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Explaining common variance shared by early numeracy and early literacy
Abstract

How can be explained that early literacy and numeracy share variance? We specifically tested whether the correlation between four early literacy skills (rhyming, letter knowledge, emergent writing, and orthographic knowledge) and simple sums (non-symbolic and story condition) reduced after taking into account preschool attention control, short-term memory, speed of processing, visual-spatial skills, vocabulary, and shared book reading. 228 Dutch native pre-schoolers (mean age 54.25; SD = 2.12 months) participated. The results revealed that 1) all literacy skills were related to sums (non-symbolic and story condition), 2) rhyming was the strongest predictor of non-symbolic sums, and letter knowledge of sums in story context, 3) visual-spatial skills explained part of the shared variance in the non-symbolic condition and visual-spatial skills, vocabulary and short-term memory explained part of the shared variance in sums in story context. Implications for the preschool curriculum and early interventions are discussed.

Published as:

Introduction

Young children with delays in early literacy skills are often also delayed in early math skills (Krajewski & Schneider, 2009) which might mean that early literacy and numeracy share variance (Simmons & Singleton, 2008). Early literacy skills typically encompass skills like phonological awareness, orthographic knowledge, letter knowledge, vocabulary, and emergent writing skills (Muter, Hulme, Snowling, & Stevenson, 2004; Whitehurst & Lonigan, 1998), and early numeracy, skills like subitizing, magnitude comparison, counting skills, number knowledge, ordinality, and cardinality (Halberda & Feigenson, 2008; Jordan, Kaplan, Nabors Ola’h, and Locuniak, 2006; Krajewski & Schneider, 2009). Early literacy skills are all rather strong predictors of how successful children will be in learning to decode (Muter, Hulme, Snowling, & Stevenson, 2004; Whitehurst & Lonigan, 1998). Early numeracy skills may facilitate insights in relations among numbers and enable solving simple sums (e.g., Dehaene, 2011; Halberda & Feigenson, 2008). Research revealed varying co-morbidity percentages among math and literacy; percentages range from 11 to 56 % for children with reading problems who also have arithmetic problems, and from 17 to 70 % in the case of children with arithmetic problems also having reading problems (Landerl & Moll, 2010).

This study aimed at highlighting the covariation between early literacy and numeracy whereby we targeted extraneous as well as intrinsic factors. From the literature appears for instance, that shared storybook reading benefits early literacy (e.g., Davidse, de Jong, Bus, Huijbregts, & Swaab, 2011; Mol & Bus, 2011; Sénéchal, Pagan, Lever, & Ouellette 2008) as well as early numeracy, which may be stimulated by storybook reading conversations about size, shape, and number (e.g., Anderson, Anderson, & Shapiro 2005; LeFevre et al., 2009; Van den Heuvel- Panhuizen & Van den Boogaard, 2008). Book reading may thus be a stimulus for both early literacy and numeracy. On the other hand, early literacy and numeracy may both appeal to the same cognitive abilities. For instance, visual-spatial skills may play an important role in both early literacy (e.g., Alloway et al., 2005; Brunswick, Martin, & Rippon, 2012; Bull, Espy, & Wiebe, 2008; Davidse et al., 2011) and numeracy skills (e.g., Assel, Landry, Swank, Smith, & Steelman, 2003; Bull et al., 2008; Duncan et al., 2007; Krajewski & Schneider, 2009; Murphy, Mazocco, Hanich, & Early, 2007; Rasmussen & Bisanz, 2005), and might explain why literacy and numeracy overlap. The current study explores
shared book reading and general cognitive skills such as visual-spatial skills as explanations for the co-variance among early literacy and early numeracy skills. For all selected factors, the literature reports significant correlations with literacy and numeracy (Simmons & Singleton, 2008).

Which Early Literacy Skills correlate with Math Skills?
Medium to large correlations among phonological awareness and numeracy skills are reported (e.g., Alloway et al., 2005; De Smedt, Taylor, Archibald, & Ansari, 2010; Kleemans, Peeters, Segers, & Verhoeven, 2012; Krajewski & Schneider, 2009; Simmons, Singleton, & Horne, 2008) although there are also null-results (see Purpura, Hume, Sims, & Lonigan, 2011). Phonological skills may be important for math development because certain arithmetical tasks appeal to the use of verbal codes (Dehaene, Piazza, Pinel, & Cohen, 2003; Simmons & Singleton, 2008). Consequently, phonological skills are related to verbal counting and arithmetic fact retrieval (i.e., small additions and subtractions), that rely on the verbal representation system, but phonological skills are not (or to a lesser extend) related to math tasks that rely on procedural strategies such as large subtractions, to untimed measures of general math achievement, or to non-symbolic math tasks like estimation (Dehaene & Cohen, 1995; De Smedt et al., 2010; Geary, Hoard, Nugent, & Bailey, 2012; Simmons & Singleton, 2008). In fact, the non-symbolic representation system of approximate quantities is assumed to be distinct from the verbal system and reveals lower correlations with phonological skills (Dehaene & Cohen, 1995).

