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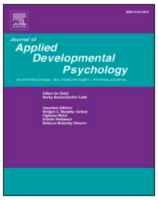

Pathways of mathematics achievement in preschool: Examining executive function and task orientation[☆]

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ABSTRACT

Despite research demonstrating the importance of mathematics achievement to children's educational success and trajectories, many children enter kindergarten without the foundational mathematics skills needed to succeed (Garcia & Weiss, 2015). Children's executive function (EF) skills and their learning-related behaviors (Anthony & Ogg, 2020) may play a key role in supporting their early mathematics achievement (Morgan et al., 2019). Additionally, there is some evidence that children's learning behaviors are a mechanism through which EF is related to math achievement (e.g., Nesbitt et al., 2015), however this pathway hasn't been fully explored. There is also little to no research that has explored whether the pathways through which EF is related to math achievement function similarly for boys versus girls, although some literature suggests that differences in the nature or strength of the associations could contribute to differences in mathematics achievement among boys and girls in elementary school (e.g., Fryer Jr and Levitt, 2010; Robinson-Cimpian et al., 2013; Robinson & Lubienski, 2011). In this study, we used longitudinal data from a racially/ethnically and linguistically diverse sample of 467 preschoolers to examine (1) if children's EF at the beginning of pre-kindergarten predicts growth in their mathematics achievement across the pre-kindergarten year, (2) whether growth in learning behaviors, specifically task orientation, mediate the associations between EF and mathematics achievement, and (3) if there are sex differences in these associations. We found that growth in children's task orientation partially mediates the association between EF and mathematics achievement for the preschoolers in our study. Although girls had significantly higher task orientation, we did not find a statistically significant difference in the direct associations between EF, task orientation, and mathematics or in the mediating effect of task orientation for boys and girls. The discussion reviews implications and directions for future research.

Children who develop strong mathematics skills in preschool are more likely to do well throughout their educational careers (National Mathematics Advisory Panel, 2008). Among both early academic and socioemotional skills, children's mathematical skills at school entry are the strongest predictor of later academic performance in not only mathematics, but also reading (Duncan et al., 2007). However, despite the increased attention to the importance of mathematics, many children enter kindergarten without the foundational mathematics skills needed to succeed (Garcia & Weiss, 2015). In an effort to improve children's mathematics knowledge, a growing number of researchers have identified children's executive function (EF) skills and their approaches to learning (ATL) as playing key roles in supporting their early mathematics achievement (Anthony & Ogg, 2020; Clark, Pritchard, & Woodward, 2010). But even with the growing focus on cross-domain development, the mechanisms underlying the associations between children's EF, ATL, and mathematical skills are not fully understood. Additionally, some research suggests that the associations between EF, ATL, and mathematics achievement may differ between boys and girls, which could help us better understand how boys come to score about a quarter of a standard deviation higher on mathematics tests than girls by the end of third grade (Fryer Jr & Levitt, 2010; Robinson & Lubienski, 2011; Robinson-Cimpian, Lubienski, Ganley, &

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Copur-Gencturk, 2014).

In the current study, we aim to shed light on these questions by using data from a longitudinal study of pre-kindergarten children from low-income families from a large, culturally, and linguistically diverse school system in the United States. More specifically, we consider whether children's mathematics achievement at the end of pre-kindergarten can be predicted by their EF at the beginning of the year, and their growth in ATL skills across the school year, and whether growth in ATL mediates the associations between fall EF and spring mathematics achievement, when controlling for fall mathematics achievement. We also examine whether the associations among EF, ATL, and mathematics achievement vary for boys and girls. Specifically, we examine whether children's sex moderates the associations between EF, ATL, and mathematics achievement and/or moderates any mediating effect of ATL on the association between EF and mathematics achievement.

Literature review

Executive function skills are foundational for children's mathematics readiness

Developmental and educational research has made substantial gains in understanding the domain-general cognitive processes that provide the foundation for children's early learning. EF skills play a critical role in planning, problem solving, and goal directed activity (see Best & Miller, 2010). EF skills include the capacity to inhibit a dominant response and choose an alternative response, hold ideas in working memory and manipulate information, and think flexibly by adjusting to changing demands or priorities (Blair & Razza, 2007; Diamond, Barnett, Thomas, & Munro, 2007). These skills develop rapidly between ages 3 to 5 and research shows that children who show lower than expected gains in EF during this time are at greater risk for learning-related problems when they start school (Willoughby et al., 2017).

