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The associations among preschool children's growth in early reading, executive function, and invented spelling skills

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Abstract The purpose of the present study was to examine associations among children's emergent literacy (early reading), language, executive function (EF), and invented spelling skills across prekindergarten. Participants included 123, primarily African American, 4-year-old children enrolled in a variety of prekindergarten settings. In addition to describing the concurrent and longitudinal relations between children's emergent literacy, EF, and invented spelling skills, this study investigated associations among children's growth in these targeted skills and explored potential indirect effects from children's EF to invented writing skill. Multiple regression analyses suggested that although early reading skills were significantly and concurrently associated with invented spelling skills, children's phonological awareness was the only early reading skill predictive of later invented spelling skills. Children's EF was not concurrently or longitudinally associated with invented spelling after controlling for early reading skills. However, regression analyses of children's residual scores suggested that children's EF skill at the beginning of the semester was predictive of their later invented spelling skills through children's letter-sound knowledge.

Keywords Early writing · Invented spelling · Executive function · Early literacy · Early childhood

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Introduction

Children develop considerable skills in writing in early childhood and these skills are related to later literacy achievement (Hammill, 2004; Hooper, Roberts, Nelson, Zeisel, & Kasambira Fannin, 2010). For example, preschool children's letter writing (Shatil, Share, & Levin, 2000) and early spelling abilities (Kim, Al Otaiba, & Wanzek, 2015) are predictive of their writing and reading skills in elementary school. One key milestone related to early writing development is children's expressions of invented spelling. Invented spelling involves children's attempts to write or spell words before they can actually read them (Gentry, 2000). Invented spelling represents an important milestone for children's writing development as the inclusion of letters in emergent writings could potentially demonstrate young children's phonemic awareness skills, grapho-phonemic awareness skills, and the ability to connect the letters with the sounds in creating words to convey meaning (Bear, Invernizzi, Templeton, & Johnston, 2008; Caravolas, Hulme, & Snowling, 2001; Read, 1971). Children's inclusion of letters, which often represent only salient sounds in words (e.g., beginning or ending sounds), are the beginnings of invented spelling (Bear et al., 2008). When children experiment with invented spelling in their writing, they enhance their awareness of sounds within words (Clay, 1985; Ehri, 1989; Richgels, 2001).

While automatic and fluent writing involves the successful interweaving of several related skills such as ideation, transcription skills such as handwriting and spelling, and executive functions (Berninger, Abbott, Abbott, Graham, & Richards, 2002; Kegel & Bus, 2014), limited existing research has explored the relations of these skills during the preschool years when invented spelling is beginning to develop (Kim et al., 2015). Although a body of research exists on children's invented spelling skills, less is known about how these skills emerge early and form a foundation for later fluent and automatized writing. Additionally, few studies have examined how children's early literacy and executive function skills are related to invented spelling development. To address this gap in the literature, this study examines how children's writing fluency, emergent literacy (i.e., phonological awareness and letter knowledge), and executive functioning (EF) skills directly or indirectly impact the growth of invented spelling in 4- and 5-year-old children in prekindergarten classrooms. Findings from this study will provide evidence for ways in which teachers might support the emergence of certain skills in order to ensure that children benefit from formal literacy instruction once they reach kindergarten.

Children's early writing development: considering invented spelling

Writing develops relatively rapidly during the preschool years as children gain an understanding that they can communicate speech through text. Writing development generally proceeds in a sequential pattern with young children moving from graphic forms, to more writing-like forms, to symbolic forms (Levin, Both-De Vries, Aram, & Bus, 2005; Levin & Bus, 2003). More specifically, children typically first produce

scribbling or drawing to experiment with writing or to convey written text, often as a single unit or scribble, (Puranik & Lonigan, 2011), gradually becoming more exact and decreasing in size (Levin & Bus, 2003). Subsequently, children move towards the use of discrete letter-like forms (Ferreiro & Teberosky, 1982). At this point, children's writing begins to resemble conventional writing with the increasing use of features such as linearity, segmentation, form complexity, multiple forms, and variety (Levin & Bus, 2003; Puranik & Lonigan, 2011). Traditionally at this point, children begin to use conventional letters. Although children begin demonstrating greater sophistication with form, they continue to demonstrate limited knowledge of letter-sound associations (Ferreiro & Teberosky, 1982; Rowe & Wilson, 2015). Children next progress to the use of beginning sounds and lastly using beginning and ending (or salient) sounds in their writing (Cabell, Tortorelli, & Gerde, 2013; Levin & Bus, 2003; Schickedanz & Casbergue, 2009), during which children's first phonetic spelling attempts emerge and invented spelling begins. Writing development is generally understood to progress in this manner, from graphic and idiosyncratic to iconic to conventional (Levin & Bus, 2003; Leyva, Reese, & Wiser, 2012; Tolchinsky, 2003); however, researchers conceptualize the nature of the progressive phases, steps, or stages in varying ways. Nonetheless, generally, research indicates that children develop understandings of writing in a predictable way—often acquiring knowledge about universal aspects of writing (e.g., writing is linear, it contains discrete forms or characters) before acquiring specific attributes pertaining to their language (e.g., invented spelling and letter formation knowledge) (Puranik & Lonigan, 2011). Further research demonstrates that early writing is comprised of three major components—conceptual knowledge, including understanding of print and the process and product of writing, procedural knowledge, related to letter knowledge and transcription skills, and generative knowledge, that is, the ability to produce written text (Puranik & Lonigan, 2014).