The correlation of math development with print knowledge is mostly smaller than the correlation with phonological awareness (e.g., LeFevre et al., 2010; Purpura et al., 2011). Print knowledge refers to the ability to recognize print among other forms and basic print conventions such as the reading/spelling direction (i.e., knowing that for instance in Dutch, words are spelled and read from left to right) (Whitehurst & Lonigan, 1998). Print knowledge may be related to aspects of math development such as familiarity with written Arabic numbers (i.e., knowing that the symbol ‘3’ refers to an amount of three). Likewise, applying non-numerical symbols like + and – appeals to knowledge about the mathematical print system (i.e., knowing that + means adding and – means subtracting) (Purpura et al., 2011). Moreover, number and letter naming are highly correlated in preschool (Piasta, Purpura, & Wagner, 2010), probably because distinguishing letters from numbers is a first step in learning letters and numbers.

Effects of General Cognitive Abilities
Several general cognitive skills may explain why early numeracy and early literacy co-vary. Recognizing and memorizing visual forms is important in memorizing letters and orthographic features (Levy, Gong, Hessels, Evans, & Jared, 2006) as well as in comparing amounts and solving simple sums (Assel, Landry, Swank, Smith, & Steelman, 2003; Rasmussen & Bisanz, 2005), which may explain why visual-spatial processing relates to early literacy and numeracy. Visual-spatial skills relate to early literacy because early in the reading development, words are recognized based on their visual shape (Levy et al., 2006). Accordingly, numerical symbols (e.g., 4, 5) are also distinguished by means of their visual-shape (Dehaene, 2011). Moreover, when counting, young children often use fingers or other objects, or they visualize objects (i.e., make a mental representation of objects), processes that rely on visual-spatial skills (Assel et al., 2003; Rasmussen & Bisanz, 2005).

Vocabulary is correlated with all the literacy measures included in the current study (Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003) as well as with math development (Purpura et al., 2011; Seethaler, Fuchs, Fuchs, & Compton, 2012). Purpura et al. (2011) reported moderate to strong correlations among vocabulary and several early numeracy skills like verbal counting and story problems. Verbal counting appeals to the use of number words, thus to vocabulary. Moreover, a certain vocabulary is necessary for extracting relevant numerical information from a story (Fuchs et al., 2006), and when using words as more, less, big, small (Anderson, et al., 2005; LeFevre et al., 2009; Van den Heuvel-Panhuizen & Van den Boogaard, 2008). Vocabulary growth is moderately to strongly related to the development of phonological awareness: The more extended children's vocabulary, the better young children perform on phonological awareness tasks (Metsala, 1999).

Likewise, the speed with which human infants process information (Weiler, Forbes, Kirkwood, & Weber, 2003), is found to relate to early literacy (e.g., Furnes & Samuelsson, 2011; Lewis et al., 2011) as well as to early numeracy and further math development (Cirino, 2011; Geary, 2011). Children delayed in acquiring early numeracy or literacy skills often have processing speed needs, as becomes evident from difficulty in performing simple cognitive tasks fluently and automatically (Weiler et al., 2003).

Another plausible hypothesis is that executive skills such as short-term memory and attention control (Davidson, Amso, Anderson, & Diamond, 2006;
Explaining common variance shared by early numeracy and early literacy

Chapter 3

Explaining common variance shared by early numeracy and early literacy

Diamond & Lee, 2011) explain co-variation as both affect early numeracy (e.g., Espy et al., 2004; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009) and early literacy skills (e.g., Davidse et al., 2011). Children with lags in executive skills run the risk of missing beneficial effects of essential experiences, the result being that children may lag behind in early literacy (Kegel & Bus, 2013) and early numeracy skills (Diamond & Lee, 2011). The working memory component of EF (Diamond, 2013) enables holding information in mind (such as the number of dots in a number comparison task), and inhibitory control is needed to repress the impulse to respond to the most salient aspect (such as size of objects or configuration) (Blair & Razza, 2007). Without these skills children may not be successful in solving simple tasks thereby acquiring new skills.

