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The contribution of executive function and social understanding to preschoolers' letter and math skills

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A B S T R A C T

The influence of executive function and social understanding on letter and math skills was examined in 129 3–5-year-olds. Tasks were administered to measure working memory, inhibition, social understanding, letter and math skills, and vocabulary. Using latent variable analyses, multiple models were compared in order to examine the influence of executive function and social understanding on participants' emerging academic skills. In the best-fitting model, working memory contributed to letter and math skills, over and above inhibition, social understanding, age, and vocabulary. Inhibition and social understanding did not uniquely contribute to letter and math skills, but significant relations were found among working memory, inhibition, and social understanding. Findings are discussed with respect to improving ways to examine the complex relations among preschoolers' executive function, social understanding, and school readiness skills.

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1. Introduction

Preschoolers' rudimentary academic skills, such as knowledge of letters and numbers, may be important for later school achievement because they create a strong motivational basis for future learning and facilitate the acquisition of further academic skills (Duncan et al., 2007; Pagani, Fitzpatrick, Archambault, & Janosz, 2010; Romano, Babchishin, Pagani, & Kohen, 2010). Empirical evidence for this claim comes from a growing body of research showing that early academic skills predict later school achievement (Lemelin et al., 2007; for a meta-analysis, see La Paro & Pianta, 2000). The majority of these studies have focused on young children's early literacy and math skills, often assessed in terms of identifying letters, words, numbers, counting, and shapes. For example, Duncan et al. (2007) analyzed six longitudinal data sets and found that preschoolers' math skills, such as their knowledge of numbers, were the most powerful predictors of later learning (average $\beta = .34$), followed by preliteracy skills, such as letter knowledge (average $\beta = .17$).

In addition to specific academic skills, recent research on school readiness and achievement has highlighted the importance of more domain-general cognitive skills (Blair, 2002; Bodrova & Leong, 2006). Executive function (EF) and, to a lesser extent, social understanding (SU) have received attention (Astington & Pelletier, 2005; Blair & Razza, 2007; Meltzer, 2007; Monette, Bigras, & Guay, 2011; Müller, Liebermann, Frye, & Zelazo, 2008; Welsh, Nix, Blair, Bierman, & Nelson, 2010). EF refers to an interrelated set of higher cognitive processes used in the control of action and thought (Garon, Bryson, & Smith, 2008; Zelazo & Müller, 2010), whereas SU (also referred to as social cognition or theory of mind) refers to the attribution of mental states to self and others that can be used to explain and to predict behavior (Astington, 1993; Carpendale & Lewis, 2006). Research suggests that a functional relation exists between EF and SU because (a) both undergo dramatic developmental changes during the preschool years, (b) both have neural underpinnings in the frontal lobes, and (c) impairments in both are implicated in various developmental disorders (Sabbagh, Bowman, Evraire, & Ito, 2008; Zelazo & Müller, 2010). Moreover, significant correlations between EF and SU tasks have been found both in typically (Moses & Tahiroglu, 2010) and in atypically (Pelicano, 2010) developing children, even after controlling for age, verbal ability, and IQ.

Whereas the relation between EF and SU in young children is well supported, the influence of each on children's school readiness is inconsistent across studies, especially in terms of their relative contribution to academic performance. Therefore, the goal of the present study was to examine the combined and unique influence of EF and SU on preschoolers' school readiness skills, specifically letter and math skills. We also sought to better explain variance in preschoolers' academic skills by using a latent variable approach.

1.1. *Executive function and school readiness*

Factor analytic studies suggest that EF in school-age children includes component processes of inhibition, working memory/updating, and shifting/flexibility (Garon et al., 2008; Huizinga, Dolan, & van der Molen, 2006; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). In these studies, inhibition refers to the ability to suppress prepotent responses, working memory to the ability to monitor and revise information, and shifting to the ability to switch between multiple tasks (Miyake et al., 2000). In preschoolers, these component processes may remain relatively undifferentiated (Zelazo & Müller, 2010). Recent latent variable studies involving a variety of EF tasks have tended to support a unitary EF factor structure in preschoolers (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011; Willoughby, Blair, Wirth, & Greenberg, 2010, 2012; Willoughby, Wirth, & Blair, 2012). However, in most of these studies, a two-factor EF structure consisting of working memory and inhibition still fit the data well, but was rejected in favor of a unitary structure on grounds of parsimony. Moreover, other latent variable studies have found that a two-component EF structure with working memory and inhibition as latent factors fit the data better than a unitary EF structure both in typically (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012) and atypically developing preschoolers (Schoemaker et al., 2012). Therefore, while the structure of EF remains open to investigation, the importance of working memory and inhibition processes is well recognized in preschoolers' EF development (Garon et al., 2008).

Composite measures of EF and different components of EF both have been linked to a variety of indicators of academic achievement in school-aged children (Best, Miller, & Naglieri, 2011; Visu-Petra, Cheie, Benga, & Miclea, 2011; Waber, Gerber, Turcios, Wagner, & Forbes, 2006; for a review, see Müller et al., 2008). Less research has been conducted with preschoolers and kindergartners, but there is increasing evidence that emerging academic skills are significantly correlated with composite measures and individual components of EF in younger children (Alloway et al., 2005; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Espy et al., 2004; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; Lan, Legare, Ponitz, Li, & Morrison, 2011). Furthermore, longitudinal studies suggest that EF facilitates the acquisition of emerging academic skills (Blair & Razza, 2007; Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; McClelland et al., 2007; Monette et al., 2011; NICHD, 2003; Welsh et al., 2010). For example, Welsh et al. (2010) found that growth in EF (i.e., working memory and attentional control) over the course of the prekindergarten year predicted (a) growth in literacy (identifying and saying letters and words) and math skills (numbers, quantities, counting, and simple arithmetic) between the beginning and end of the prekindergarten year and (b) kindergarten reading and math achievement after controlling for growth in literacy skills, math skills, and verbal ability.

Although research suggests that EF contributes to school readiness skills, findings concerning the relative contribution of different components of EF are inconsistent. There is evidence that individual differences in inhibition explain variance in preschoolers' emerging literacy and math skills concurrently as well as prospectively (Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007; NICHD, 2003). For example, Blair and Razza (2007) measured inhibition and shifting in preschoolers and again a year later in kindergarten, when their letter and math skills were also assessed (numbers, quantities, sizes, shapes, and basic arithmetic and graphic relations). After controlling for shifting, IQ, and verbal ability, inhibition uniquely predicted (a) concurrent letter knowledge in kindergarten and (b) both concurrent and prospective math knowledge in kindergarten. In addition, Espy et al. (2004) examined the relative contribution of inhibition, working memory, and shifting to preschoolers' math skills (subitizing, counting, and simple arithmetic). Both inhibition and working memory accounted for unique variance in math skills after controlling for age, language skills, and maternal education. However, after controlling for the other EF components as well, only inhibition accounted for a unique portion of variance in math skills, suggesting that inhibition is particularly important for early math skills.

