2005; Koponen et al., 2016).

Counting and Nonverbal Reasoning

Besides language skills and memory, the relationship between nonverbal reasoning skills and counting has been examined in children with language impairment (see Cowan et al., 2005), as well as in a population-based samples, where the role of counting as a mediator of nonverbal reasoning skills on arithmetic have been studied (Koponen et al., 2007; Krajewski & Schneider, 2009; Zhang et al., 2014). Cowan and colleagues found that nonverbal abstract reasoning, measured using raven-coloured matrices, was related to counting in a sample consisting of children with language impairment against their age and language matched controls. Zhang and colleagues (2014) found that nonverbal reasoning, measured in kindergarten using a subtest of spatial relations from the Woodcock and Johnson (1977) test battery, predicted the level of arithmetic in first grade and later growth through third grade. These associations were mediated by counting skill measured in first grade. Similarly, in the study by Krajewski and Schneider (2009), nonverbal reasoning was related to counting, which, in turn, was related to the later-emerging number skills and through these number skills to arithmetic. However, in most of these studies, nonverbal reasoning was measured concurrently with counting (Cowan et al., 2005; Krajewski & Schneider, 2009), and the predictive power of early nonverbal reasoning skills on counting skill at the beginning of formal schooling remains unclear. Moreover, the theoretical framework on how nonverbal reasoning skills are related to counting skill is still lacking (Cowan et al., 2005).

Environmental Factors, Gender, and the Child's Task-Orientation

Counting skill is not innate, but rather, it emerges and develops through individual learning and cultural transmission. Thus, factors such as parents' socioeconomic status should be taken into account when trying to understand factors that influence the development of counting skill, especially before the phase of formal learning. There are several possible reasons why parents' educational levels predict children's later academic skills. One view is based on the assumption that parents learn something during schooling that influences the way in which they interact with their children regarding learning activities at home. Another view indicates that education influences parents' skills, values, and knowledge of the educational system, as well as methods for educational practices at home, and children's skills (for review, see Eccles, 2005). In line with this suggestion, parents' educational levels have been shown to be related to counting and later arithmetic skills (Koponen et al., 2007).

There are several meta-analyses showing that there are no gender differences in math and that the gender differences in math performance may have narrowed from the 1970s to now (see Hyde, 2016). However, findings are still robust and gender is worth of controlling although large differences between boys and girls are not expected.

Besides the child's cognitive capacity and environmental factors, children's orientations and persistence in task situations have been shown to be related to later academic learning. Previous research has shown that positive achievement-related behaviours, such as task-focused behaviours, are related to good academic outcomes, whereas negative behaviours, such as task-avoidant behaviours, are related to poor academic outcomes (e.g., Aunola, Nurmi, Lerkkanen, & Rasku-Puttonen, 2003). Weak orientation in task situations, that is, task avoidance, means low levels of effort in learning tasks or task-irrelevant activities (Onatsu-Arvilommi & Nurmi, 2000), and it has been shown to have effects on the development of math skills (e.g., Hirvonen, Tolvanen, Aunola, & Nurmi, 2012). In the present study, the focus is on cognitive predictors of rote counting skill, but parents' educational levels, as well as children's task-orientation and persistence, are also taken into account.

Present Study

Because of the lack of a comprehensive view of the cognitive background of counting skill, the present study aimed to model the relationships between various cognitive predictors measured concurrently at the age of 5 and counting skill measured 2 years later at the beginning of first grade. The associations were examined in a population-based sample, and thus, extending the previous literature which is mainly based on the findings in children with language difficulties. The specific research questions were as follows:

- To what extent can language, memory, and nonverbal reasoning skills at age 5 predict rote counting skill at the beginning of the first grade?
  Based on previous studies we expect that language and memory skills are significant predictors of later counting skill (Cowan et al., 2005; Fazio, 1994, 1996). However, previous studies have mainly examined these relations among children with a specific deficit, such as language impairment, and thus, strong hypothesis cannot be made considering our population based sample. Nonverbal reasoning has been found to be related to counting skill also among a population based sample (Krajewski & Schneider, 2009; Zhang et al., 2014), and we expect to find a similar relation also in the present study. It should be noticed, however, that predictive relation between nonverbal reasoning and counting has not been examined in previous studies.