If these domain-general factors (visual-spatial skills, vocabulary, speed of processing and EF) affect academic learning from an early age, control for those factors may weaken the correlation between early literacy and early numeracy skills (Simmons & Singleton, 2008). There is indeed some evidence of reduced relations among early numeracy and literacy due to these general abilities. For instance in the study of Krajewski and Schneider (2009), the significant relation \( r = .51 \) between phonological awareness and early numeracy skills like comparing magnitudes (i.e., knowing that five is more than three) and insights in relations among numbers (i.e., the difference between two numbers is another number), became non-significant after controlling for significant effects of visual-spatial skills. Likewise after controlling for working memory, phonological awareness was no longer significantly related to counting, adding and subtracting up to 10 (Alloway et al., 2005). On the other hand, not all relevant studies reveal the same results: Kleemans et al. (2012) found that after controlling for working memory and visual-spatial skills, phonological skills still accounted for variation in a composite measure of early numeracy. The inconsistency in outcomes may be due to the fact that Alloway et al. (2005) controlled for external factors such as maternal education and number of years in preschool, whereas Kleemans et al. (2012) did not take background variables into account that may affect early literacy and numeracy.

In sum, the common variance shared by early numeracy and literacy may reduce after controlling for effects of general abilities (Simmons & Singleton, 2008). In other words, general abilities that relate to both early numeracy and early literacy may thus explain why numeracy and literacy co-vary substantially.

Effects of Home Activities

Next to general abilities, shared book reading relates to both early numeracy and early literacy (e.g., Lefebvre, Trudeau, & Sutton, 2011; Mol, Bus & de Jong, 2009) and consequently may reduce the common variance shared by early numeracy and literacy. Letter knowledge (Mol et al., 2009) and phonological awareness (measured with rhyming, initial consonant comparison, syllable segmentation, and syllable deletion) for instance can be enhanced by shared book reading (Lefebvre et al., 2011). Similarly, mathematical talk and mathematical thinking is stimulated by shared storybook reading (Anderson et al., 2005; Van den Heuvel-Panhuizen & Van den Boogaard, 2008). A coding scheme was used which arranged utterances by the child for instance by number-related utterances such as resultative counting (i.e., mentioning/understanding that the final number represents the total amount) and using ordinal numbers (Van den Heuvel-Panhuizen & Van den Boogaard, 2008). Results are based on the number of utterances assessed in each domain. Mathematical talk involves using words as big or small (size), bigger than (when comparing objects), how long (referring to length or time), lots and tons (approximation), and the ball is round (referring to shape). Anderson et al. (2005) found that the amount of mathematical talk differed among storybooks and families. For eliciting mathematical thinking, however, it does not matter whether a storybook is written with the specific purpose of mathematical instruction or not (Van den Heuvel-Panhuizen & Van den Boogaard, 2008). LeFevre et al. (2009) also reported direct effects on formal mathematics: The more storybook reading the better children performed on simple addition sums.

In all, by means of shared storybook reading, using a variety of storybooks, the development of early numeracy skills as well as literacy skills can be supported. In other words, the relation between early numeracy and literacy might weaken when controlling for shared storybook reading.

Present Study

In sum, there is evidence that the co-variance among early numeracy and literacy skills results from general cognitive processes or experiences that are assumed to affect both (Geary et al., 2012; Simmons & Singleton, 2008). Despite the need of simultaneous control of factors that influence both (Geary et al., 2012), most studies testing co-variation of early literacy and math development did not consider the role of book reading activities, EF skills, visual-spatial skills, speed
of processing, and vocabulary. The main goal of the current study was therefore testing whether these variables may explain unique co-variance among early numeracy (simple sums) and early literacy. We also test which variables are the most stable and strong indicators for a variety of early literacy and numeracy skills (e.g., Krajewski & Schneider, 2009; LeFevre et al., 2010; Purpura et al., 2011; Simmons, Singleton, & Horne, 2008). By controlling for all other potential indicators we estimate the unique variance for each factor measured in this study. We used rhyming, letter knowledge, orthographic knowledge, and emergent writing as indicators of early literacy and simple addition and subtraction sums in a non-symbolic and in a story context as indicators of early numeracy. The study was conducted among pre-schoolers to specify which skills in particular need attention in preparation of instruction in first grade (Duncan et al., 2007) and how supportive literacy experiences are for math experiences and vice versa.