Other researchers, however, have emphasized the importance of working memory for school readiness and achievement (Alloway et al., 2005; Gathercole & Alloway, 2008; Gathercole, Pickering, Knight, & Stegmann, 2004; Passolunghi, Vercelloni, & Schadee, 2007; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). In fact, there is some evidence that in older children, working memory is more important for school achievement than inhibition. Working memory has been found to explain a larger amount of variance in school achievement than inhibition (St. Clair-Thompson & Gathercole, 2006) and to be the only component of EF that uniquely predicted mathematical ability in school-age children over and above reading ability and other components of EF (Bull & Scerif, 2001; Swanson, 2006). In a similar vein, recent studies suggest that working memory, but not inhibition, in kindergarteners makes a unique contribution to academic skills (Bull et al., 2008; Lan et al., 2011; Monette et al., 2011). For example, Monette et al. (2011) found that kindergarteners' working memory, but not their inhibition or shifting, predicted their math achievement at the end of grade 1, even after controlling for earlier school readiness skills (colors, letters, numbers), age, maternal education, and family income. However, none of the EF components directly predicted reading and writing achievement at the end of grade 1.

Few studies have examined the relative contribution of shifting to preschoolers' school readiness, and most studies that have included measures of shifting have not shown significant relations to school readiness (Espy et al., 2004; Monette et al., 2011). One exception is a recent study by Vitiello, Greenfield, Munis, and George (2011) showing that teachers' ratings of preschoolers' attention and persistence mediated the relation between shifting and school readiness (colors, letters, numbers, sizes, object comparisons, and shapes) in preschoolers in Head Start classrooms. However, the zero-order correlation between shifting and school readiness was relatively small ($r = .19$, $p < .01$). Thus, shifting may have some influence on preschoolers' school readiness, but the influence seems to be small or indirect. Shifting may be a relatively indistinct component of EF among preschoolers, as suggested by recent latent variable studies of EF that do not identify a unique shifting component in preschoolers (Miller et al., 2012; Willoughby, Blair, et al., 2010, 2012) or elementary school children (Lee et al., 2012; Van der Ven et al., 2012). Overall, given existing evidence is inconsistent, the relative contribution of different EF components to early literacy and math skills as well as to school achievement merits further clarification.

1.2. Social understanding and school readiness

A milestone in the development of SU emerging around 4 years of age is false belief understanding, or comprehending that less-informed people may hold and act on beliefs that are not true (Astington, 1993; Carpendale & Lewis, 2006; Wellman, Cross, & Watson, 2001). In the classical task used to assess false belief understanding (Wimmer & Perner, 1983), children have to predict where a protagonist (Maxi) will search for an object that unbeknownst to him has been moved to a new location. Although children know where the object has been moved to, they need to realize that the protagonist will act on his false belief and search for the object in the original location. False belief understanding has been linked to language development (Milligan, Astington, & Dack, 2007), and children's language skills are important in forming interpersonal relationships that contribute to early academic success (Mashburn & Pianta, 2006).

Astington and Pelletier (2005) have suggested that SU, and false belief understanding in particular, is important for school achievement because it is associated with social maturity, collaborative learning ability, cognitive monitoring, narrative comprehension, and scientific thinking. They found that false belief understanding was related to reading ability and understanding of narrative; the latter, but not the former, relation remained significant after controlling for language competence. Similarly, Blair and Razza (2007) found that false belief understanding predicted 6-year-olds' letter knowledge after controlling for performance on EF tasks, IQ, and verbal ability (at age 5). Furthermore, Blair and Razza (2007) found a positive zero-order correlation between preschoolers' false belief understanding and math skills (numbers, sizes, shapes) in kindergarten, but the relation became insignificant after controlling for EF and effortful control. However, given the sparse evidence, it remains to be determined whether a functional relation exists between SU and emerging academic skills. Specifically, it is unclear whether SU accounts for unique variance in children's early letter and math skills because either no (Astington & Pelletier, 2005) or few (Blair & Razza, 2007) EF components have been accounted for in these studies.

1.3. Present study

The objective of the present study is to clarify the extent to which EF and SU contribute to letter and math skills in preschool children. As summarized, previous research has shown that both EF and SU are related to early letter and math skills. However, with one exception (Blair & Razza, 2007), previous research has not included as predictors both EF and SU. At the same time, several studies have shown that EF and SU (especially false belief understanding) are significantly correlated in preschool children (for a review, see Moses & Tahiroglu, 2010). As a consequence, the unique contribution of EF and SU to letter and math skills in preschoolers remains unclear. A further problem is that latent variable model comparisons are rarely used to assess these relations. Latent variable approaches have the advantages of (a) examining theory-driven, a priori relations between factors and (b) accounting for measurement error by extracting only the common variance shared by different tasks that are stipulated to measure the same latent factor (Bryant & Yarnold, 1994; Klem, 2000). With few exceptions (e.g., Bull et al., 2011; Lee et al., 2012; van der Sluis, de Jong, & van der Leij, 2007; Van der Ven et al., 2012; Willoughby, Blair, et al., 2010, 2012), latent variable model comparisons have not been used to evaluate the contributions of EF or SU to school readiness and academic skills. Accordingly, we wished to use this method to ascertain the relative contribution of different aspects of EF and SU to early letter and math skills. More broadly, the study should illuminate the relation between more general cognitive skills, such as EF and SU, and domain-specific academic skills.

2. Method

2.1. Participants

One hundred thirty-one children aged 3–5 years were recruited from daycare centers, from preschools, and through community advertisements in a metropolitan area of southwestern Canada. Two children were dropped from the sample because of concerns about major developmental delays. The final sample consisted of 55 3-year-olds, 64 4-year-olds, and 10 5-year-olds, for a total of 129 children (51 girls; M_{age} = 4.17 years, SD_{age} = 0.58 years, age range: 3.00 to 5.67 years). The majority (about 80%) of the sample was Caucasian and came from two-parent families (n = 113) with two or more children (n = 97). The median maternal and paternal education was some college or university education.

2.2. Procedure

Children were tested individually in two 45-min sessions. The order in which children completed the two sessions was randomly assigned, and intervals between test sessions were never longer than 2 weeks. A fixed task order within each session was chosen in order to separate tasks of similar cognitive demand and facilitate comparisons across tasks (Carlson & Moses, 2001). Two trained experimenters administered the tasks in the child's daycare center or preschool, or in a university laboratory setting. All sessions were videotaped, and children received two small gifts ($1 in value) for their participation.

2.3. Measures

2.3.1. Executive function

2.3.1.1. Working memory. Four measures of working memory were selected to predominately capture active rule maintenance. In the Backward Digit Span and Backward Word Span tasks (Davis & Pratt, 1995), children verbally repeated in reverse order sequences of single-digit, non-sequential numbers and single-syllable, non-semantically related words, respectively. Following a two-digit or word practice trial, children were given two trials each of two, three, and four digit or word lengths. The tasks ended when errors were made on both trials of a given length. A previous study (Miller et al., 2012) showed similar results when performance was measured in terms of number of correct trials or in terms of the highest digit or word length completed; the latter were used here.