- To what extent do the child's task-orientation or persistence in preschool, gender, and parents' educational levels explain the counting skill at the beginning of first grade in addition to cognitive skills?
  Because differences between families in SES are relatively small in Finland (unlike to many countries like USA), SES has usually been found as a significant but typically not very strong predictor of academic achievement (for example see Koponen et al., 2016). In line with this, parents' education is expected to have significant and moderate association to counting. Similarly, it is not expected that we could find large gender differences in counting based on the recent literature involving math and gender (Hyde, 2016). However, both parent's educational level as well as child's gender are important background variables to control. Finally, it is expected that child's task-orientation and persistence is a significant predictor of counting skill because it has been found to be related to both performance level and development of math in previous studies in population-based sample (e.g., Hirvonen et al., 2012).

Method

Participants

All participants (*n* = 101) spoke Finnish and were recruited as a part of the longitudinal study in Finland (Lyytinen et al., 2008). The children were originally selected as participants from among 9,368 newborns in the province of central Finland between April 1993 and July 1996 for one of two groups: with family risk for dyslexia (*n* = 108) or without it (*n* = 92). For the current study, we strove for a representative sample of the Finnish population. To achieve this, we first included all children without family risk for dyslexia in our sample. Second, we added a random selection of nine children from the family risk group to attain a full distribution of parental reading skills, and as a consequence, full distributions of children's reading-related cognitive skills, which were used as the cognitive predictors of counting in this study. The size of the addition (nine children) was based on the estimate of the prevalence rate of dyslexia in the population, which has been shown to vary between 5% and 12% (Katusic, Colligan, Barbaresi, Schaid, & Jacobsen, 2001; Landerl & Moll, 2010; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). For full details of the recruitment process, see (Leinonen et al., 2001). In Finland, children begin their 9-year comprehensive school in August of the year they turn 7 years old and kindergarten 1 year earlier when they turn 6 years old. Thus, first graders and preschoolers in Finland are older than their counterparts in many other countries.

Measures

Trained testers assessed children's skills individually in a laboratory setting; the children were 5 and 5.5 years old, and just beginning the first grade (age 7.2). In addition, children's persistence in tasks was evaluated at age 6 by their kindergarten teachers. Composite scores (arithmetical means) for each skill using z-scored values were calculated and used when reporting correlative associations between skills (for full details of measures, see Pennala et al., 2013).

Parents' Education

The education of mothers and fathers was classified using a 7-point scale, taking into account both a basic level of education and advanced educational training (e.g., 1 = comprehensive school education without any vocational education; 7 = comprehensive school or upper secondary general school diploma combined with a master's or doctoral degree). The parents' educational distributions resembled that of the Finnish population (mothers: *M* = 4.51, *SD* = 1.38; fathers: *M* = 3.84, *SD* = 1.48).

Vocabulary

At 5–5.5 years, a composite mean (Cronbach α = 0.75) was calculated from three different measures, including both receptive and expressive vocabulary: Peabody Picture Vocabulary Test–Revised (PPVT; Dunn & Dunn, 1981), the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), and the vocabulary scale of the WPPSI-R (Wechsler Preschool and Primary Scale of Intelligence-R; Wechsler, 1989).

Phonological Awareness

At 5.5 years, the composite mean was derived from performance in three tasks (Cronbach α = 0.66): from the word or pseudoword segmentation task, including both phoneme- and syllable-level segments (Pennala et al.,

2013), the initial phoneme naming task (Poskiparta, Niemi, & Lepola, 1994), and one computer-based task, that is, phoneme-level segment identification (Puolakanaho, Poikkeus, Ahonen, Tolvanen, & Lyytinen, 2003).

Morphological Skill

At 5 years, mastery of the highly inflected Finnish morphology was measured with the Berko-type elicitation test (Lyytinen & Lyytinen, 2004), which covers items of adjective inflection (comparative and superlative), verb inflection (present and past), and noun inflection (adverb and elative; i.e., how and from something or somewhere). The test words were unfamiliar to the children but adhered to the phonotactic rules of Finnish. Cronbach α reliability for the three scales was 0.73.

Verbal Short-Term Memory

At 5–5.5 years, a composite mean was calculated from three tasks (Cronbach α = 0.66): digit span (Gathercole & Adams, 1994) and syllable span (both computerised) at 5 years and sentence repetition (NEPSY; Korkman, Kirk, & Kemp, 1998) at 5.5 years.