Although these developmental understandings and progressions (e.g., Levin & Bus, 2003; Puranik & Lonigan, 2011, 2014) provide salient theoretical foundations for understanding children's writing development globally, progressions pay less attention to the development of multiple individual component skills of early writing (i.e., handwriting, spelling, and composing; Kaderavek, Cabell, & Justice, 2009). Despite such skills being interdependent (Kaderavek et al., 2009) it is important to consider them separately as children develop them at variable rates (e.g., Puranik & Lonigan, 2014). For example, at kindergarten entry, most children are able to write their names, but are in the beginning progression of phonetic spelling (Oullette & Sénéchal, 2017; Puranik & Lonigan, 2011). Hence, it is important examine the nature of, and the contributions to, children's invented spelling in preschool as this is the time in which the skill first emerges.

Young children's invented spelling is a critical early writing skill because it represents children's intentional writing attempts utilizing phonemic awareness (Richgels, 2001), before the development of automatized skills such as letter formation, conventional spelling, and reading (Read, 1971). Invented spelling skills begin to develop in preschool as children learn to differentiate between phonetic similarities and differences, along with visual memorization, in ways that convey thoughts and ideas through print. Because the skill is emerging in preschool and

kindergarten, young children frequently make spelling mistakes; however, such mistakes are often logical and systematic (Invernizzi & Hayes, 2004; Read, 1971). In this way, once they reach invented, or phonemic spelling, children's writing often demonstrates an emerging knowledge of the systematic structure of spelling rules (Read, 1971; Richgels, 2001). In comparison to the increasing knowledge of young children's development of name writing and letter writing skills, knowledge of young children's invented spelling skills is emerging.

Existing research on children's invented spelling skills is limited in important ways. First, existing studies of invented spelling generally focus on elementary-aged children's writing (e.g., kindergarten; Clemens, Oslund, Simmons, & Simmons, 2014; Puranik & Al Otaiba, 2012; Oullette, Sénéchal, & Haley, 2013; Ahmed & Lombardino, 2000; Plaza & Cohen, 2007) despite the fact that the development of beginning invented spelling skills appear before kindergarten (Bear & Templeton, 1998; Pendergast, Bingham, & Patton-Terry, 2015). Such exclusion may be due to the importance of spelling skills to elementary writing standards and curricula (Ahmed & Lombardino, 2000; Clemens et al., 2014) and the limited focus of writing in preschool curricula (Gerde, Wright, Skibbe, & Douglas, 2016). A clear understanding of how invented spelling skills emerge before formal school entry is important as there may be foundational skills that early childhood educators can address in their curriculum.

A second consideration is the limited attention to component skills that relate to children's development of invented spelling skills. Although research has demonstrated the power of invented spelling-focused interventions towards building foundational literacy skills (e.g., word reading and phonemic skills; see Hofslundsengen, Hagtvet, & Gustafsson, 2016; Oullette & Sénéchal, 2008; Rieben, Ntamakiliro, Gonthier, & Fayol, 2005; Sénéchal et al., 2012), less is known about the inverse, that is, the contributions of literacy and other potentially related skills to children's invented spelling development, particularly among preschoolers. Although existing literature does suggest contributions from letter-sound knowledge and phonemic awareness (Oullette & Sénéchal, 2008), early writing skills such as name and letter writing (Puranik, Lonigan, & Kim, 2011), and self-regulation and executive functioning (e.g., behavioral regulation: working memory: Kegel & Bus, 2014; Oullette & Sénéchal, 2008), research exploring the precise nature of associations between related skills and invented spelling is limited. Additionally, despite research demonstrating a link between children's EF and early literacy development (Blair & Razza, 2007; McClelland et al., 2007), less is known about how EF relates to early writing skills. Importantly, recent theoretical and conceptual examinations of early writing development do not include an EF component to date (Puranik & Lonigan, 2014). Meanwhile, EF skills are usually included in studies of writing among older children (Berninger & Amtmann, 2003; Berninger & Winn, 2006; Hayes & Flower, 1980).

A final limitation of existing research on children's invented spelling development relates to the fact that most include children among middle-to-high socioeconomic status populations (McNeill et al., 2013; Oullette & Sénéchal, 2008). Additionally, few studies examine the development of these skills among ethnically diverse children (Foy & Mann, 2013; Dice & Schwanenflugel, 2012).

Homogeneity in research sampling limits the implications of the research findings and the development of classroom instruction across multiple populations and demographic groups. Aiming to address these limitations and extend existing literature of young children's writing development, this study followed a group of ethnically diverse children from low socioeconomic backgrounds for a school year, assessing their emergent literacy (i.e., early reading skills) and writing skills, and investigated both concurrent and longitudinal relations between literacy, writing, and EF. In the next section, we consider existing research related to children's EF and literacy skills.

Executive function and literacy development

Executive functioning (EF) involves three core self-regulation skills: attentional or cognitive flexibility, working memory, and inhibitory control (Garon, Bryson, & Smith, 2008; McClelland & Tominey, 2014). EF allows children to memorize information, to shift and control attention, and to automatically respond to stimulation (Blair, Protzko, & Ursache, 2011).

During children's early childhood years (i.e., between birth to five years old), children's skills of all three EF domains are emerging with different speed (Garon et al. 2008). Many researchers believe that young children may be more capable of performing tasks involving usage of inhibitory control and working memory (Hoskyn & Tzoneva, 2008). This may be related to the fact that inhibitory control is considered a domain of executive functions that precedes and supports the development of the other domains in early childhood (Altemeier, Abbott, & Beninger, 2008). For this reason, integrative measures that explore all three executive function components simultaneously are more reliable of children's abilities than individual measures as EF in young children represents a single construct (McClelland & Tominey, 2014).

The importance of examining EF is found in a seminal study conducted by Blair and Razza (2007), which indicates that EF skills are strong correlates to young children's emergent literacy skills in kindergarten (e.g., phonemic awareness and letter knowledge). Similarly, Kegel and Bus (2014) demonstrate that executive functions and emergent literacy skills (e.g., letter knowledge, letter-sound knowledge, and word recognition) are strongly correlated concurrently in kindergarten. Although different EF measures, either verbal or nonverbal, may relate differently to emergent literacy skills (Foy & Mann, 2013), the important role that EF plays in young children's literacy development has been consistently demonstrated.