The Boxes task (Hrabok, Kerns, & Müller, 2007) was a computerized self-ordered search task in which children had to find a jack-in-the-box while keeping in mind boxes they had already searched. Following a two-box practice session, children received two trials each of two, three, four, and five boxes. Once children found Jack in a particular box, Jack would not appear in that box for the rest of the trial. If children selected a box in which they had previously found Jack earlier in the trial, a search error was recorded. The task was discontinued when children made search errors on both trials of a given length. Performance was measured with a ratio of the number of correct searches (i.e., hits) to the number of total searches (i.e., hits plus errors) for completed three- and four-box trials. The two- and five-box trials were eliminated from the analysis because total errors were at floor (M = 0.26, SD = 0.57) and ceiling (M = 8.40, SD = 4.32) levels, respectively. A ratio was used because a significant number of children were not administered the four-box trials due to the discontinue rule.

The Preschool Continuous Performance Test (P-CPT; Kerns & McInerney, 2007) was a computerized task in which children pressed a computer button in response to the infrequent appearance of a target animal (i.e., a sheep) on a computer screen but had to refrain from responding to the frequent appearance of different non-target animals (e.g., horse, cow, dog). Each animal was paired with a corresponding animal sound. Following a short practice session, the task lasted 5 min and included 200 stimulus presentations of which 29 were targets. Working memory performance was measured with the number of omission errors (i.e., not responding to the target animal), indicating the number of times children failed to remember the rules (Miller et al., 2012; see also Egeland & Kovalik-Gran, 2010).

2.3.1.2. Inhibition. Four measures of inhibition were selected to predominantly capture the suppression of prepotent responses. First, inhibition was measured with the number of commission errors (i.e., pressing for a non-target animal) on the P-CPT, indicating the number of times children failed to inhibit an incorrect response. Commission errors as indicators of prepotent response inhibition have been shown to yield a more distinct latent component of inhibition than the use of a ratio of correct responses to total responses (Miller et al., 2012).

The Boy-Girl Stroop (Kerns & McInerney, 2007; adapted from Diamond, Kirkham, & Amso, 2002) was a computerized task in which children said "boy" when a cartoon picture of a girl appeared on a computer screen, and they said "girl" when a cartoon picture of a boy appeared on the computer screen. Following a short practice session, each type of picture appeared 10 times, never more than three times in succession. Two children were unable to correctly explain the rules after completing the task, and their performance indicated that they did not understand the task. Accordingly, their scores were excluded and treated as missing data. Score was the number of correctly labeled picture presentations, with self-corrections counted as incorrect.

The Tower of Hanoi task has been classified as a complex task requiring multiple EF components (Miyake et al., 2000), but previous research suggests that it is well-represented as a measure of inhibition in preschoolers (Miller et al., 2012; Wiebe et al., 2008). Here the Tower of Hanoi task (Kerns & McInerney, 2007; adapted from Welsh, 1991) was presented in a computerized form. Children were instructed to transfer three monkeys of graduated size from a starting position to a specified goal state (a) by moving only one monkey at a time and (b) without placing bigger monkeys on top of smaller monkeys. Following a short practice session, test trials progressively increased in one-move increments from a two-move trial to a six-move trial. A trial was considered correct if children completed it in the maximum number of moves allowed (i.e., 10 moves plus the trial length). The task was discontinued when children did not perform correctly on two consecutive trials. A previous study (Miller et al., 2012) showed similar results when performance was measured in terms of number of correct trials or in terms of a ratio of the total number of correct trials to the number of overall moves; the former was used here.

The Go/No-Go task (Kerns & McInerney, 2007) was a computerized task in which children pressed a computer button in response to the appearance of a target stimulus (e.g., a cartoon dog) on a computer screen, but had to refrain from responding to the appearance of a non-target stimulus (e.g., a cartoon koala). The task was divided into four blocks, a baseline block and three test blocks. The non-target animal did not appear during the baseline block, which helped to build a prepotent response to the target animal. For each successive test block, the role of target and non-target switched, with the target appearing 13 times and the non-target appearing 12 times over a period of 45 s. Number of commission errors (failing to inhibit an incorrect response) were assessed during the first test block only. Later test blocks were not included due to the possibility that they make strong demands on attention flexibility (Ozonoff, Strayer, McMahon, & Filloux, 1994).

2.3.2. Social understanding

Four SU tasks were administered, two False Belief (Unexpected Transfer) tasks and two Real-Apparent Emotion tasks. In the False Belief tasks (Wimmer & Perner, 1983; adapted from Carlson, Moses, & Breton, 2002), children watched a puppet transfer a toy from one container to another container, unbeknownst to the toy's owner (a second puppet). Children then were asked to choose the container in which the owner would look for the toy (test question), followed by two control questions about the current and original locations of the toy. Total number of correct answers to the test and control questions served as the performance measure.

In the Real-Apparent Emotion tasks (Harris, Donnelly, Guz, & Pitt-Watson, 1986), children heard two separate stories in which a protagonist's physical actions were in opposition to how he or she was actually feeling in order to (a) not upset a friend (Positive Emotion) and (b) trick a parent (Negative Emotion). Children then were asked to state both the protagonist's real emotion and the protagonist's apparent emotion (test questions), followed by two control questions that pertained to details of the story. Total number of correct answers to the test and control questions served as the performance measure.

2.3.3. School readiness

The Bracken School Readiness Assessment (BSRA; Bracken, 2002) was used to assess school readiness. The BSRA is a standardized measure of school readiness that is normed for 3–6 year-olds (Bracken, 2002; Panter, 2000). Previous versions of the BSRA have been shown to predict performance on the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R), to correlate highly with the Stanford-Binet-IV, and to outperform another school readiness measure, the Gesell Developmental Exam, in predicting academic achievement (Panter & Bracken, 2009). The assessment consisted of six subscales assessing knowledge of 11 common colors, 16 upper- and lower-case letters, 19 single- and two-digit numbers with counting, 12 sizes (e.g., tall), 10 object comparisons (e.g., longer), and 20 basic shapes. The experimenter stated each item, and children had to point to the corresponding picture from four or more alternatives. The majority of the subscales were designed to test early mathematical knowledge, with numbers and counting providing an index of arithmetic knowledge; distinguishing between objects in terms of size and shape provided an index of geometry knowledge (Bracken, 2002). A math aggregate score was created by summing knowledge of numbers/counting, sizes, object comparisons, and shapes (rs ranged from .50 to .58, all $ps < .001$). Knowledge of colors was dropped from the analyses due to ceiling effects (65% of children had a perfect score). Children's letter and math aggregate scores were used in the data analyses.