Performance IQ

At 5 years, a short form of the WPPSI-R (Wechsler, 1989) was administered that consisted of three verbal quotient subtests (vocabulary, arithmetic, and comprehension) and three performance quotient subtests (block design, object assembly, and picture completion). Only the score of performance IQ was used in this study, and it was estimated based on three subtests according to the standard guidelines given in the manual. Cronbach α reliability for the three scales was 0.68.

Task-Orientation and Persistence

At 6 years, children's persistence was calculated from three items, with which their preschool teachers rated children's behaviour using a 5-point Likert scale (1 = not at all this kind of behaviour, 5 = extremely often this kind of behaviour). The three questions used in this study were as follows: *Does the child actively seek a solution even when confronting a difficult task? Does the child easily give up? Does the child show persistence when doing preschool tasks?* The second item was reversed before calculating the mean score representing child's persistence. Cronbach α reliability for this scale was 0.81.

Counting Skill

In the first grade, at 7.2 years, a series of six items of counting was administered just after school started in August–September. Three measures of counting were calculated, each including three items: (a) counting forward included counting from 1 to 31 and counting by 10s from 10 up to 150, (b) counting backward entailed counting backward from 10 to 1 and from 23 to 1, and (c) counting challenging items included counting forward by twos (skip-counting) in multiples of 2 up to 30 and counting backward from 83 to 60. For each set of six items, error-free outcomes were allocated 2 points while 1 point was awarded for completing the item with up to two errors, and a score was given for more than two errors or a failure to complete the list within any item. The maximum was 4 points in all the three measures of counting, that is, counting forward, counting backward, and counting challenging items (see Table 1). Cronbach's alpha reliability for the counting measure was 0.71.

Data Analysis

Pearson correlations were used to examine the associations between the predictors and outcome measures, as well as between the predictors themselves. The relations between measures were further modelled in a structural equation model (SEM) framework using the Mplus 6.12 program (Muthén & Muthén, 1998–2011). Latent factors were created first, one for each of the skills and abilities: vocabulary, phonological awareness, morphological skill, verbal short-term memory, performance IQ, persistence, and counting skill. All latent factors of the predictors, as well as the outcomes, were constructed from three variables. After creation of each latent factor, the significance of its predictive path to counting skill was tested as a starting point. After this, starting with the best cognitive predictor and outcome in the model, the model was further elaborated on by adding other significant cognitive predictors one by one and testing the significance of the predictive paths. After obtaining a final cognitive prediction model, the effects of task-orientation and persistence to further explain variance in counting skill were tested by adding its latent factor and relative path to the model. Likewise, the effects of parental education were tested. All error variances were estimated freely. The parameters of the models were estimated using the MLR procedure. The goodness of fit of the estimated model was evaluated using five indicators: the χ^2 test, Comparative Fit Index (CFI), Tucker-Lewis Fit Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR).

Results

Descriptive statistics for all measures used in the latent factors are presented in Table 1. The distributions of all measures were normal or close to normal. Correlations between the predictors and outcome, as well as between the predictors, are presented in Table 2. Children's vocabulary and morphological skills at 5 years of age were significantly associated with counting skill 2 years later at the start of first grade. Moreover, father's education was significantly associated with counting skill and association between gender and counting was close to significant (p = .051). Additional analyses revealed, that correlation between parent's education and counting did not differ between boys and girls. Moderate to high correlations were found among the language-related predictors: vocabulary, phonological awareness, morphological skill, and verbal short-term memory. What stands out is that child's gender was not associated with any of the language-related predictors. Finally, children's performance IQ was also significantly related to previously mentioned language measures (except morphological skills) and to children's task-orientation and persistence.

Associations between the cognitive predictors and counting skill were further inspected in an SEM framework to be able, first, to use latent factors of the skills instead of means of raw scores, second, estimate error variances in measures, and, third, see the simultaneous effects of each predictor on counting skill. Factor constructs, including loadings for each of the measures, are presented in Figure 1, the model with all language-related predictors and persistence in Figure 2, and the final predictive model with child's gender in Figure 3.

Table 1

Descriptive Statistics for All Measures (Raw Scores) Used in Creating the Latent Factors Used in the SEM Model.