Despite increasing literature about the contribution of EF to early literacy development, the role of EF in early writing development is unclear. Studies of elementary children's writing performance (e.g., Berninger et al., 2002; Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002) conceptualize children's writing as a process in which children coordinate handwriting, spelling, and EF to successfully generate written text. However, limited attention is given to EF skills in existing frameworks of young children's writing development (e.g., Puranik & Lonigan, 2011; 2014; Kaderavek et al., 2009). This may be due to the nature of EF component-specific tasks, which may be considered too challenging for young

children (McClelland & Cameron, 2012). Not until recently, with the development of an EF assessment tool for preschool children (e.g., Head-Toes-Knees-Shoulders; Ponitz et al., 2008), have researchers and professionals begun to investigate the relations between children's EF and their writing skills.

There are relatively few studies that have examined preschoolers' early writing and EF components. Those that have examined these associations did not find direct relations between EF and early writing skill. For example, in a study examining factors contributing to children's name writing ability, Gerde et al. (2012a, b) did not find EF to be a direct and significant predictor of name writing ability above and beyond children's literacy skills. Although this study did not find a direct association between EF and children's name writing skill, EF may have an indirect association with writing through literacy skills, something not tested by the authors. This conjecture is supported in work by Hoskyn and Tzoneva (2008) who found that preschoolers' working memory explained significant and unique variance in name writing skills indirectly through children's age and letter copying ability. Studies on kindergarten-aged children appear to confirm the limited direct relation of EF to invented spelling. Oullette and Sénéchal (2008), for example, found that while working memory and invented spelling were correlated to one another, working memory did not account for variance in invented spelling above and beyond the contribution of phonemic awareness.

Given the consistent and significant relations between children's EF and early literacy skills (Nesbitt, Farran, & Fuhs, 2015; Blair & Razza, 2007), and between early literacy (i.e., early reading skills) and writing skills, EF may be related to writing skills through other literacy skills. Although existing research has not examined the indirect affect that EF may play on writing through children's developing early literacy skills, the current study examines a potential mediation model with attention to how children's EF at an earlier time relates to growth in literacy skills in ways that impact children's development of invented spelling skills.

Research questions

The current study investigated pre-kindergarten children's invented spelling skills for a year to examine the development of invented spelling skills prior to their kindergarten entry, and component skills related to this development. Importantly, we analyzed children's data from two time points (Fall and Spring semester), which allowed for the investigation of longitudinal relations among children's early skills and the exploration of factors that may contribute to growth in invented spelling. Given the consistent correlation between emergent literacy and writing skills in existing literature (Ahmed, Wagner, & Lopez, 2014; Pendergast et al., 2015), we also examined the potential indirect longitudinal relations between EF and children's invented spelling skills through children's early reading skills.

This study aims to extend current literature by (1) describing the concurrent and longitudinal relations between children's emergent literacy, EF, and invented spelling skills, (2) investigating relations among the children's growth in emergent

literacy, EF, and invented spelling skills over the preschool year, and (3) the significance of the pathway from EF through children's emergent literacy skills to children's invented writing skills. Children with stronger executive functioning likely have more developed early reading skills, which, in turn, may promote early writing development overall. Thus, we hypothesized that children's EF may be indirectly related to children's invented writing skills through early reading skills.

Method

Participants

Participants in this study were prekindergarten (Pre-K)-aged children (ages 4 and 5) who were enrolled in early childhood sites in two states in the Southern U.S. Children came from 12 classrooms serving 4- and 5-year old children (prekindergarten) across the six sites. Participating classrooms were from various program types including Head Start, community-based childcare centers, and state-sponsored Pre-K. Although programs varied, all utilized the same curriculum, Creative Curriculum (Dodge, Colker, & Heroman, 2002), in their programs.

Children were typically developing, with no known disabilities as indicated by family surveys and Pre-K teacher report. Children averaged 58 months ($SD = 6$ months) at the fall assessment point. A total of 123 children (52% female) participated in fall and spring assessments. Children were primarily African American (82%) and, although individual family socio-economic status was not available, the majority of children came from low-income backgrounds as evidenced by their participation in Head Start classrooms (54%). Parents evidenced variability in educational backgrounds. According to surveys completed by children's primary caregivers (94% completion rate), 12% did not complete high school, about 24% of parents reported obtaining a high school degree, 38% of respondents reported attending at least some college or having obtained an associate's degree, and 19% of parents reported a BA degree or higher. The majority of respondents were mothers (88%), and most families (93%) reported using only English as their home language.

Data collection

Children's writing, emergent literacy, and executive function skills were assessed in the fall and spring of their Pre-K year. Testing occurred in October and November in the fall semester and April and May in the spring semester, with approximately 6 months between each assessment point. Children were assessed individually by a trained data collector in a quiet area of their school and assessments were conducted in sessions on different days to avoid testing overload or fatigue. On average, testing was split into 2 different sessions, which lasted approximately 20 min each. Children were given a small token (a pencil or sticker) after participating in each assessment.

Measures

Several measures were used to assess children's emergent literacy, EF, and writing abilities across the PreK year. Children's early reading skills were assessed with measures of letter knowledge, letter sound knowledge, and phonological awareness while language was assessed with a receptive vocabulary task. EF was assessed with an integrated self-regulation task. Children's writing development was assessed with three different tasks: name writing, letter writing fluency, and invented spelling. Each measure is explained below with student mean performance on each measure presented in Table 1.