2.3.4. Verbal ability

Because of the high verbal demands of the BSRA, receptive vocabulary was assessed with the Peabody Picture Vocabulary Test-Third edition (PPVT-III; Dunn & Dunn, 1997). The PPVT-III is highly correlated with full-scale verbal intelligence measures such as the WPPSI-R (Carvajal, Parks, Logan, & Page, 1992) and the verbal subscale of the Stanford-Binet IV (Hodapp, 1993). The experimenter stated a word, and children had to point to the corresponding picture from four alternatives. The task ended when children made at least 8 errors on a set of 12 words. The performance index was the ceiling item minus total errors.

3. Results

3.1. Data preparation

To control for the influence of non-executive motor processes on the computerized EF tasks, we used regression analyses to factor out reaction time from the EF scores. However, controlling for reaction time yielded results similar to analyses with the raw data. Thus, for ease of interpretation, analyses were conducted with the raw data. In addition, preliminary screening of the P-CPT and Go/No-Go data revealed that a majority of children ($n = 107$, and $n = 74$, respectively) had extremely short response times (i.e., <150 ms) for at least one non-target stimulus directly following a target stimulus (average of 4.6% of P-CPT responses and average of 5.6% of Go/No-Go responses). A review of the video recordings led us to believe that these fast responses were the result of children who initiated a late response to a target stimulus or of children who held the computer button down longer than necessary, thereby recording a commission error when their performance suggested a correct response. Consequently, these 'fast response' commission errors were excluded from children's P-CPT and Go/No-Go scores because they did not accurately represent children's performance on these tasks.

All variables were screened for univariate and multivariate outliers, for skewness, and for kurtosis using the software package Predictive Analytics SoftWare Statistics 18.0. Five outliers were found for P-CPT commission errors and three outliers for the Boy-Girl Stroop. These outlier values were replaced with the highest/lowest remaining score ± 1 unit under the assumption that children's true scores were extreme on these tasks (Tabachnick & Fidell, 2007, p. 77). A review of the video recordings confirmed that these children were engaged but had difficulty with the particular task. No multivariate outliers appeared. P-CPT commission errors were positively skewed and leptokurtic (i.e., values ≥ 2). Attempts to correct for this departure from normality (e.g., logarithmic transformation) yielded results similar to analyses with the untransformed data. Therefore, for ease of interpretation, analyses were conducted with the untransformed data. All other variables had acceptable distributions with only minor departures from normality.

Table 1
Descriptive statistics for all manifest variables, age, and maternal education.

Variable: performance indicator	*N*	*M*	*SD*	Range	Skew. (*SE*)	Kurt. (*SE*)
Working memory						
Backward Digit Span: highest length	128	0.81	1.14	0–4	0.97 (.21)	−0.55 (.43)
Backward Word Span: highest length	125	1.14	1.25	0–4	0.59 (.22)	−0.92 (.43)
Boxes task: hits/total responses	120	0.73	0.13	0.50–1.00	0.56 (.22)	−0.37 (.44)
P-CPT: omission errors	119	7.80	6.39	0–24	0.70 (.22)	−0.54 (.44)
Inhibition						
P-CPT: commission errors	119	6.24	7.67	0–31	2.17 (.22)	4.10 (.44)
Boy-Girl Stroop: correct trials	118	15.86	3.46	5–20	−1.29 (.22)	1.52 (.44)
Tower of Hanoi: correct trials	125	2.46	1.52	0–5	−0.09 (.22)	−1.18 (.43)
Go/No-Go: commission errors	110	2.39	2.03	0–8	0.78 (.23)	−0.27 (.46)
Social understanding						
False Belief A: control + test questions	126	2.25	0.74	0–3	−0.81 (.22)	0.53 (.43)
False Belief B: control + test questions	127	2.13	0.79	0–3	−0.83 (.22)	0.59 (.43)
Positive Emotion: control + test questions	124	0.60	0.76	0–2	0.81 (.22)	−0.82 (.43)
Negative Emotion: control + test questions	125	1.16	0.72	0–2	−0.25 (.22)	−1.05 (.43)
Bracken School Readiness Assessment						
Letters subscale	126	8.12	5.62	0–16	−0.15 (.22)	−1.56 (.43)
Math aggregate subscale	125	35.21	13.14	6–59	−0.13 (.22)	−0.98 (.43)
Age in months	129	50.45	6.97	36.0–68.2	0.40 (.21)	−0.45 (.42)
PPVT-III: raw score	127	67.87	18.24	25–102	−0.23 (.22)	−0.69 (.43)
Maternal education	129	3.61	0.87	2–5	0.19 (.21)	−0.79 (.42)

Note. P-CPT = Preschool Continuous Performance Test; PPVT-III = Peabody Picture Vocabulary Test-Third edition.

3.2. *Descriptive statistics*

Table 1 displays descriptive statistics for all manifest variables. Girls performed significantly better than boys as indexed by commission errors on both the P-CPT and the Go/No-Go. No other sex differences appeared. Variations in task sample sizes were due to children's request to end a task or to their failure to perform a task. In total, 4.7% of the data were missing and handled with full information maximum likelihood estimation in Amos 18.0 (Arbuckle, 2009). Zero-order correlations among all manifest variables are presented in Table 2. For ease of interpretation, variables scored in terms of error responses (P-CPT omission errors, P-CPT commission errors, and Go/No-Go commission errors) were reverse scored. In most cases, stronger correlations were found among variables that shared a common latent process (i.e., working memory, inhibition, or SU). All variables were positively correlated with receptive vocabulary ($ps \leq .05$). With the exceptions of the Boxes task and the Boy-Girl Stroop, all variables also were positively correlated with age ($ps \leq .05$). Maternal education was not significantly correlated with any of the manifest variables and was not analyzed further.

3.3. *Statistical procedures*

To examine relations among EF, SU, and school readiness, latent variable models were created and then estimated using confirmatory factor analysis (CFA) and structural equation modeling (SEM). First, CFA was used to determine whether (a) latent working memory, inhibition, and SU factors could be identified in the data, (b) these latent factors were correlated, and (c) the manifest variables loaded onto their respective latent factors. Next, SEM was used to investigate direct and indirect relations (or paths) between latent factors and letter and math skills, over and above age and verbal ability.

Based on the covariance matrix of the manifest variables, Amos 18.0 (Arbuckle, 2009) was used to fit all CFA and SEM models with full information maximum likelihood estimation. Estimated means and intercepts were selected to account for missing data. To scale each model for estimation, a single manifest variable was fixed to load at 1.00 on each latent factor. For all estimated models, the error variances between both Backward Span tasks and between both False Belief tasks were correlated due to similarities in scaling and in method variance. All other error variances were uncorrelated. Model

Table 2
Zero-order correlations ($N = 129$).