Measure	Range	*M*	*SD*	Skewness (*SE*)
Vocabulary				
PPVT	22 – 120	73.10	22.26	-0.06 (.24)
Boston Naming	23 – 46	35.52	5.59	-0.39 (.24)
WPPSI-R Vocabulary	5 – 18	11.55	2.96	-0.13 (.24)
Morphological skills				
Adjective inflections	0 – 29	13.46	8.70	-1.30 (.24)
Verb inflections	0 – 29	20.56	6.21	0.14 (.24)
Noun inflections	0 – 30	22.39	7.30	-0.99 (.24)
Phonology				
Word / pseudoword segmentation	5 – 20	13.79	2.87	-0.26 (.24)
First phoneme production	2 – 9	7.52	1.50	-1.24 (.24)
Word segmentation, phoneme level	0 – 24	11.98	5.07	-0.50 (.26)
Verbal short term memory				
Digit span	0 – 8	3.67	1.57	-0.23 (.24)
Syllable span	0 – 6	2.74	1.25	-0.12 (.24)
Sentence repetition	12 – 28	21.39	3.54	-0.37 (.26)
Performance IQ				
WPPSI-R, Object assembly	3 – 15	9.78	2.69	-0.14 (.24)
WPPSI-R, Picture completion	4 – 15	11.11	2.46	-0.52 (.24)
WPPSI-R, Block design	4 – 17	10.20	2.59	0.03 (.24)
Task-orientation / persistence				
Solving difficult tasks	1 – 5	3.72	1.11	-0.55 (.25)
Persistence in pre-school tasks	1 – 5	3.81	1.01	0.75 (.25)
Giving up easily	1 – 4	2.03	1.01	-0.74 (.24)
Parental education				
Mothers' education	1 – 7	4.51	1.38	0.19 (.26)
Fathers' education	1 – 7	3.84	1.48	0.37 (.26)
Counting skill				
Counting forward	0 – 4	2.60	1.19	-0.33 (.24)
Counting backward	1 – 4	3.34	0.82	0.00 (.24)
Counting difficult items	0 – 4	1.59	1.33	0.19 (.24)

All factor constructs were satisfactory. The significance of each of the latent cognitive factors as a predictor of counting skill was tested first. Vocabulary, morphology, and verbal short-term memory turned out to be significant predictors, explaining 9.3%, 9.9%, and 10.2% of counting skill 2 years later, whereas the predictive paths from phonological awareness and performance IQ turned out to be nonsignificant. Next, to assess the simultaneous effects of the cognitive predictors on counting skill, each was added one by one into a model where the best predictor (verbal short-term memory) predicted counting skill. In all cases, adding another cognitive predictor besides verbal short-term memory resulted in a reduction in the goodness-of-fit indices and produced situations where none of the predictive paths were significant. Thus, vocabulary, morphology, and verbal short-term memory turned out to be interchangeable predictors of counting skill, each explaining roughly 10% of its variance, but not fitting into the model at the same time.

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Table 2

Correlations Between Parents' Education, Children's Cognitive Skills, Persistence, Gender, and Counting Skill

Measure	1	2	3	4	5	6	7	8	9
1. Mother's education									
2. Father's education	.36***								
3. Vocabulary	.08	.16							
4. Phonological awareness	.04	.01	.37***						
5. Morphological skill	.07	.08	.40***	.26**					
6. Verbal short-term memory	.22*	-.01	.49***	.36***	.37***				
7. Performance IQ	.06	.00	.36***	.29**	.14	.32**			
8. Persistence	.14	.09	.16	.05	.07	.11	.23*		
9. Counting skill	.19	.28**	.21*	.18	.25*	.19	.13	.17	
10. Gender	.16	.19	-.02	-.13	-.06	-.03	-.11	-.15	.20