Vocabulary

Children's receptive vocabulary skills were measured using the Peabody Picture Vocabulary Test-4th edition (PPVT-4; Dunn & Dunn, 2007). The PPVT-4 is a well-established norm-referenced assessment of receptive vocabulary skills for individuals ages 2.5 months and older. The PPVT-4 has high internal consistency (.95 to .97 for the 2–6 year old age range) and strong test–retest reliabilities (.91 to .94; Dunn & Dunn, 2007). Children were prompted to point to one of four pictures in the testing book that best matched the meaning of the word stated by the assessor (e.g., point to "dog"). Assessors followed standard administration procedures outlined in the users' manual, which included establishing a baseline of children's skills and then continuing until children reached a defined ceiling.

Letter and letter sound knowledge

Children's letter knowledge (Turnbull, Bowles, Skibbe, Justice, & Wiggins, 2010) and letter-sound knowledge (Drouin, Horner, & Sondergeld, 2012) were assessed to uncover children's alphabetic knowledge. For the letter knowledge task, children were shown a random set of six upper and lower case letters to name. In order to assess children's letter-sound awareness, children were, similarly, shown a randomly selected set of 6 upper and lower case letters and asked to tell the sound they make. Item response theory analyses was used to create parallel forms of equal difficulty and one of these short form sets was randomly selected for administration for each child in the fall and spring (see: Bowles, Pentimonti, Gerde, & Montroy; 2014; Drouin et al., 2012). Both measures, letter knowledge and letter-sound knowledge, indicated strong reliability (.91 and .98, respectively).

Phonological awareness

Children's phonological awareness (PA) was assessed using a subtest of the Test of Preschool Early Literacy (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007). The TOPEL-Phonological Awareness subtest assesses children's ability to blend and segment sounds in words. Specifically, the TOPEL-PA subtest consists of two blending and two elision tasks that have two levels of cognitive demand—picture-based multiple-choice items and free response items. Each of these four tasks also

Table 1 Descriptive statistics of children's performance in assessments ($N = 123$)

	Fall				Spring					
	Min	Max	Mean	SD	Min	Max	Mean	SD	*t*	*d*
Writing fluency	0	24	5.68	3.43	0	22	6.04	3.60	2.12*	.40
Name writing	0	7	5.57	1.81	2	7	6.31	1.17	3.01**	.58
Invented spelling	0	17	2.56	3.30	0	20	4.37	4.86	6.95**	1.52
TOPEL PA	0	26	14.75	5.84	0	27	15.28	6.39	3.01**	.58
PPVT	12	111	73.60	20.94	28	123	79.79	21.66	6.48**	.82
Letter naming	0	8	5.07	2.77	0	8	5.79	2.57	5.58***	1.05
Letter sound	0	6	.56	2.17	0	6	3.58	2.14	6.45***	1.21
EF	0	40	14.21	15.33	0	40	17.38	15.32	2.59**	.52

* $p < .05$; ** $p < .01$; *** $p < .001$

included two levels of linguistic complexity—words and phonemes. For example, the two elision subtasks assess a child's ability to identify a target word that resulted from deletion of part of a word with the use of a picture (e.g., "Look at these pictures. Now point to *batman* without *bat*.") and without the picture prompt ("We are going to do some without pictures. If you take away *bell* from the word *doorbell*, what word do you have?"). A total score was computed for all blending and elision subtests. The internal consistency reliability was good for this sample (Cronbach's $\alpha = .89$).

Executive function

Children's executive function was assessed using the Head, Toes, Knees, and Shoulders (HTKS; Ponitz et al., 2008) task. During this assessment, children are asked to play a game in which they must do the opposite of what the experimenter says. In the first section, children were taught two oral commands ('touch your head' and 'touch your toes') and then do the opposite of what the researcher said. For example, if the researcher instructed the child to touch his/her head, the child is expected to touch his/her toes. In the second section, two additional opposing commands are added ('touch your knees,' and 'touch your shoulders'). Responses were scored as 0 = incorrect, 1 = self-corrected (i.e., child changed an incorrect response to a correct one with no help from the administrator), or 2 = correct. Higher scores indicate higher levels of self-regulation (score range 0–40). Recent work demonstrates strong reliability and validity of the HTKS (Masten et al., 2012; McClelland et al., 2007; Ponitz et al., 2009).

Name writing

Children's name writing skill was measured using the name writing subtest of the Phonological Awareness Literacy Screening-Preschool (PALS Pre-K, Invernizzi,

Sullivan, Meier, & Swank, 2004). Children are given a blank page of paper and marker and asked to draw themselves and write their name. The name writing is scored on a developmental continuum from scribbling to letter-like form to name spelled correctly. Scores range from 0 to 7. The PALS Pre-K demonstrates good inter-rater reliability ($r = .90$) and concurrent validity.

Writing fluency

Children's writing fluency was assessed with a modified version of the alphabet task (Abbott & Berninger, 1993; Graham, Harris, & Fink, 2000). For the adapted form of this task, children are given a piece of paper and asked to write as many letters as they can within a 1-min time frame. Children are given a point for each legible letter they write. The original version of this task demonstrates adequate inter-rater reliability ($r = .81$).

Invented spelling

Children's invented spelling was assessed using the invented spelling subtest from the Phonological Awareness Literacy Screening-Kindergarten (PALS-K; Invernizzi, Swank, Juel, & Meier, 2003). For this task, each child is given a sheet of paper with the capital letters of the alphabet lining the top of the page and five blank lines. The administrator asks the child to write, or attempt to write, five single-syllable, high-frequency, consonant–vowel–consonant (CVC) words (e.g., hug, sad, net, lip, and job). The child is asked to write each word on a blank line by the examiner. The administrator can repeat the word as necessary for the children. A child receives 1 point for each letter of the word that is written correctly with a child receiving a bonus point if the child spells the entire word correctly. Common invented spelling errors are also credited to the child (writing/m/for/n/) as indicated in the technical manual (Invernizzi et al. 2003). The number of correct phonemes represented with phonetically acceptable letter choices and bonus points are totaled for a possible 20 points. The spelling subtask evidences good inter-rater reliability ($r = .99$; $p < .01$) and test–retest reliability ($r = .89$).