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Backward Digit	–													
2. Backward Word	.78**	–												
3. Boxes hit ratio	.23*	.24*	–											
4. P-CPT om.	.38**	.50**	.19*	–										
5. P-CPT com.	.20*	.26**	.09	.28**	–									
6. Boy-Girl Stroop	.12	.26**	.19*	.15	.24*	–								
7. Tower of Hanoi	.23**	.27**	.24**	.22*	.35**	.17†	–							
8. Go/No-Go com.	.13	.15	.15	.24*	.39**	.31**	.23*	–						
9. False Belief A	.31**	.37**	.19*	.17†	.25**	.06	.21*	.17†	–					
10. False Belief B	.22*	.28**	.17†	.17†	.07	.22*	.30**	.12	.48**	–				
11. Positive Emotion	.23*	.35**	.09	.16†	.25**	.15	.13	.18†	.19*	.15†	–			
12. Negative Emotion	.33**	.32**	.08	.24*	.27**	.14	.20*	.05	.32**	.19*	.32**	–		
13. Letters	.46**	.54**	.28**	.36**	.19*	.23*	.34**	.12	.26**	.24**	.18*	.18*	–	
14. Math	.51**	.62**	.24**	.48**	.34**	.24**	.34**	.30**	.32**	.26**	.31**	.23**	.63**	–
Age in months	.48**	.52**	.09	.45**	.18*	.12	.35**	.22*	.28**	.33**	.30**	.42**	.39**	.55**
PPVT-III raw score	.46**	.48**	.18*	.29**	.35**	.22*	.39**	.30**	.43**	.35**	.42**	.44**	.48**	.70**
Maternal education	–.03	.06	.03	–.06	.05	.01	.02	.01	.14	.04	.06	.05	.12	.15†

Note. Variables 4, 5, and 8 are reverse scored to ease interpretation. P-CPT = Preschool Continuous Performance Test; om. = omission errors; com. = commission errors; Letters = Bracken School Readiness Assessment – Letters subscale; Math = Bracken School Readiness Assessment – Math aggregate; PPVT-III = Peabody Picture Vocabulary Test-Third edition.

† $p \leq .10$.

* $p \leq .05$.

** $p \leq .01$.

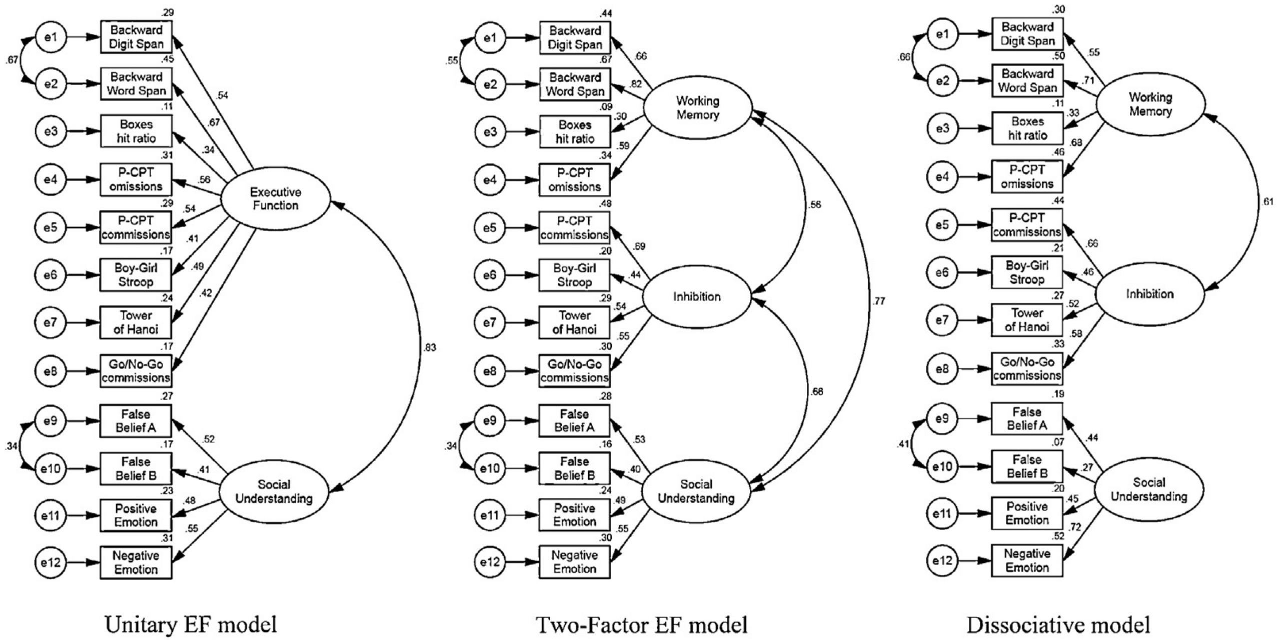

Fig. 1. Estimated confirmatory factor analysis models. Circles represent latent factors, and rectangles represent manifest variables. The numbers next to the curved, double-headed arrows are the latent factor correlations. The numbers above the straight, single-headed arrows are the standardized parameter estimates. The squared multiple correlation values are above each manifest variable. P-CPT = Preschool Continuous Performance Test.

fit was evaluated using the chi-square goodness-of-fit test (Loehlin, 1998), chi-square/degrees-of-freedom (Bollen, 1989), the comparative fit index (CFI; Bentler, 1990), and the root mean square error of approximation (RMSEA; Steiger, 1990). Good model fit was associated with a low chi-square value, chi-square/degrees-of-freedom ≤ 3, a CFI $\geq .95$, and a RMSEA $\leq .06$ (Kline, 2005). Nested model comparisons were evaluated using the chi-square difference test. If two nested models fit the observed data equally well, the simpler model was preferred when comparison to a more complex model did not differ significantly at $p \leq .05$ (Bollen, 1989). Model comparisons also were evaluated using Akaike's information criterion (AIC; Bozdogan, 2000), which penalizes more complex models by accounting for the number of estimated model parameters. Lower AIC values represented better model fit (Kline, 2005).

3.4. *Confirmatory factor analysis*

Based on previous research, we expected (a) a positive correlation between separate working memory and inhibition factors (Carlson et al., 2002; Miller et al., 2012) and (b) a positive correlation between EF and SU (Carlson et al., 2002; Hala, Hug, & Henderson, 2003; Moses & Tahiroglu, 2010). Because preschoolers' EF structure is controversial, we first examined whether EF was best represented in terms of a unitary-factor structure or in terms of a two-factor structure consisting of working memory and inhibition. Next, we tested whether constraining the relation between EF and SU resulted in a better model than leaving the relation unconstrained. Overall, we tested three CFA models: (a) a Unitary EF model, in which all EF indicators loaded on a single EF factor and the SU indicators loaded on a single SU factor, (b) a Two-Factor EF model, in which the EF indicators loaded on either a working memory or an inhibition factor and the SU indicators loaded on a single SU factor, and (c) a Dissociative model, in which the correlation between EF and SU was constrained to assume that EF and SU were unrelated (see Fig. 1).

As shown in Table 3, the overall fit between the observed data and both the Unitary EF and the Two-Factor EF models was good, whereas the overall fit between the Dissociative model and the observed data ranged from adequate to less than adequate. Next, model comparisons were conducted in order to determine the best-fitting model. The chi-square difference between models indicated that the Two-Factor EF model fit the observed data significantly better than both the Unitary EF model and

Table 3
Model fit indices for confirmatory factor analysis models and structural equation models ($N = 129$).