Method

Participants

228 Dutch native pre-schoolers (117 boys and 111 girls) with a mean age of 54.25 (SD = 2.12 months) participated in the study. The sample was recruited from 22 randomly selected schools in the Western part of the Netherlands. The preschool curriculum in the Netherlands involving four-year-olds is not yet focused on emergent literacy and numeracy. The schools were attended by Dutch-speaking children with a low to middle socioeconomic background. The mainstream of parents had a degree in intermediate or higher vocational education (58.10 % of the mothers and 54.40 % of the fathers). Of the mothers, 31.40 % only finished primary or secondary school, compared to 29.00 % of the fathers. 10.50 % of the mothers and 16.60 % of the fathers had a university degree. All parents gave informed consent for participation.

Instruments

Early Literacy Skills

Letter knowledge. On a computer screen, children were shown in succession eight uppercase letters (S, M, K, P, R, O, V, A) and three lower case letters, insofar as lower case form differed from the uppercase form (m, r, a). Each letter was visible during 4 s. Children were instructed to give the name or sound of each letter as soon as possible. The score equaled the number of correct responses (max score is 11). Alpha reliability equaled .90.

Early Numeracy Skills

Addition and subtraction sums: Non-symbolic and story context condition. This task was adapted from Jordan et al., 2006. In the non-symbolic condition, children were able to use material (checkers) to solve the sums. The experimenter said for example: “Look, I have two stones. Now I’m covering them. Look carefully, I’m adding one stone. How many stones do I have now? Show it to me by using your stones and then tell me the number.” The addition as well as the subtraction sums had one practice item where the experimenter

Rhyming. On a computer screen one picture appeared (for example a picture of a hand), and simultaneously the question: “Which word rhymes with hand [Dutch word for hand]?” is read aloud by the computer. Next three pictures appeared in succession and simultaneously the name of the object was read aloud (for example, kast, mand, vaas [cupboard, basket, vase]). The child had to name or point to the rhyming word (in this example mand [basket]). One practice trial and 10 test trials were presented. The score equaled the number of correct responses (max score is 10). Alpha reliability equaled .84.

Emergent writing. Children were asked to write down their proper name and the words mama, fire, cheese, wheel, and boot. The writings were scored based on a scale ranging from 0 (scribble produced by scratching) to 13 (conventional spelling); see Levin, Both-de Vries, Aram, & Bus (2005) for a detailed description. The writing scores were summed, resulting in a maximum score of 78. Alpha reliability equaled .90.

Orthographic knowledge. This task was adapted from Levy et al. (2006). Children had to recognize the correct orthography among pairs consisting of a correctly spelled word and the same word containing a violating of a spelling convention. A total of 12 spelling conventions were tested: A scribble, spacing in the word, a word written upside down, one of the letters replaced by a number, a picture instead of a written word, only vowels, only consonants, letter-like characters, a word written backwards, the use of capitals in the word, repeating the first letter of the word (e.g., sss), and violation of linearity. The stimuli pairs appeared on a computer screen, one at a time. The child was asked to point to the correctly spelled word. After responding, the next trial was presented. This task consisted of a total of 87 items (and 2 practice items). Alpha reliability equaled .80. The score equaled the number of correct responses (maximum score was 87). Alpha reliability equaled .84.
corrected the child if needed. A total of four addition (2 + 1; 4 + 3; 2 + 4; 3 + 2) and four subtraction sums (3–1; 7–3; 5–2; 6–4) were used.

In the story context condition, exactly the same sums were done, but this time in a story context. Children were not allowed to use the checkers to solve the sums. The experimenter asked for example: “Mary has six bananas, Joe takes away four bananas. How many bananas does Mary have now?”

Control Variables

**Book-cover recognition.** A storybook-cover recognition task was used as indicator of book exposure experiences across a variety of situations (library, school, and home) (Davidse et al., 2011). Picture storybooks were selected based on top 100 sales lists from the Stichting Collectieve Propaganda van het Nederlandse Boek (CPNB) [Collective Promotion for the Dutch Book] CPNB, 2006), and library lending numbers from 1999 to 2006 (picture storybooks that were in the top 100 most often borrowed) in the Netherlands. Books that were on both lists were included, resulting in 41 items that differed in familiarity. On a computer screen, children saw covers of picture storybooks one at a time. Per cover, the experimenter asked the child three questions: “Who is this/who are these?”; “What is the name of the story?”; and “Can you tell what the story is about?” Based on these answers, the experimenter coded whether a child was acquainted with the story book or not. The maximum possible score was 41. For example, when a child replied “frog” on seeing the cover of Kikker en het Vogeltje [Frog and the Birdsong], but the child could not tell anything about the story, or the story that was told did not match with the one in the book, it was assumed that the child was not acquainted with the book. Frog is a highly merchandized character and just knowing the main character’s proper name did not establish conclusive proof of knowing the story. Alpha reliability equaled .67.