Data analysis

In order to address the proposed research questions, two sets of hierarchical regression analyses were conducted. First, we conducted regression analyses with raw scores of children's assessment performance to investigate the contribution of literacy and EF skills to invented writing skill. Second, we created residual scores of children's assessment performance by regressing their fall scores to winter scores. Residual scores suggest the amount of growth in children's assessment performance across the semester. We conducted the same hierarchical regression models with the residual scores to explore the relations among the growth of children's emergent literacy, EF, and writing skills. Lastly, we tested a mediation model in which children's growth in early reading skills (i.e., residual scores of children's performance) mediated the longitudinal relation between EF in fall and invented

spelling in spring. We conducted the mediation analyses with Hayes's (2013) regression-based analytic approach and PROCESS codes in SPSS 23.

Results

Descriptive statistics of children's performance on all assessment tasks are presented in Table 1. As evidenced in this table, on average, children wrote less than three correct letters in the invented spelling task, and correctly identified less than one correct letter sound in the fall semester. Children's EF scores typically fell below the 40th percentile, suggesting that they were just beginning to develop this skill as assessed by the HTKS. Importantly, paired T-tests showed that participating children made significant gains across the year on all assessment tasks. Specifically, children's invented spelling skills grew significantly across the school year, χ^2 $(1,121) = 13.05$, $p < .001$.

Concurrently, children's writing, early reading, and executive functioning skills were moderately to highly correlated both in the fall and spring (see Table 2). Children's EF was not significantly correlated to children's letter sound skill in fall but it was in the spring. Importantly, because children's age was only significantly correlated to children's performance on one assessment (fall EF), children's age was not included in regression analyses.

A correlational matrix of residual scores revealed a different patterns of association (see Table 3). The residual scores of EF significantly correlated with the residual scores of early reading skills (e.g., phonological awareness, letter naming and letter sound knowledge), but not with residual scores of early writing skills. While the residual scores of children's early reading skills were not significantly correlated with children's writing fluency skill, residual scores of letter and letter-sound knowledge were significantly correlated with name writing. The residual

Table 2 Correlational matrix of children's performance in assessments ($N = 123$)

Fall	Spring								
	1	2	3	4	5	6	7	8	9
1. Age	1	−.08	−.02	−.07	−.02	.01	.01	−.01	.09
2. Writing fluency	−.04	1	.33**	.38**	.37**	.45**	.38**	.32**	.17
3. Name writing	.12	.55**	1	.33**	.46**	.47**	.56**	.47**	.24**
4. Invented spelling	.04	.35**	.38**	1	.37**	.56**	.44**	.55**	.37**
5. PPVT	−.01	.32**	.53**	.44**	1	.49**	.45**	.61**	.52**
6. TOPEL PA	.06	.33**	.35**	.49**	.61**	1	.57**	.52**	.58**
7. Letter naming	−.03	.46**	.55**	.41**	.45**	.35**	1	.76**	.43**
8. Letter sound	−.06	.45**	.42**	.50**	.41**	.38**	.68**	1	.36**
9. EF	.25**	.20*	.34**	.37**	.41**	.50**	.20*	.14	1

* $p < .05$; ** $p < .01$

Table 3 Correlational matrix of residual scores of children's assessment ($N = 123$)

	1	2	3	4	5	6	7	8
1. Writing fluency	1							
2. Name writing	.10	1						
3. Invented spelling	.20†	.12	1					
4. PPVT	.10	.07	−.05	1				
6. TOPEL PA	.10	.17†	.21*	.05	1			
7. Letter naming	.12	.38**	.00	.05	.08	1		
8. Letter sound	.12	.24*	.23*	−.02	.14	.37**	1	
9. EF	.01	.15	.15	.21**	.36**	.19*	.25*	1

† $p < .10$; * $p < .05$; ** $p < .01$

score of phonological awareness and letter-sound knowledge were significantly correlated with name writing and invented spelling residual scores. This may suggest that children's growth in EF and early reading skills develop at a similar pace during the preschool year, while different early reading skills may be correlated with different writing skills.This finding also suggests a mediating role of early reading skills in the relation between EF and writing skills.

Concurrent and longitudinal associations to invented spelling skills

In order to investigate the concurrent and longitudinal contribution of early reading skills and EF to invented spelling, we conducted two sets of hierarchal regression analyses with children's raw scores in spring and fall. In the first set of analyses, we investigated the concurrent contribution of targeted variables to children's invented spelling skills. In order to investigate the unique contribution of EF to children's writing, EF was entered into the model first. Given the assumption and observation that children's writing skills are highly related, variables of children's writing (e.g., writing fluency and name writing) were entered into the model subsequently, children's vocabulary performance was entered next, and early reading skills (i.e., phonological awareness, letter naming, and letter sound knowledge) were entered last (see Table 4). At both time points, children's letter sound knowledge and phonological awareness were significantly associated with their invented spelling skills. These early reading skills collectively explained 20% unique variance of children's invented spelling skills in fall, and 25% unique variance in spring.