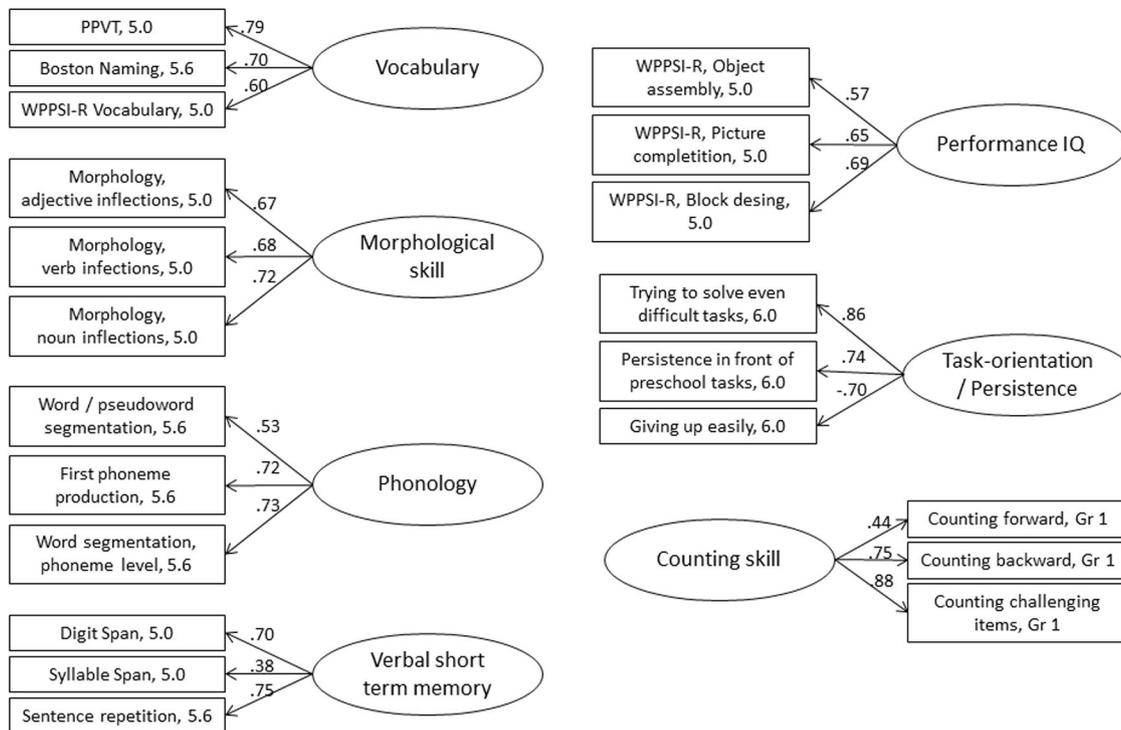*p < .05. **p < .01. ***p < .001.

Figure 1. Factor constructs of the cognitive predictors at age of five, task-orientation and persistence, and counting skill.
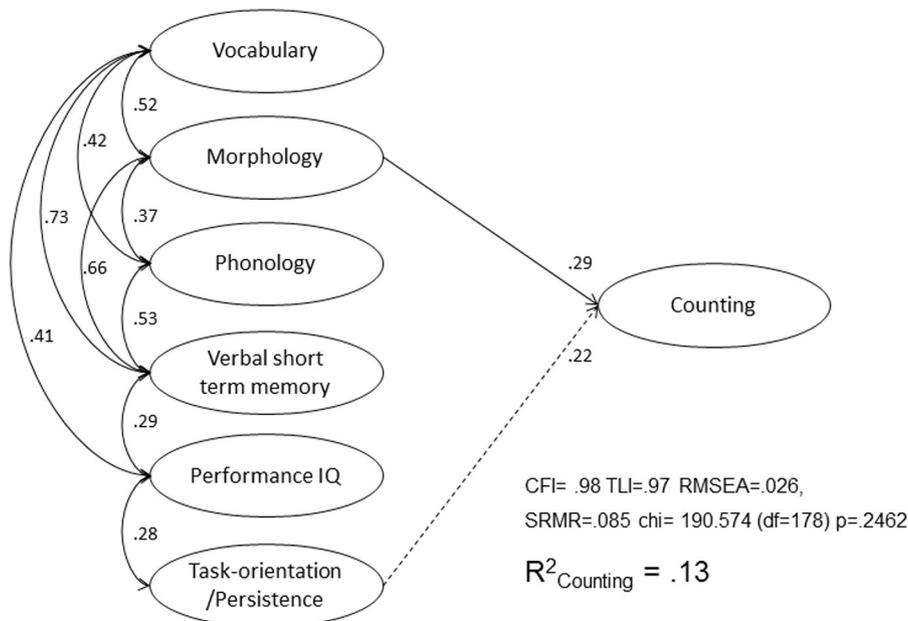
Figure 2. The model with all significant paths of the language-related predictors and persistence included.

Finally, to test the predictive power of children's task-orientation and persistence, it was added into the model together with one of the significant cognitive predictors (vocabulary, morphology, or verbal short-term memory). The best goodness-of-fit indices and highest portion of explained variance in counting skill were reached with morphology and task-orientation and persistence as predictors. No more than 13.25% of the variance in counting skill could be explained with this final model. Morphological skill explained 8.41% of the outcome variance of counting in the final model. The predictive path of children's task-orientation and persistence was barely significant (p = .056) and raised the explanatory power of the model by 4.84%. Adding the father's education into the model resulted in a collapse of the goodness-of-fit indices, indicating a bad fit of the model to the data. Moreover, the predictive paths from morphology and task-orientation and persistence on counting skill were no longer significant. After removing these nonsignificant predictors from the model, goodness-of-fit indices remained unsatisfactory, and the father's education alone explained 10.4% of the variance in counting skill, whereas the effect of the mother's education was nonsignificant. Because child's gender was associated with counting skill, a final model was constructed by adding child's gender to the predictors already included in Model 2 (see Figure 3).