**Executive skills: Short-term memory.** The Digit Span Forwards of the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983) was used as indicator of short-term memory. Numbers needed to be repeated in exactly the same order. The test started with one practice item including two numbers similar to the first level and increased with one number every next level (three items per level). The test consisted of 19 items and was discontinued if a child made an error in two consecutive items of the same length. The score equaled the number of correct responses.

Executive skills: Attention control. For attention control three subtests of the computerized Amsterdam Neuropsychological Tasks [Amsterdamse Neuropsychologische Taken; De Sonneville, 2005] were applied. In the GONOOGO task, two different abstract figures appeared randomly on the computer screen during about 2 min. Clicking was only allowed when one of the two figures appeared. In the Sustained Attention task, during about 10 min animals appeared in a window of a house (one at a time). Children were allowed to click, but only when a cat was visible. In the Memory Search Object task level 1, four different animals appeared in the windows of a house. Clicking was only allowed when one of the four animals was a mouse. The task took about 2 min. Accuracy and response time were automatically registered. Total score per task was the number of correct responses minus the number of false alarms and missing items (items where a child erroneously did not click). Confirmatory factor analysis on the three tests of attention control revealed one factor, explaining 64.07% of the variance with factor loadings of .84, .85 and .70, respectively (Tabachnick & Fidell, 2007), therefore this composite measure was used.

**Visual-spatial skills.** The standardized subtest Patterns of the Snijders-Oomen Nonverbal Intelligence test (SON) (Tellegen, Winkel, Wijnberg-Williams, & Laros, 1998) was selected as indicator of visual-spatial skills: Copying abstract figures of increasing complexity while they remained present.

**Speed of processing.** The subtest picture naming of the Rapid Automatized Naming test (Van den Bos, Lutje Spelberg, & Ruizeveld-de Winter, 2008) was used. As quickly as possible, children had to name pictures of a bike, a duck, a tree, pair of scissors, and a chair that all appeared repeatedly on a sheet, randomly divided in 5 rows. The response time in milliseconds per item was calculated by diving the total response time by the number of named pictures (total of pictures minus omissions). Hardly any errors were made, therefore errors were not taken into account (Van den Bos et al., 2008).

**Vocabulary.** The Dutch version of the PPVT-III, the Peabody Picture Vocabulary Test-III-NL (Schlichting, 2005), was used as an indicator of receptive vocabulary.

Participants’ scores were the number of correct items.
Results

Correlations
In Table 3.1 the descriptive statistics for all measures are displayed. All literacy variables correlated significantly with addition and subtraction sums, non-symbolic and in story context (see Table 3.2). Rhyming correlated with sums in story context ($r = .34$) and non-symbolic sums ($r = .32$). Letter knowledge was the strongest literacy correlate of sums in story context ($r = .39$). The control variables short-term memory, visual-spatial skills, attention control, and vocabulary correlated significantly with both types of sums and with all four literacy measures. Speed of processing correlated with both types of sums and with letter knowledge, rhyming, and emergent writing, but not with orthographic knowledge. Shared storybook reading correlated significantly with all four literacy measures and with sums in the non-symbolic and story context. In all, this implies a substantial overlap among achievement in early numeracy and literacy.

Table 3.1
Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Min</th>
<th>Max</th>
<th>mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonsymbolic sums (percentage correct)</td>
<td>0</td>
<td>100</td>
<td>40.82</td>
<td>20.23</td>
</tr>
<tr>
<td>Sums in story context (percentage correct)</td>
<td>0</td>
<td>100</td>
<td>28.43</td>
<td>19.92</td>
</tr>
<tr>
<td>Rhyming</td>
<td>1</td>
<td>10</td>
<td>7</td>
<td>2.92</td>
</tr>
<tr>
<td>Letter knowledge</td>
<td>0</td>
<td>10</td>
<td>2.73</td>
<td>3.18</td>
</tr>
<tr>
<td>Orthographic knowledge</td>
<td>27</td>
<td>86</td>
<td>51.39</td>
<td>11.15</td>
</tr>
<tr>
<td>Emergent writing</td>
<td>10</td>
<td>71</td>
<td>42.93</td>
<td>14.11</td>
</tr>
<tr>
<td>Shared storybook reading</td>
<td>0</td>
<td>8</td>
<td>2.67</td>
<td>2.33</td>
</tr>
<tr>
<td>Short-term memory</td>
<td>0</td>
<td>11</td>
<td>6.50</td>
<td>1.93</td>
</tr>
<tr>
<td>Attention control (factor score)</td>
<td>-3</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Speed of processing (milliseconds)</td>
<td>45000</td>
<td>422500</td>
<td>105608.41</td>
<td>40983.30</td>
</tr>
<tr>
<td>Visual-spatial skills</td>
<td>5</td>
<td>13</td>
<td>9.03</td>
<td>1.35</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>33</td>
<td>105</td>
<td>66.28</td>
<td>11.52</td>
</tr>
</tbody>
</table>