In the second set of analyses, we conducted similar regression models treating children's invented spelling in spring as a dependent variable and children's writing, early reading, vocabulary, and EF skills in Fall as independent variables. Children's EF was entered first, followed by writing variables (i.e., name writing, writing fluency and invented spelling), vocabulary skill was entered next, and lastly early reading variables (letter naming, letter sound, and phonological awareness), were entered. The results showed that the final model explained 55% of variance in

Table 4 Regression analyses of the concurrent relations to invented spelling ($N = 123$)

Model	Variables	Fall					Spring				
		B	SE	β	R^2	ΔR^2	B	SE	β	R^2	ΔR^2
Step 1	EF	.09	.02	.37***	.13***		.12	.03	.36***	.13***	
Step 2					.24	.11**				.26	.13***
	EF	.04	.02	.26**			.09	.03	.28***		
	Writing fluency	.20	.10	.22*			.37	.11	.28***		
	Name writing	.60	.24	.20†			.73	.36	.17*		
Step 3					.28	.04*				.27	.01
	EF	.04	.02	.17			.07	.03	.23*		
	Writing fluency	.20	.10	.21*			.34	.12	.26**		
	Name writing	.20	.26	.10			.58	.38	.15		
	PPVT	.04	.02	.25*			.03	.02	.12		
Step 4					.41	.13***				.44	.17***
	EF	.03	.02	.14			.03	.03	.08		
	Writing fluency	.09	.10	.09			.19	.11	.14†		
	Name writing	.05	.25	.03			.02	.39	.01		
	PPVT	.02	.02	.10			−.01	.02	−.02		
	TOPEL PA	.11	.07	.20†			.09	.03	.33***		
	Letter Sound	.50	.18	.33**			1.05	.25	.46***		
	Letter Naming	−.01	.16	−.01			−.33	.24	−.17		

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

children's invented spelling skills in spring, F (6,77) = 15.84, $p < .001$. Children's fall invented spelling ($b = .83$, $SE = .15$, $p < .001$) and fall phonological awareness ($b = .18$, $SE = .08$, $p < .05$) were significantly and positively associated with children's invented spelling skills in the spring. Phonological awareness in the fall explained 7% of the unique variance of children's invented spelling in the spring. Children's name writing ($b = -.79$, $SE = .32$, $p < .05$) in fall, however, was negatively related to invented spelling skill in spring. No significant relation was detected between children's EF in fall and children's invented spelling skills in spring.

The associations among children's growth in early skills and writing

We conducted the same hierarchical regression analyses with children's residual scores by treating children's growth of invented spelling as a dependent variable. Children's residual scores of EF were entered first, followed by residual scores of name writing and writing fluency, children's residual scores of vocabulary were entered next, and early reading skills were entered last. The final regression model significantly explained 14% of variance in child outcomes, F (3,78) = 2.82, $p < .05$. In the final model, children's residual score of letter-sound knowledge was significantly associated with the residual score of invented spelling skills ($b = .64$, $SE = .28$, $p < .05$). Children's residual scores of writing fluency ($b = .21$, $SE = .12$, $p = .08$) and phonological awareness ($b = .17$, $SE = .10$, $p = .08$) were positively associated with invented spelling, but not to a statistically significant degree. Children's growth in EF was not related to growth in spelling skill.

The indirect relation between EF and invented spelling

Having recognized the significant correlations between children's residual scores of EF and early reading skills, and children's residual scores of letter-sound and invented spelling skills, we investigated a mediation model (see Fig. 1). In this

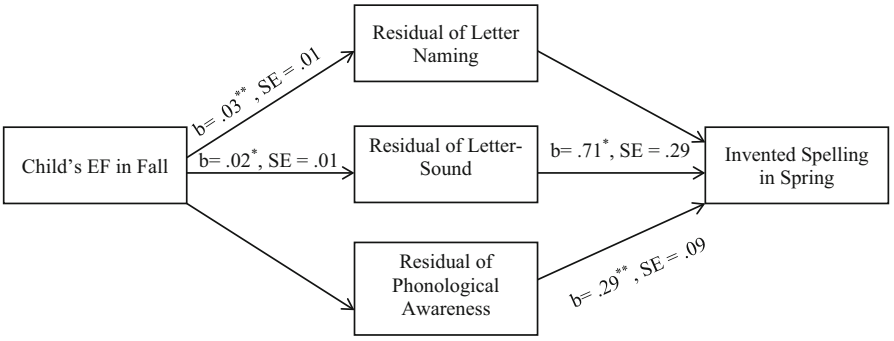

Fig. 1 The indirect association between children's executive function and invented spelling skill. *Note* $^{\dagger}p < .10$; $^{*}p < .05$; $^{**}p < .01$

model, children's EF in fall is indirectly related to children's invented spelling skills in spring through the residual scores of early reading skills.

This model explained 25% of the variance in children's invented spelling skills in spring, F (4,102) = 8.49, $p < .001$. Children's EF in fall significantly related to children's growth in letter naming, F (1,105) = 7.27, $p < .01$, and letter-sound knowledge, F (1,105) = 3.38, $p < .05$. Children's EF also explained 6% of the unique variance in children's growth in letter naming, and 3.5% of the unique variance in children's growth in letter-sound knowledge. Children's growth in letter-sound knowledge and phonological awareness were significantly related to invented spelling skills in the spring. The total effect from EF to invented spelling was statistically significant, $b = .11$, $SE = .03$, $p < .001$. The direct effect from EF to invented spelling was significant, $b = .09$, $SE = .03$, $p < .001$. The indirect effect from EF to invented spelling through the residual score of letter-sound knowledge was statistically significant, $b = .01$, $SE = .01$, $p < .05$. The significant indirect effect suggested that children's EF at the beginning of the preschool year indirectly contributed to children's invented spelling skills at the end of the preschool year through children's growth in letter-sound knowledge.

The same mediation model was tested with children's EF in the fall, residual scores of writing skills (i.e., name writing and writing fluency), and invented spelling skills in the spring. No significant direct or indirect effects from EF to invented spelling were found.

Discussion

This study not only investigated relations among preschool children's early reading, EF, and invented spelling skills, but also examined the relations among the growth of children's performance in assessment tasks. This allowed us to explore the concurrent and longitudinal contribution of early reading skills and EF to children's invented spelling. We also extended existing knowledge about the relation between children's EF and writing development (e.g., Aram et al., 2014; Kegel & Bus, 2014) by examining the indirect impact from EF to invented spelling through early reading skills.