Altogether, 21.6% of the variance in counting skill could be explained by morphology, child's persistence, and gender. All three measures explained close to a similar portion of the outcome measure: 8.41%, 5.76%, and 7.29%, morphology, child's persistence, and gender, respectively. What also was remarkable was that the significance of the predictive association from child's persistence to counting skill sank below .05, i.e. to .029.

Because of the small amount of explained variance in counting observed in the population-based sample additional regression analyses were conducted in a sample including children with dyslexia (*N* = 38) in order to see whether the predictive power of language and memory would be stronger in a sample with compromised cognitive skills. Children with dyslexia are known to have deficient language related cognitive skills (see Snowling & Melby-Lervåg, 2016, for review and meta-analysis; Vellutino, Fletcher, Snowling, & Scanlon, 2004, for review;

Casalis, Colé, & Sopo, 2004). Results from the regression analyses, where child's persistence and gender were entered in the first step and one of the cognitive predictors (vocabulary, morphology, phonology, and verbal short term memory) at a time in the second step, showed that the total explained variance of counting varied from 34% to 46% verbal short-term memory being the strongest cognitive predictor (standardized β = .36).
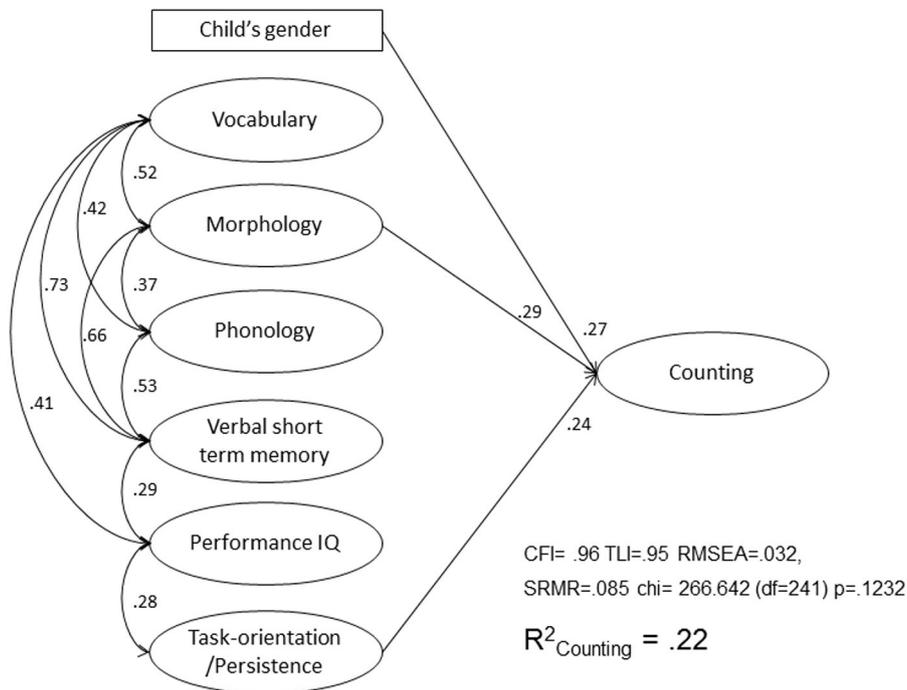

Figure 3. The final model, including language-related predictors, child's persistence, and gender. All significant paths included.

Discussion

In the present study, we examined to what extent language skills (phonology, vocabulary, and morphology), memory, and nonverbal reasoning skills at the age of 5 could explain counting skills 2 years later at the beginning of first grade. The question was examined in a population-based sample with a SEM, where each of the skills was represented by a latent factor constructed from three measures, allowing us to estimate the error variances as well. Despite using this sophisticated method, we were only able to explain 22% of the variance in counting at the beginning of first grade. Cognitive skills were found to be closely associated with each other, and vocabulary, morphology, and verbal short-term memory were found to be interchangeable predictors of counting skill. Child's task-orientation and persistence explained an additional 5% and gender 7% when included in the model. Finally, the father's educational level alone explained 10% of counting skills, but the fit of the model without cognitive predictors was unsatisfactory. Additional analysis among children with dyslexia revealed that memory and language skills, together with child's persistence and gender, had stronger predictive value on counting skill explaining 34-46% of counting skill.