Regression Analyses
First a series of hierarchical regression analyses was carried out to test whether rhyming, letter knowledge, orthographic knowledge, and emergent writing
explaining common variance shared by early numeracy and early literacy

In the next step of the regression, control variables were entered to test whether effects of literacy skills reduced after controlling for preschool regulatory skills (short-term memory and attention control), visual-spatial skills, speed of processing, vocabulary, and shared storybook reading. A reduction of the correlation with letter knowledge to non-significance means that the substantial co-variance among early literacy and numeracy can be explained by significant effects of one or more control variables (see Table 3.3). Effects of control variables indicate unique variance given that we entered all control variables simultaneously. When orthographic knowledge was the literacy predictor, speed of processing was not included as control variable since it did not correlate significantly with orthographic knowledge.

### Non-Symbolic Sums

All four literacy tasks uniquely related to non-symbolic sums (see Tables 3.3, 3.4). Rhyming was the strongest correlate among the literacy skills (see Tables 3.3, 3.4). The effects of all literacy skills substantially reduced after preschool short-term memory, attention control, visual-spatial skills, speed of processing, vocabulary and shared storybook reading were taken into account (see Tables 3.2, 3.3). Only rhyming remained a significant predictor after entering the control variables. Visual-spatial ability was the only significant predictor among the control variables, meaning that this variable explained unique variance in the overlap between literacy and numeracy.

### Sums in Story Context

The results revealed that all four literacy tasks uniquely predicted sums in story context (see Tables 3.5, 3.6). Letter knowledge was the strongest correlate among the literacy skills, followed by rhyming (see Tables 3.4, 3.5). The effects of the literacy skills significantly reduced after preschool short-term memory, attention control, visual-spatial skills, speed of processing, vocabulary and shared storybook reading were taken into account (see Tables 3.5, 3.6). Letter knowledge continued to be a significant predictor, whereas the effects of rhyming, emergent writing and orthographic knowledge reduced to non-significance. Of all control variables, visual-spatial skills and vocabulary were significant predictors and short-term memory was a marginally significant predictor (with the exception that visual-spatial skills did not significantly relate to sums in story context when emergent writing was a predictor; \( p = .08 \)).

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### Table 3.3
Predicting nonsymbolic sums with rhyming and letter knowledge

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1 (β-values)</th>
<th>Model 2 (β-values)</th>
<th>Variable</th>
<th>Model 1 (β-values)</th>
<th>Model 2 (β-values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhyming</td>
<td>.32***</td>
<td>.22*</td>
<td>Letter knowledge</td>
<td>.24***</td>
<td>.10</td>
</tr>
<tr>
<td>Shared storybook reading</td>
<td>.03</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-term memory</td>
<td>.08</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention control</td>
<td>.02</td>
<td>.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of processing</td>
<td>-.09</td>
<td>-.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual-spatial skills</td>
<td>.21**</td>
<td>.23**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary</td>
<td>-.07</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.10***</td>
<td>.16***</td>
<td>( R^2 )</td>
<td>.06***</td>
<td>.15***</td>
</tr>
<tr>
<td>( ΔR^2 )</td>
<td>.06*</td>
<td>.09**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. * \( p < .05 \); ** \( p < .01 \); *** \( p < .001 \).

### Table 3.4
Predicting nonsymbolic sums with emergent writing and orthographic knowledge

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1 (β-values)</th>
<th>Model 2 (β-values)</th>
<th>Variable</th>
<th>Model 1 (β-values)</th>
<th>Model 2 (β-values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergent writing</td>
<td>.21**</td>
<td>.02</td>
<td>Orthographic knowledge</td>
<td>.17*</td>
<td>.05</td>
</tr>
<tr>
<td>Shared storybook reading</td>
<td>.03</td>
<td>.03</td>
<td></td>
<td></td>
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<tr>
<td>Short-term memory</td>
<td>.10</td>
<td>.11</td>
<td></td>
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</tr>
<tr>
<td>Attention control</td>
<td>.08</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of processing</td>
<td>-.09</td>
<td>Not included(^a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual-spatial skills</td>
<td>.23**</td>
<td>.24**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary</td>
<td>.02</td>
<td>.006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.04**</td>
<td>.13***</td>
<td>( R^2 )</td>
<td>.03*</td>
<td>.13***</td>
</tr>
<tr>
<td>( ΔR^2 )</td>
<td>.08**</td>
<td>.10***</td>
<td></td>
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</tbody>
</table>