Concurrent and longitudinal relations between early reading, EF and writing skills

Children's early reading, writing, and EF skills improved significantly over the prekindergarten year. Even though spelling is a challenging task, approximately 69% of children were using invented spelling to some degree at the end of the pre-kindergarten year. This suggests that the preschool years represent an important period when children's spelling skills begin to emerge and grow rapidly. Consistent with existing literature, children's emergent literacy (i.e., vocabulary, letter knowledge and phonological awareness), writing skills (i.e., name writing and writing fluency), and EF are significantly correlated with invented spelling skills concurrently (both at Fall and Spring). These significant associations resemble and

extend findings from Ouellette and Senechal's (2008) study with kindergarten children by suggesting that children appear to begin coordinate letter sound knowledge and phonological awareness when spelling words as early as prekindergarten. As young children develop this emerging understanding, they first need to transform the aural representation of the word into print utilizing word-specific orthography and then form the necessary letters with phonological and orthographic accuracy. Significant correlations among EF and early reading skills suggest that children may need EF to coordinate a variety of skills to perform spelling tasks (Gentry & Gillet, 1993; Richgels, 1995). During a classroom writing activity, for example, children must direct their attention in a planful way for a certain period of time in order to encode salient sounds into words. In order to benefit from classroom writing opportunities and writing instruction, they must be able to pay attention to teachers' modeling and support. They also need to retrieve literacy knowledge from their memory in order to complete the writing task. All of these behaviors and actions require the application of EF skills.

Analyses of longitudinal relations further supported the important role of children's phonological awareness in the development of invented spelling skill. Among all early reading skills, only phonological awareness in the fall was significantly predictive of children's invented spelling skills in the spring after controlling for children's initial writing skills. While previous studies suggest that young children's letter knowledge (i.e., letter naming and letter-sound knowledge) is an important skill to their name writing and letter writing performance (Gerde, Skibbe, Bowles, & Martoccio, 2012b; Diamond, Gerde, & Powell, 2008), the non-significant relation between letter knowledge at an earlier time and children's later invented spelling revealed in our analyses suggest that phonological awareness is more critical to spelling. When children spell a word based on the pronunciation of the word, they need to coordinate phonological knowledge in order to write letters based on the syllable-structure of the word. A possible factor in differential findings related to letter knowledge, phonological awareness and writing skills may relate to the age of children being examined, with children in this study being slightly older than the children in other studies (Gerde et al., 2012b; Diamond et al., 2008). Children in the current study were at least four years old and it is possible that their letter knowledge was no longer an obstacle for their spelling performance at the end of the school year. In contrast, phonological awareness, another fundamental skill for writing development, is still a challenging skill for many young children to master.

The correlational matrix of children's residual scores in early reading, writing, and EF assessments revealed the relations among the growth of children's early skills. While children's growth in letter knowledge was significantly related to growth in name writing, children's growth of sound knowledge (i.e., letter-sound and phonological awareness) was significantly related to the growth of invented spelling skills. This finding further confirms the contribution of different early reading skills to children's early writing skills. In other words, while the extent to which children were developing name writing skills was related to their increasing knowledge of letter names, improvements in invented spelling skills were associated with increasing knowledge of letter sounds and phonological awareness.

Lombardino et al.'s (1997) study of the developmental pattern of kindergarten children's invented spelling skills suggested that children with stronger phonological awareness skills performed better on a spelling task while other children who did not perform as well tended to spell the words using random letters. Our study suggests many prekindergarten-aged children have already begun to coordinate letter-sound knowledge and phonological awareness in their writing. Findings also suggest the importance of developing letter knowledge and letter-sound awareness in prekindergarten as the connection between letter names and sounds prepares a foundation for developing strong phonological awareness skills (Kim, Petscher, Foorman, & Zhou, 2010).

Consistent with existing studies (Kegel & Bus, 2014; Oullette & Sénéchal, 2008) no direct significant relation between EF and children's invented spelling was detected after controlling children's early reading and writing skills in regression analyses. Although EF explained a significant amount variance in children's spelling skills concurrently when it was entered first in regression models, the unique variance that EF accounted for decreased after children's reading skills were entered. In other words, while EF may be a critical skill that supports children's invented spelling, it appears to operate through children's letter-sound knowledge and phonological awareness skills in the prekindergarten year. It appears that children who are just beginning to spell phonetically may need to master basic reading skills such as letter knowledge and letter-sound knowledge in order to intentionally encode specific letters when spelling a word based on the word's pronunciation (Clay, 1998; Ehri, 2000). Given that young children's EF is still emerging (McClelland, Geldhof, Cameron, & Wanless, 2015), more direct associations between EF and spelling skills, as well as writing quality, may not emerge until children have more fully developed skills (Graham & Harris, 2000).

A mediating role of early reading skill in children's invented spelling development

Mediation analyses tested whether early reading skills mediated the longitudinal relation between children's EF in the fall and children's invented spelling skills in the spring. Results demonstrate that children's EF at the beginning of the school year significantly related to the amount of growth in children's letter naming and letter-sound skills across the year, but was not related to the growth of phonological awareness. The significant relation between EF and children's growth in letter naming and sound knowledge may be due to the challenging nature of letter-sound recognition. In this task, in addition to recognizing printed letters which were randomly selected, children needed to match them to specific names and sounds retrieved from their memory, and tell the corresponding names and sounds to research assistants. This required children to coordinate attention and working memory skills, in addition to letter knowledge, to complete the task.