The low percentage of the variance in rote counting skill explained by the cognitive skills was surprising, and it challenges the previous literature as well as our hypothesis considering rote counting as a strongly language-

based skill that requires verbal short-term memory resources to develop normally (e.g., Fazio, 1994, 1996). Morphology and vocabulary both explained about 9–10% of the variance in counting when included as the only predictor in a model. Although the predictive power was lower than expected, the finding is in line with previous findings of vocabulary and morphology as an underlying cognitive factor in counting (Bloom & Wynn, 1997; LeFevre et al., 2010; Liu et al., 2016). Bloom and Wynn proposed that children's early knowledge of number word meaning comes through attention to both syntactic and semantic linguistic cues, such as the word order in a sentence, the closed-class morphemes they co-occur with, and the count–mass status of the nouns they modify. LeFevre et al. (2010) argued that the breadth of receptive vocabulary might reflect children's abilities to acquire vocabulary in the number system, and in line with that, Negen and Sarnecka (2012) showed that a strong correlation was found between number–word knowledge and vocabulary: both receptive and expressive vocabulary were related to number–word knowledge in children between 30 and 60 months old. However, in Negen and Sarnecka's (2012) study children were younger and it can be assumed that variance in early counting skills could be more related individual differences in acquiring vocabulary. Moreover, in study by Negen and Sarnecka number–word knowledge was assessed by using a 'give a number' task that measured more of mastering the semantic meaning of number words than rote counting skill, that is, mastering the sequences of number words.

The relation between morphology and counting skills could be explained by a similar kind of learning process. Learning the morphological structure of language happens quite early in children's development and without explicit instruction, as is the case in the early developmental phase of counting. Moreover, mastering morphology in a highly inflectional language such as Finnish, where one must correctly inflect verbs, substantives, or adjectives, relies on processing sequential information and rule learning. It requires detecting the root of the word and its morphological endings (Lyytinen & Lyytinen, 2004). However, although morphology predicted later counting skill, the relation between morphology and counting in Finnish was much weaker than what had been recently found in Chinese (Liu et al., 2016). The differences in morphology because of the differences in languages might have influenced the findings. Finnish is a highly inflectional language, and the morphology measure used in the present study tapped the inflections of nouns, verbs, and adjectives; however, compounding morphology is dominant in Chinese, and a study by Liu et al. (2016) had a morphology test that assessed the ability to produce new compound words by combining acquired morphemes. It can be proposed that learning sequences of number words in both languages (Finnish and Chinese) relies more on compounding than inflecting words. Thus, the role of compounding morphology as a predictor of later counting skill in Finnish, as well as in other alphabetic languages, should be studied in the future.

Verbal short-term memory was also associated with counting, which had been found in previous studies (e.g., Cowan et al., 2005; Koponen et al., 2016). Rote counting is a serial process requiring holding information in one's memory while articulating items and retrieving for the next; thus, a significant relation between verbal memory and counting skills was not surprising. According to Fazio (1994), counting requires auditory memory of the number terms, as well as auditory sequential memory of the correct order of number words. The auditory, sequential nature of counting is expected to be an obstacle for children with language impairment and who are showing clear difficulties in acquiring counting skills (Cowan et al., 2005; Fazio, 1994, 1996). However, the found relation was not very strong in the present study. This finding suggest that, among population-based sample, where the minority of children is expected to have severe deficits in verbal short-term memory, individual differences in counting skills at the beginning of first grade are mainly related to other factors than an ability to hold verbal information in correct order for a short time.