Note. * \( p < .05 \); ** \( p < .01 \); *** \( p < .001 \); a. did not correlate with orthographic knowledge.
Discussion

Similar to previous research, the present study shows that early literacy skills co-vary with early math development (e.g., De Smedt et al., 2010; Krajewski & Schneider, 2009; Purpura et al., 2011). Correlations in the current study were low to moderate ranging from .18 for non-symbolic sums and orthographic knowledge to .39 for sums in story context and letter knowledge. After taking effects of all control variables into account some correlations between literacy and numeracy remained significant, which indicates that similar cognitive processes are active or that other not measured skills might explain overlap. Letter knowledge remained a significant predictor of sums in story context and rhyming of non-symbolic sums, explaining 6.25 % and 4.84 % of the variance, respectively (Alloway et al., 2005; DeSmedt, Taylor, Archibald, & Ansari, 2010; Piasta et al., 2010; Simmons et al., 2008). Both literacy and numeracy skills may share ease of manipulating verbal codes as can be derived from the study by Dehaene et al. (2003) showing brain activity in the same cortical regions. In so far overlap can be explained as the result of the in the current study measured cognitive and language factors, visual-spatial skills explained most co-variance. These skills partly or completely explain the co-variance between solving sums and familiarity with written forms as appears from the results of the regression analyses. At a young age when letters and word forms are not yet stored in long-term memory, children may heavily rely on visual-spatial representations when holding characteristics of written forms in mind for a short period (Bull et al., 2008), and words are mainly distinguished by means of their visual shape (Levy et al., 2006). Moreover, visual-spatial skills play an important role early in math development. The inborn ability to immediately see amounts up to four without counting (subitizing) may for instance be associated with cerebral circuits of our visual-system (Dehaene, 2011). When deciding whether two digits are the same (i.e., 4 and 5) processing the visual shape as well as linking numbers to quantities is essential (Dehaene, 2011). When linking numbers to quantities, visual-spatial skills enable a visual mental representation of numbers, which helps by deciding what is more (i.e., 4 or 5) (Krajewski & Schneider, 2009). It seems plausible that letters and numbers can more easily be distinguished and remembered by means of their shape, when visual-spatial skills are better developed (Shatil, Share, & Levin, 2000). Moreover, the weak relationship between rhyming and visual-spatial skills seems a plausible finding, because rhyming appeals less than

<table>
<thead>
<tr>
<th>Table 3.5</th>
<th>Predicting sums in story context with rhyming and letter knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Model 1 (β-values)</td>
</tr>
<tr>
<td>Rhyming</td>
<td>.33*** .09</td>
</tr>
<tr>
<td>Shared storybook reading</td>
<td>.01</td>
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<tr>
<td>Attention control</td>
<td>.04</td>
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<tr>
<td>Visual-spatial skills</td>
<td>.15*</td>
</tr>
<tr>
<td>R²</td>
<td>.11*** .20***</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001; † p = .054; ‡ p = .06

<table>
<thead>
<tr>
<th>Table 3.6</th>
<th>Predicting sums in story context with emergent writing and orthographic knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Model 1 (β-values)</td>
</tr>
<tr>
<td>Emergent writing</td>
<td>.27*** .09</td>
</tr>
<tr>
<td>Shared storybook reading</td>
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</tr>
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<td>Visual-spatial skills</td>
<td>.11</td>
</tr>
<tr>
<td>R²</td>
<td>.07*** .16***</td>
</tr>
</tbody>
</table>

Note. * p < .05; ** p < .01; *** p < .001; † p = .06; a. did not correlate with orthographic knowledge.
emergent writing, orthographic and letter knowledge to the ability to recognize written forms.

Only when predicting sums in story context, vocabulary in addition to visual-spatial skills explains co-variance among literacy and numeracy (cf. Purpura et al., 2011; Seethaler et al., 2012). Extracting relevant numerical information from a story appeals to children’s vocabulary (Fuchs et al., 2006). Vocabulary did not explain co-variance in the non-symbolic condition as these sums appeal to a lesser extent to verbal abilities than do sums in a story context (Simmons & Singleton, 2008).