Children's EF supports learning across a range of subjects and has been shown to be particularly important for their mathematics development (Blair & Razza, 2007). Mathematics places increased demands on children's EF skills (Bull & Lee, 2014). Additionally, less time is typically devoted to mathematics than other subjects, particularly in the early years, and therefore EF skills are more likely to be activated as children are exposed to new concepts (Sasser, Bierman, & Heinrichs, 2015). In a meta-analysis, Jacob and Parkinson (2015) found a moderate unconditional association between EF and mathematics achievement that is invariant across age, EF construct, and measurement type. In addition, there is growing evidence that all three areas of EF (inhibitory control, working memory, and cognitive flexibility) positively and significantly predict math achievement (Morgan et al., 2019; Nesbitt, Farran, & Fuhs, 2015).

In summary, research suggests that the EF skills that children have when they begin school are important for their academic success in mathematics, and that these skills develop rapidly in the period leading up to and during preschool. Although there is substantial evidence documenting the association between EF and mathematics achievement, we know less about the mechanisms by which the foundational EF skills that children have when they enter preschool shapes their mathematics achievement throughout preschool. Research suggests that cognitive EF skills directly contribute to mathematics achievement by regulating cognition that shapes learning. Inhibitory control is required to suppress inappropriate strategies (e.g., adding when subtracting is necessary) and attending to relevant numerical information. Cognitive flexibility helps in switching between operations, strategies, and between steps of multi-step problems. Working memory allows children to hold relevant information in their minds and store and retrieve relevant information while solving problems (Bull & Lee, 2014; Cragg & Gilmore, 2014; Ropovik, 2014).

Research that links cognitive measures of EF skills with observable child behavior also indicates that EF is involved in regulating behavior in addition to cognition (e.g., Sasser et al., 2015). Lower EF skills are strongly implicated in developmental disorders that have substantial behavioral components, like attention-deficit/hyperactivity disorder (Lambek et al., 2011; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Willoughby et al., 2017) and oppositional-defiant disorder (Moffitt, 1993; Morgan & Lilienfeld, 2000). Studies suggest that children who display symptoms of these disorders have difficulty regulating their behaviors and inhibiting impulses. These studies support the idea that EF skills represent domain-general cognitive processes that are associated with children's regulation of behavior. Given the fact that mathematics learning is situated in the classroom environment, where behavior can contribute to achievement in multiple ways, it may be important to not only examine the direct impacts of EF on mathematics achievement, but also whether the development of learning-related behaviors in preschool may be a pathway through which EF is related to mathematics achievement.

Children's approaches to learning and mathematics achievement

Broadly defined, ATLs are a set of observable learning-related skills that facilitate learning opportunities (Anthony & Ogg, 2020; McClelland et al., 2007). ATLs have been considered a key domain of school readiness (e.g., U.S. Department of Health and Human Services, Administration for Children and Families, 2015) and encompass motivation, persistence, attention to tasks, and frustration tolerance, that affect how children approach and engage with learning tasks (Razza, Martin, & Brooks-Gunn, 2015; Vitiello & Greenfield, 2017).

ATLs have been shown to predict children's skills across learning domains with better ATLs linked to higher academic achievement (Razza et al., 2015; Sung & Wickrama, 2018; Vitiello & Greenfield, 2017; Vitiello, Greenfield, Munis, & George, 2011). Although ATLs have been linked to both mathematics and literacy growth across the early years (Li-Grining, Votruba-Drzal, Maldonado-Carreño, & Haas, 2010), developmental and educational experts have suggested that mastery of mathematics skills may rely more heavily on ATL skills in early childhood than other academic skills. For example, because mathematics is less likely than other content domains to receive significant instructional time in early childhood classrooms (Early et al., 2010; Pianta, Whittaker, Vitiello, Ansari, & Ruzek, 2018), preschool children are required to independently engage in mathematics content in ways that rely more heavily on their ATLs (Fuhs, Nesbitt, Farran, & Dong, 2014). Indeed, studies have shown that, even when controlling for demographic characteristics, children's early interest, attention, and persistence predict mathematics knowledge and skills in early elementary grades (DiPerna, Lei, & Reid, 2007; Dobbs-Oates & Robinson, 2012), and that this relationship may be stronger even for mathematics than literacy (Gullo & Impellizeri, 2021).

As described above, children's ATL skills are broadly defined and encompass multiple skills. In this study, we focus specifically on preschoolers' task orientation – or the degree to which children are able to stay focused on a task, resist distractions, and persist appropriately – is related to their executive function and mathematics achievement (McWayne, Hampton, Fantuzzo, Cohen, & Sekino, 2004). We focus narrowly on task orientation because task orientation is a central component of children's ATL and is correlated with adaptive classroom behavior in kindergarten (Rimm-Kaufman, Curby, Grimm, Nathanson, & Brock, 2009) and multiple measures of school adjustment in early elementary school (Ballantine & Klein, 1990). Longitudinal studies have shown that children's early attention skills may be a particularly salient predictor of later mathematics achievement (Duncan et al., 2007). In a study that explored longitudinal associations between school entry academic skills across six data sets, social-emotional skills, and attention skills and later academic achievement, growth in attention skills significantly predicted later math performance.