Model	*df*	χ^2 [a]	χ^2/df [b]	CFI [c]	RMSEA [d]	AIC [e]	Model comparison	Δdf	$\Delta\chi^2$ [f]
CFA									
Unitary EF (EF & social understanding)	51	67.76	1.33	0.94	.051	145.76	–	–	–
Two-Factor EF (working memory, inhibition, & social understanding)	49	51.23	1.05	0.99	.019	133.23	Unitary EF vs. *Two-factor EF*	2	16.53***
Dissociative (working memory & inhibition)	51	88.89***	1.74	0.87	.076	166.89	*Two-factor EF* vs. Dissociative	2	37.66***
SEM									
1. Working memory, inhibition, & social understanding	86	85.54	1.00	1.00	.000	217.54	–	–	–
2. Working memory	90	95.81	1.07	0.99	.022	219.81	*Model 1* vs. Model 2	4	10.27*
3. Inhibition [g]	90	107.92	1.20	0.97	.039	231.92	*Model 1* vs. Model 3	4	22.38***
4. Social understanding	90	98.78	1.10	0.99	.028	222.78	*Model 1* vs. Model 4	4	13.24*

Note. The preferred models are italicized. CFA = confirmatory factor analysis; EF = executive function; SEM = structural equation model.

[a] Lower values indicated better model fit; values with $p \leq .05$ indicated that the model did not fit the data better than a saturated model.

[b] Values ≤ 3 indicated good model fit.

[c] Values $\geq .95$ indicated good model fit; values $\geq .90$ indicated adequate model fit.

[d] Values $\leq .06$ indicated good model fit; values $\leq .08$ indicated adequate model fit.

[e] When comparing models, lower values indicated the better model fit.

[f] Values with $p \leq .05$ indicated that the simpler model was significantly less satisfactory than the comparatively complex model.

[g] Not positive definite covariance matrix.

* $p \leq .05$.

*** $p \leq .001$.

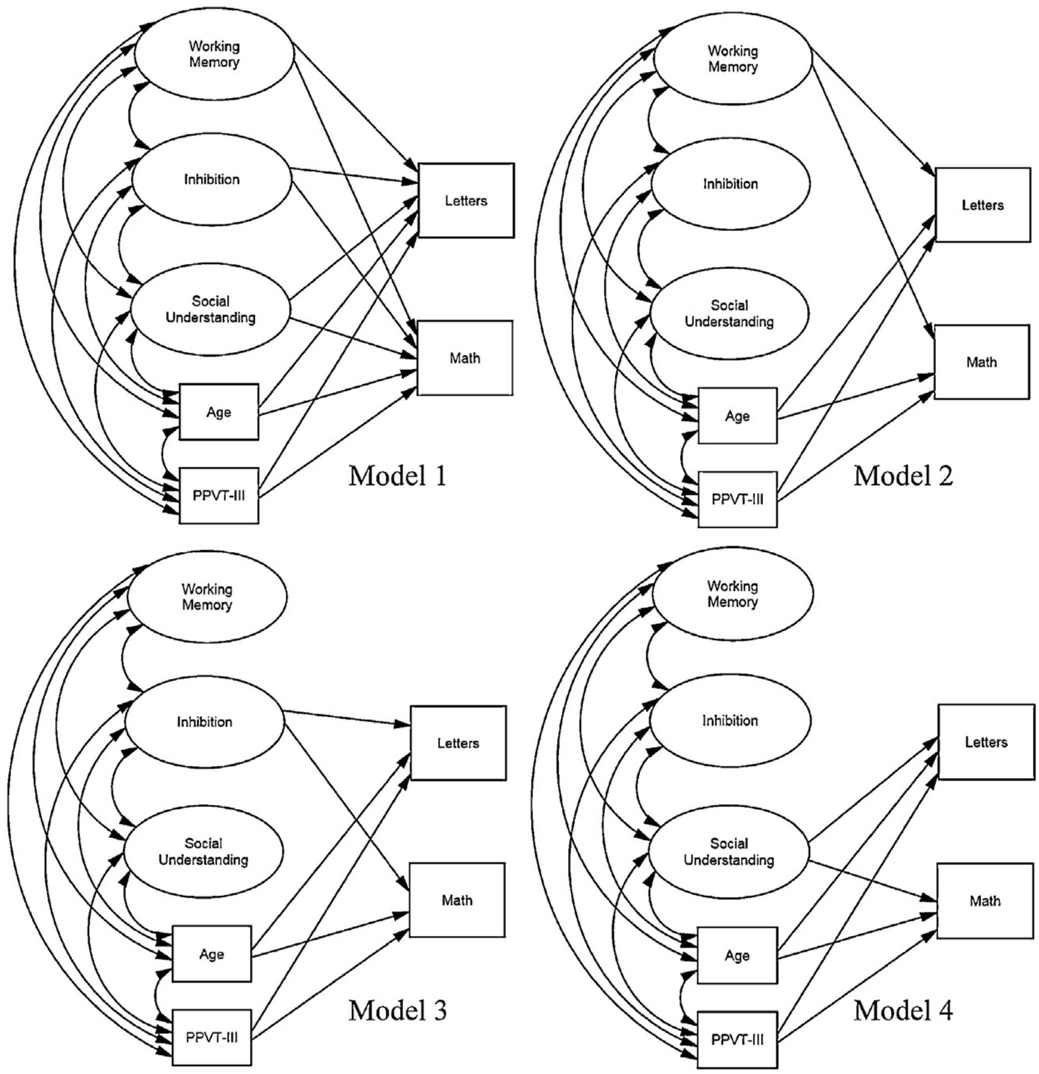

Fig. 2. Hypothesized structural equation models. PPVT-III = Peabody Picture Vocabulary Test-Third edition.

the Dissociative model. Moreover, the Two-Factor EF model had a lower AIC value than both other CFA models, which indicated better absolute fit. As a result, the Two-Factor EF model was favored over the two other tested models. Factor correlations, standardized parameter estimates, and squared multiple correlation values for all three CFA models are depicted in Fig. 1. All factor correlations were positive and significant in each model (*p*s < .01), and all manifest variables loaded significantly onto their corresponding latent factors with critical ratios ranging in value from 2.19 to 8.75 (*p*s < .05). There was no indication of problems with residual values (e.g., large or negative values), and the error variance correlations between both Backward Span tasks and between both False Belief tasks were positive and significant (*p*s < .05).

3.5. Structural equation modeling

Having established that the Two-Factor EF model best captures the relations among working memory, inhibition, and SU, a series of four SEM models (see Fig. 2) were evaluated in order to investigate the extent to which working memory, inhibition, and SU contributed to school readiness. We wished to examine (a) the joint influence of working memory, inhibition, and SU on letter and math skills, over and above age and verbal ability (Model 1) and (b) the influence of each individual latent factor on letter and math skills, over and above age and verbal ability (Models 2–4). For each SEM analysis, factor loadings and factor correlations were allowed to vary in order to test the stability of the Two-Factor EF model. In other words, the parameter estimates in each SEM analysis could differ from those in the

Table 4
Correlations for structural equation Model 1 ($N = 129$).