Pre-schoolers often face novel tasks that strongly appeal to short-term memory capacities (Alloway et al., 2005; Bull et al., 2008) which may explain why short-term memory also explains some co-variance albeit only when sums are presented in story context. Effects were only marginally significant. The differential effect of short-term memory on non-symbolic sums versus sums in the story context may be due to differences in memory load among the two simple sum conditions (Rasmussen & Bisanz, 2005). In the story context, the children had to remember the story, whereas in the non-symbolic condition, children had the opportunity to use the checkers simultaneously with the experimenter, which may reduce memory load.

Finally, phonological awareness is in general stronger related to symbolic than to non-symbolic numeracy skills, probably because symbolic math skills rely more on verbal codes than do non-symbolic math skills (e.g., Dehaene et al., 2003; Geary et al., 2012; Simmons & Singleton, 2008). Surprisingly we found comparable correlations between rhyming and sums in the non-symbolic ($r = .32$) versus the story context condition ($r = .34$). The sums in both contexts had to be read aloud because of the young age of the children in the current study (4; 3–4; 9 years). Consequently both conditions contained anyhow a verbal component, which may explain comparable effects of rhyming in both conditions.

Although speed of processing, attention control, and shared storybook reading were all significantly correlated with all literacy and numeracy measures, these variables did not explain the variance shared by early literacy and numeracy. Although correlations with the other mediators were low to moderate, there was no evidence for multicollinearity as an explanation for these null-results. Shared book reading may not explain co-variance as it had rather specific effects on literacy development, as appeared from the marginally to low correlations with the sums compared to the much stronger correlations with the literacy skills. Attention control may be less influential than is short-term memory, when predicting early numeracy from several EF skills (Kroesbergen et al., 2009), and may gain impact later on when instruction becomes more formal. Unlike Furnes & Samuelsson (2011) and Cirino (2011), we found rather low correlations between speed of processing and early numeracy and literacy. Probably later on in math and reading development when skills become automatized, speed of processing becomes more important (Geary, 2011) and a source of covariation. An alternative hypothesis is that although a slow processing speed may be associated with delays in academic skills, it may not be a precursor of developmental delays in numeracy and literacy (Weiler et al., 2003).

### Conclusions

The commonly reported substantial co-variance among early literacy and early numeracy skills (Krajewski & Schneider, 2009) differs depending on the literacy skill and the numeracy skills measured. Of the literacy skills assessed, rhyming and letter knowledge correlated strongest with both types of sums. The common variance among early literacy, especially rhyming and letter knowledge, and sums can be partially explained by visual-spatial skills, short-term memory, and vocabulary. More specifically, significant effects of familiarity with the written form on sums became non-significant after taking visual-spatial skills into account. When sums were presented as stories, vocabulary and short-term memory (although only marginally) also reduced the common variance. Shared storybook reading and speed of processing did not explain any unique co-variance. To make understandable the more puzzling finding that attention control did not explain co-variance we hypothesize that the ability to stay attentive grows in importance when formal instruction has begun and time for learning new skills is limited.

Within the school curriculum it seems important that teachers are aware of the fact that delays in literacy often go together with delays in mathematics and vice versa. As certain early literacy and early numeracy skills co-vary, it is vital to test early numeracy skills when delays in early literacy are noticed and vice versa, early literacy skills should be monitored when delays in early numeracy are diagnosed. Moreover, interventions to enhance early literacy and numeracy skills should take into account that, as a result of the importance of domain-
general skills, training of early numeracy may support early literacy skills and, vice versa, training of early literacy may support early numeracy.

Limitations and Future Directions
Although phoneme deletion/detection might be a more sophisticated measure of phonological awareness, in the current study we used rhyming as indicator of phonological awareness because the phoneme detection task we applied appeared to show bottom effects for the 4-year olds in the current sample.

Because all skills were assessed at the same time-point we cannot make inferences about causal relationships; domain-general skills may explain variance among certain early numeracy and literacy skills, but when numeracy and literacy skills develop this might also affect the development of domain-general skills.

In the current study we found specific relations among rhyming, letter knowledge and sums. Relations among early literacy and other early numeracy skills like counting and estimation skills, and comparing amounts, can be assessed in future research in order to make more general assumptions regarding the co-variance among early numeracy and early literacy. Moreover, other general cognitive abilities can be assessed in order to expand current outcomes.

Intervention studies testing whether training of general skills also enhances numeracy and literacy skills, or whether training numeracy skills affects literacy development and vice versa, may lead to deeper insights in the co-variance among early numeracy and literacy skills.