More surprisingly, phonological awareness at the age of 5 did not predict later counting skills. In previous studies, the role of phonological processing in the development of early number skills, especially in counting, has been strongly assumed. According to previous studies, number words are phonologically coded in memory (e.g., Simmons & Singleton, 2008; Stanescu-Cosson et al., 2000), and the weakness of phonological representations for number words in long-term memory likely makes it more difficult to retrieve them quickly and accurately (Simmons & Singleton, 2008). Lower correlations compared to previous studies (e.g., Koponen et al., 2007) might be because in previous studies, a strong correlation was found when counting, and phonological awareness was assessed concurrently; however, in the present study, phonological awareness was assessed at age 5 and counting skills at age 7. Krajewski and Schneider (2009) suggested that shifting from the string level to the unbreakable list level in counting requires phonological awareness to be able to separate number words from each other. It might be that the ability to recognize and process sounds and syllables in spoken words is more related to earlier phases of counting skill development. This hypothesis might also explain the generally low predictive power of measured language skills on counting. Language might play a stronger role in the early phases of development in counting skill, and when language skills are intact, they enable one to learn number words and their sequential order and move on to next developmental phase. This is not the case in children with language impairment who struggle with number sequence skills; language skills continue to be stronger predictors of counting skill after the early years (e.g., Cowan et al., 2005).

The second aim of the study was to examine whether the child's task-orientation and persistence or parents' educational level would explain the level of rote counting skill at the beginning of first grade. Children's task-orientation and persistence was significant, explaining 5% of the variance in counting. This finding was in line with our hypothesis and similar to those found in previous studies (Aunola et al., 2003; Hirvonen et al., 2012). In the study by Hirvonen et al. (2012), a high initial level of task-avoidant behaviour predicted less and slower improvement in math performance. Father's educational level had the strongest correlation with counting among all the variables and explained 10% of the variance in counting. This finding is in line with previous studies, where parents' educational levels were found to be related to counting and later arithmetic skill (Koponen et al., 2007). It has been suggested that parents learn something during schooling that influences the ways in which parents interact with their children in learning activities at home; or it is possible that parents' skills, values, and knowledge of the educational system also influence methods for educational practices at home and children's skills (for review see Eccles, 2005). Unfortunately, home numeracy activities were not assessed in the present study. Also, gender was significantly associated with counting skill, boys being a bit better than girls. In general, recent meta-analyses has not found gender differences in math (Hyde, 2016). However, at the subskill level, small or moderate effects of gender can be found.

Some limitations of the present study are worth mentioning. When generalising these findings across countries, the morphological structure of the language and specific features in the number word system should be considered. It should also be noticed that, because of a lack of standardised measures in Finland, we had only one measure of language comprehension, and it was not possible to create a latent factor, as was the case in other cognitive predictors. For this reason, language comprehension was not included in the models. However, its correlation with counting was not significant. Language should be measured using a wider battery of subskills in future.

Third, home numeracy was not included, and there is a need to examine this variable in future research. For example, the relation between parents' number talk about large sets of present objects and children's cardinal-

number knowledge has found to be significant, even after controlling for factors such as parents' socioeconomic status and other measures of parents' number and non-number talk (Gunderson & Levine, 2011). Moreover, children's innate magnitude representation systems, that is, exact (small numbers) and approximate number systems, were not assessed; although, they are suggested to be fundamental, especially for number concept development, but can be relevant also for more general development of counting skills.

Rote counting skill has been suggested to be a language-based skill requiring verbal short-term memory, but this hypothesis has rarely been examined explicitly. Thus, empirical evidence is missing. The present study indicated that verbal short-term memory, together with vocabulary, phonological awareness, and morphology, measured at the age of 5 explains very little of the variance in rote counting skill at the beginning of the first grade. A rethinking of the nature of rote counting skill and empirical research are important in the future because rote counting has been shown to have a strong predictive power on later reading and arithmetic fluency and is an important early predictor of academic achievement.

It should be also considered that the relation between language skills and rote counting might differ depending on the sample. Our additional analysis showed that language and memory, together with child's persistence and gender, explained twice the amount of the variance in counting among dyslexic children when compared to children without cognitive deficiencies. It seems that in a normal population, the associations are not as strong as among children with language impairment or dyslexia indicating that other factors are more important among 5- to 7-year old children with typical language development. However, it could be possible to find stronger relation of language and memory skills with counting skills among younger typically developing children. It could be assumed that requirements for verbal memory capacity would be stronger at the early developmental phase when children are practicing and learning rather arbitrary sequences of number words (Finnish number words below 20) in contrast to later developmental phase when children practice number words that in Finnish language start to be transparent with ten-base system (number words larger than 20). However, longitudinal studies following the early number skill development and their cognitive correlates is needed in order to exam this proposal. Moreover, cross-linguistic studies are needed as well because languages vary in how they grammatically mark number (e.g., in nouns, verbs, and so forth), and this has found to influence the development of early number word development (Almoammer et al., 2013) and, thus, number concept development.

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