Variable	Working memory	Inhibition	Social understanding	Age in months
Working memory	–			
Inhibition	.58**	–		
Social understanding	.75**	.65**	–	
Age in months	.65**	.40**	.67**	–
PPVT-III	.57**	.59**	.81**	.55**

Note. PPVT-III = Peabody Picture Vocabulary Test-Third edition.
** $p \le .01$.

Two-Factor EF model. Overall, changes in the parameter estimates were small for each SEM analysis, indicating that the Two-Factor EF model was highly stable.

Model 1 included correlations among working memory, inhibition, SU, age, and verbal ability, and paths from these variables both to letter and to math skills. As shown in Table 3, the overall fit between Model 1 and the observed data was good. In addition, all correlations among the latent factors were positive and significant (see Table 4). However, working memory was the only factor that significantly contributed both to letter and to math skills, over and above the other latent factors, age, and verbal ability (see Table 5). As a result, Model 2 was estimated in which we trimmed (i.e., constrained to zero) the direct paths from inhibition and SU in order to examine the unique influence of working memory on letter and math skills (see Fig. 2). The overall fit between Model 2 and the observed data was good (see Table 3). Moreover, correlations were positive and significant among all latent factors ($rs \ge .58$, $ps < .01$), and working memory still contributed significantly to both letter skills ($B = 5.90$, $SE = 1.33$, $p < .001$, $R^2 = .52$) and math skills ($B = 12.62$, $SE = 2.74$, $p < .001$, $R^2 = .75$), over and above age and verbal ability. Nevertheless, the model fit comparison values indicated that Model 1 fit the observed data significantly better than Model 2 (see Table 3).

Although working memory was found to be the only factor that significantly contributed to letter and math skills in Model 1, previous studies suggest that inhibition, independent of working memory and false belief understanding (Blair & Razza, 2007; Espy et al., 2004), is the main contributor to children's performance on measures of literacy and math ability. Therefore, we estimated Model 3 (see Fig. 2), in which the paths from inhibition to letter and math skills were retained but the paths from working memory and SU to letter and math skills were trimmed. Also, to evaluate the possibility that SU contributed to letter and math skills independent of working memory and inhibition, we estimated Model 4 (see Fig. 2), in which the paths from SU to letter and math skills were retained but the paths from working memory and inhibition to letter and math skills were trimmed. The fit indices (see Table 3) showed that both Models 3 and 4 provided a good overall fit to the observed data. However, the covariance matrix for Model 3 was not positive definite, which meant that the factor solution for Model 3 was inadmissible (Arbuckle, 2009). In Model 4, SU did not significantly contribute

Table 5
Summary of results for structural equation Model 1 ($N = 129$).

Variable	Letters				Math			
	β	B	SE	R^2	β	B	SE	R^2
Model 1				.52				.81
Working memory	.80	6.04**	1.62		.77	13.51**	3.92	
Inhibition	.02	0.02	0.21		.14	0.36	0.49	
Social understanding	−.59	−9.04†	5.45		−.75	−27.07†	15.93	
Age in months	−.03	−0.02	0.13		.09	0.17	0.30	
PPVT-III	.50	0.16*	0.07		.74	0.54**	0.17	

Note. Letters = Bracken School Readiness Assessment – letters subscale; Math = Bracken School Readiness Assessment – math aggregate; PPVT-III = Peabody Picture Vocabulary Test-Third edition.
† $p \le .10$.
* $p \le .05$.
** $p \le .01$.

either to letter or to math skills (*ps* > .05). Moreover, Model 1 fit the observed data significantly better than both Models 3 and 4. As a result, Model 1 was retained as the preferred model.

4. Discussion

We estimated and compared a series of CFA and SEM models in order to examine the extent to which EF and SU contributed to preschoolers' early letter and math skills. Specifically, the models examined (a) the structure of EF and its relation to SU, (b) the joint influence of latent working memory, inhibition, and SU factors on letter and math skills, over and above age and verbal ability, and (c) the influence of each individual latent factor on letter and math skills, over and above age and verbal ability. The results of the CFA indicated that a two-factor model of EF consisting of separate but related working memory and inhibition factors fit the data better than a unitary-factor model of EF. In addition, working memory, inhibition, and SU all shared a significant, positive relation. Results of the SEM analyses indicated that working memory was a unique predictor of early letter and math skills, over and above inhibition, SU, age, and verbal ability. Specifically, working memory uniquely accounted for 52% and 75% of the variance in letter and math skills, respectively. Moreover, in our preferred model, inhibition and SU processes did not uniquely contribute to either letter or math skills, although there were significant relations among inhibition, SU, and working memory.

4.1. Executive function and social understanding

The goals of the CFA were to (a) examine the EF structure in preschoolers and (b) examine the relation between preschoolers' EF and SU. EF in preschoolers was best represented by a two-factor structure consisting of working memory and inhibition (see also Miller et al., 2012). Moreover, the working memory and inhibition factors were significantly correlated, indicating that the two EF processes are separable but related components of EF in preschool children. This finding differs from those of other latent variable studies indicating that EF in preschoolers is best represented as a unitary construct (Hughes et al., 2010; Wiebe et al., 2008, 2011; Willoughby, Blair, et al., 2010, 2012; Willoughby, Wirth, et al., 2012). However, in most of these studies, the favored single-factor models fit the data equally well as a two-factor model comprising working memory and inhibition. Our findings are strengthened by the fact that the Two-Factor EF model outperformed the Unitary EF model in terms of both model fit and model comparison values (Table 3).

Having established the EF structure, we examined the relation between EF and SU by comparing the Two-Factor EF model and the Dissociative model (Fig. 1). As expected, the Two-Factor EF model outperformed the Dissociative model, indicating that SU was correlated with both working memory and inhibition. This finding is consistent with the extant literature (Moses & Tahiroglu, 2010) and further supports the existence of a functional, developmental relation between EF and SU in preschoolers (Carlson, Mandell, & Williams, 2004; Müller, Liebermann-Finestone, Carpendale, Hammond, & Bibok, 2012). Our next and primary goal was to use the Two-Factor EF model to investigate the influence of working memory, inhibition, and SU on preschoolers' emerging letter and math skills.

4.2. Working memory and school readiness

Our SEM findings support previous studies showing that EF predicts individual differences in early literacy and math skills (Bull et al., 2011; Kroesbergen et al., 2009; Welsh et al., 2010). Furthermore, using a latent variable approach, we determined that domain-general working memory processes are uniquely important predictors of domain-specific school readiness skills, such as letter knowledge and math skills. Our findings are consistent with other studies showing that working memory accounted for more variance in academic skills than inhibition (Bull et al., 2008; Lan et al., 2011; Lee et al., 2012; Monette et al., 2011; Rose, Feldman, & Jankowski, 2011; St. Clair-Thompson & Gathercole, 2006; Swanson, 2006).