While the growth of letter-sound knowledge and phonological awareness were significantly related to children's invented spelling skills in the spring (see Fig. 1), only growth in letter-sound knowledge mediated the relation between children's EF and invented spelling. It may be that children who have stronger EF skills at the

beginning of the pre-kindergarten year achieve higher gains in letter-sound knowledge across the school year, which then, in turn, contributes to children's invented spelling skills. This conjecture appears to be supported by Levin and Aram (2013) intervention study of kindergarteners' literacy and spelling skills. They found that children who had stronger self-regulatory skills improved at a greater rate in both letter knowledge and spelling skills from the intervention than children with lower self-regulatory skills. One explanation is that children with higher EF were more focused than other children during literacy and writing tasks, and, thus, were more likely to benefit from instruction. Findings from this study suggest that children with stronger EF may develop better letter-sound knowledge, which enables them to eventually complete more complex writing tasks, such as invented spelling. Shaul and Schwartz's (2014) study of the role of EF in school readiness skills suggests that EF plays an increasingly important role in the development of kindergarten aged children's literacy skills and that the relation between EF and orthographic skills (e.g., letter naming, letter, and word recognition). They found that EF was one of the strongest predictors of such skills even after controlling for cognitive skills. Taken together, findings about the importance of EF to invented spelling skills through children's development of orthographic knowledge appears supported by existing research.

Implications

The current study highlights associations among children's EF and early reading skills as they relate to children's writing development. Supporting children's EF, early reading, and writing skills should be a focus of prekindergarten instructional practices. Unfortunately, previous research documents that prekindergarten teachers' instructional practices are of relatively low quality in relation to early literacy and writing instruction (Bingham, Quinn, & Gerde, 2017). One reason for this challenge may be that teachers have limited understanding about how to support children's writing skills or that existing guidelines for writing instruction in preschool are relatively underdeveloped (Gerde et al., 2016). Recent studies suggest that teachers' should support children's early writing attempts by focusing on helping children understand the connection between spoken and written language and support their emerging knowledge of the alphabetic principle (Bingham et al., 2017). Given the robust concurrent and longitudinal association between children's phonological awareness and invented spelling skills revealed in this study, findings highlight the importance of supporting children's spelling attempts with attention to phonological awareness skills. For example, teachers should draw attention to children's emerging knowledge about the sounds that letters make and then assist children with writing the salient beginning and/or ending sounds they hear.

Our findings also suggest an important role of children's EF in the development of letter knowledge and invented spelling skills. Because children's EF was found to significantly relate to the growth of children's letter knowledge, and indirectly relate to invented spelling, preschool teachers should engage children in activities that intentionally draw their attention to both early reading skills and writing skills in meaningful and engaging contexts. For example, teachers can incorporate writing

into authentic dramatic play activities in ways that support children's use of their emergent writing skills. Encouraging children to write a grocery list or take an order during play, while scaffolding invented spelling skills, will engage children's interest and attention to writing processes. Additionally, teachers should encourage children to write their names on art work and encourage them to write or recognize the names of other children in the class (Gerde, Bingham, & Wasik, 2012a). Our findings appear to suggest that children's attentional processes (e.g., EF), may support children's letter knowledge in ways that impact children's invented spelling skills. Such attempts to support children's early writing should focus on helping children understand the connection between spoken and written language and support their emerging knowledge of the alphabetic principle (Bingham et al., 2017).

Limitations and future directions

There are limitations in this study that need to be acknowledged. First, we did not control for classroom factors that may directly or indirectly contribute to children's writing performance. Literacy materials in classrooms and teachers' instruction are important contextual factors for children's early learning experiences. Previous research demonstrates the importance of the classroom writing environment (i.e., writing material and teacher's instruction) to the development of children's name writing and invented spelling skills (Gerde, Bingham, & Pendergast, 2015). Future studies should continue to examine how classroom environments and teachers' supportive writing practices relate to children's invented spelling development. Second, we did not account for home variables that may impact children's writing development during prekindergarten. Given findings of the importance of parents to children's writing development (Aram, 2010), more attention should be given to how parents contribute to this development in the early years. Third, we used an integrative EF measure, HTKS, to assess children's EF skills across prekindergarten. Previous studies demonstrate that different EF measures may yield different relations to early literacy skills (Foy & Mann, 2013); thus, future studies should consider employing additional EF measures to further investigate the direct and indirect relations among EF and children's writing skills. Fourth, we assessed children's writing skills and coded children's writing samples based on the extent to which children completed the writing tasks accurately. While WE captured the developmental status of children's handwriting and invented spelling writing development, additional studies, examining a more comprehensive set of writing skills, are needed. Future studies may investigate the pattern of errors that children make during writing tasks and examine whether young children's spelling errors suggest their emerging EF or developing reading skills. In addition, our study suggested a potential bidirectional relation between children's phonological awareness and invented spelling skills. While previous studies suggest invented spelling may have positive impacts on kindergarten-aged children's development of phonological awareness (Levin & Aram, 2013; Sénéchal et al., 2012), we found that children's growth in phonological awareness in preschool year was related to children's spelling skills at the end of prekindergarten. Given the relatively limited

research examining children's EF, letter knowledge, and early writing skills, additional research is needed in order to examine how these skills develop across time and relate to each other. Although some research suggests a bidirectional relation between letter knowledge and letter writing skills (Diamond et al., 2008), the nature and magnitude of these relations (and how they may be mutually reinforcing across time) remains unclear.

Conclusion

This study explored the role of EF in children's invented spelling development utilizing children's early literacy, writing, and EF residual scores. Results demonstrate that although children's EF may be concurrently related to invented spelling skills, EF does not explain unique variance in invented spelling above and beyond children's letter knowledge and phonological awareness skills. Longitudinally, only phonological awareness at the beginning of the prekindergarten school year was significantly predictive of invented spelling skills at the end of the year. Importantly, EF at the beginning of the school year was significantly and indirectly related to invented spelling at the end of the school year through the growth of letter-sound knowledge. Findings suggest the need to examine both direct and indirect associations among children's EF, early literacy, and writing skills across early childhood. Supporting children's acquisition of these skills, particularly as they develop, may be important to ensuring that children begin school ready to benefit from formal reading and writing instruction.

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