In contrast to Alloway et al. (2005), we found working memory to be associated not only with letter knowledge but also with math skills. This discrepancy may be due to the fact that Alloway and colleagues used different outcome measures and did not control for error variance by using SEM.

Increasing working memory capacity allows children to consciously reflect on rules (Zelazo, Müller, Frye, & Marcovitch, 2003), which is likely useful for many academic skills, such as learning the order of letters in a word or counting a string of numbers. We selected working memory tasks designed to capture active rule maintenance, which may be a reason we found such strong effects of working memory. The high parental education level of the sample may have influenced the results, but we nonetheless replicated findings from previous latent variable model series (Miller et al., 2012; Monette et al., 2011). Overall, our findings are consistent with the view of Gathercole and Alloway (2008), who suggest that working memory is a factor that has the potential to disrupt the learning process, particularly in terms of acquiring early literacy and math knowledge.

4.3. Inhibition, social understanding, and school readiness

We did not replicate findings that inhibition and SU uniquely contribute to early academic skills (Astington & Pelletier, 2005; Blair & Razza, 2007), although indicators of both had significant positive zero-order correlations with letter and math skills. It is possible that the ability to inhibit a prepotent response is useful in academic situations that involve extraneous or distracting information (Diamond et al., 2002). For instance, inhibition may be needed to discriminate between letters or numbers when learning the alphabet or counting to ten. In the present study, inhibition may have been obscured by its functional reliance on working memory processes and its shared variance with our latent working memory variable (Lan et al., 2011). Indeed, the CFA revealed that the inhibition and working memory factors were strongly correlated (Fig. 1). Alternatively, inhibition may affect literacy and math skills only when children (a) have acquired a larger knowledge base, making the inhibition of task-irrelevant information more challenging or (b) confront more complex tasks (e.g., complex arithmetic problems; but see Censabella & Noël, 2008). Thus, the relation between inhibition and academic skills may become more important as children get older. This possibility needs to be examined using longitudinal designs that cover a broad age range (Van der Ven et al., 2012) and employing tasks that independently vary working memory and inhibition demands (Beveridge, Jarrold, & Pettit, 2002).

Although SU was related to both working memory and inhibition, the SEM analyses showed that SU did not explain a significant amount of variance over and above working memory and inhibition (Table 5), even when working memory and inhibition were constrained in the model and only age and verbal ability were controlled for. This is likely due to the fact that SU shares a significant amount of variance with age and verbal ability as indicated by the zero-order correlations (Table 2). By contrast, Blair and Razza (2007) found that false belief understanding predicted letter knowledge even after controlling for verbal ability. However, the children in their study were somewhat older, and, as Blair and Razza (2007, p. 659) acknowledged, the majority of the children performed at ceiling with respect to letter knowledge. Because letter knowledge is an indicator of reading ability, the relation between letter knowledge and false belief understanding might be limited to children with problems in reading.

Our findings, however, do not rule out the possibility that SU plays an important role in later school adjustment (Ladd, Birch, & Buhs, 1999). We included only a few measures of SU. Numerous other measures of SU (e.g., desires and diverse beliefs; Wellman & Liu, 2004) may influence school readiness and achievement. SU also has been found to promote children's understanding of teaching (Ziv & Frye, 2004; Ziv, Solomon, & Frye, 2008), which may in turn contribute to children's learning letter and math skills. Moreover, SU and social skills are important in establishing positive relationships with peers and teachers, thereby promoting academic progress (Mashburn & Pianta, 2006). Furthermore, interventions designed to promote social problem-solving skills have been shown to promote EF, which in turn positively affects academic skills (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008). Thus, it is possible that SU and EF are not in direct competition, but that EF mediates the effects of well-adjusted social functioning on academic achievement. As such, SU as well as social–emotional regulation (Monette et al., 2011) may mediate the effects of EF on children's academic achievement. Longitudinal studies are necessary to further examine these possibilities.

One issue that requires further clarification is the negative loadings of SU on letter and math skills in Model 1 (Table 5). One reason for the negative loadings may be that SU acted as a negative suppressor variable. Negative suppression seems reasonable in this case because (a) all manifest SU variables were positively correlated with letter and math skills, (b) all manifest SU variables were positively correlated with all manifest working memory variables, (c) most of these correlations were significant at $p \leq .05$, (d) the SU factor was positively correlated with the working memory factor, and (e) with working memory in the model, SU received negative regression weights for letter and math skills (Maassen & Bakker, 2001). When negative suppression is suspected, Maassen and Bakker (2001) suggest dropping the suppressor variable for reasons of parsimony. This was done in both Models 2 and 3, and the results still indicated that Model 1 provided the best fit to the data.

4.4. Conclusions

Our findings suggest that preschool children with strong working memory skills are at an advantage in terms of acquiring the early letter and math skills that are precursors of reading, writing, and math achievement. More longitudinal studies using a SEM approach are necessary to establish this causal relation, but extant data (Bull et al., 2008; Lan et al., 2011; Lee et al., 2012; Monette et al., 2011; Van der Ven et al., 2012) are consistent with this claim. In addition, recent training studies with school-age children have shown that working memory training leads to an improvement in working memory capacity and to improvements in children's mathematical reasoning (Holmes, Gathercole, & Dunning, 2009) and reading skills (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012). Furthermore, working memory training, but not training of inhibitory skills, has been shown to improve preschoolers' performance on EF tasks (Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2008). Thus, one approach to more firmly establishing a causal relation is to assess whether working memory training in preschoolers also leads to improvements in early literacy and math skills. However, as our results show, preschoolers' working memory skills share complex relations with other social–cognitive constructs, such as inhibition and SU. It is important to keep in mind that interventions designed to train working memory might also enhance other aspects of social–cognitive function related to working memory that have the potential to affect academic outcomes. At the same time, recent reviews of working memory training stress the need for more direct measures and suggest that the effects of training working memory are short-term and may not generalize to other skills (Melby-Lervåg & Hulme, 2013; Shipstead, Redick, & Engle, 2012). Therefore, to clarify how working memory and other complex skills directly influence academic outcomes in preschoolers, future studies must take into account complexities in the structure of the relevant constructs (Willoughby, Wirth, et al., 2012) and incorporate appropriate control tasks (van der Sluis et al., 2007) to account for indirect effects.

In conclusion, our findings suggest that working memory accounts for significant variance in preschoolers' letter and math skills, which in turn are important predictors of later academic achievement. In contrast, inhibition and SU did not independently influence academic outcomes, although both constructs were strongly correlated with preschoolers' working memory. In order to better understand the relations among preschoolers' EF, SU, and school readiness, future studies need to examine the structure of these social–cognitive constructs by testing and comparing various competing models. In addition, to achieve greater clarity regarding the direct and indirect effects of EF and SU on different academic outcomes throughout the school years, such studies need to include relevant control tasks and take advantage of different development designs, such as combining latent variable and longitudinal approaches.

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