As a fundamental component of ATLs, studying how growth in task orientation throughout pre-kindergarten relates to the association between EF and mathematics achievement can provide specific insights into how young children's ability to stay focused and attend to tasks relates to their mathematics development and learning in preschool. Examining task orientation will also contribute to our knowledge of the construct, which has not been as thoroughly studied as ATLs broadly.

Task orientation as a mediator of EF and mathematics achievement

The literature makes clear that children's EF and task orientation both play an important role in their mathematics achievement. However, to date, less attention has been paid to *why* or *how* these skills matter, and how these skills may relate to one another to shape children's mathematics achievement. Some scholars have hypothesized that ATLs may be one of the key mechanisms through which EF is associated with mathematics achievement (Anthony & Ogg, 2020; Nesbitt et al., 2015; Sung & Wickrama, 2018; Vitiello et al., 2011). These studies suggest that EF facilitates children's learning-related behaviors, which in turn, promotes children's mathematics achievement. For example, using a nationally representative sample of kindergartners from the Early Childhood Longitudinal Study Kindergarten Cohort of 2011, Sung and Wickrama (2018) found that children with a higher level and faster growth rate in EF and ATL showed a faster rate of change in reading and mathematics between kindergarten and first grade. There was both a direct effect of EF trajectories on academic achievement, and an indirect effect through ATL trajectories. Similarly, Vitiello et al. (2011), in a study of 121 Head Start children, found that ATL mediated the relations between cognitive flexibility and mathematics knowledge and skills.

Importantly, some research has not found the same associations between EF, ATL, and achievement. Vitiello and Greenfield (2017), for example, found no significant mediation, although both EF and ATL skills independently contributed to children's achievement gains. Similarly, in a longitudinal study, Sasser et al., (2015) also found that EF and ATLs directly predicted pre-kindergarten children's mathematics achievement, but no significant mediation was found for mathematics outcomes (although mediation was significant for reading skills). Similarly, in their study of how EF relates to achievement and learning-related behaviors, Brock, Rimm-Kaufman, Nathanson, and Grimm (2009) found that children's classroom behavior did not account for the association between cognitive EF skills and math achievement. Furthermore, in a large-scale study of how instruction, EF, and ATL relate to mathematics achievement in kindergarten and 1st and 2nd grades, Ribner (2020) found that while EF was strongly associated with mathematics achievement in all grades, there was a negative association between ATL and math achievement.

The presence of such mixed findings highlights the need for further research into how EF, ATL, and mathematics achievement relate, particularly in pre-kindergarten during which time children engage in coursework and interactions intended to improve their school readiness skills.

Our study contributes by specifically examining how growth (e.g., residualized change) in children's task orientation *across the school year* is related to children's EF skills when they enter preschool and whether growth in task orientation mediates the association between fall EF skills and mathematics achievement over the year. This differs from previous research in important ways. First, we examine EF skills in the fall of preschool as a set of foundational cognitive skills that contribute to children developing learning-related skills that contribute to their academic achievement in preschool. This proposes and tests a specific developmental pathway between EF and ATLs that is not examined in research that measures task orientation or other measures of ATLs at one point of time during the year (e.g., Brock et al., 2009; Ribner, 2020; Vitiello & Greenfield, 2017). Assessing ATL at the beginning or end of the year does not examine how growth (i.e., residualized change) in ATL contributes to the relationships between EF and mathematics achievement. In our study, we also specifically position fall EF skills as foundational to the development of task orientation skills across the school year. This also differs from research that focuses on growth in EF or in how ATL's predict EF skills. Furthermore, unlike studies examining associations starting in kindergarten or later (e.g., Ribner, 2020; Sung & Wickrama, 2018), we focus on the growth of task orientation during preschool, at a time when children have experienced rapid development of EF skills and when they are engaging in an environment intended to support their school readiness.

Differential pathways to mathematics achievement for boys and girls

We also explore whether there are sex differences in how EF relates to task orientation and whether these differences could contribute to differences in how boys and girls learn math in preschool. Research shows that by high school, boys are more engaged and interested in their mathematics coursework and consistently outperform girls on standardized mathematics assessments (e.g., Else-Quest, Hyde, & Linn, 2010). There is evidence that these gaps begin to emerge as early as kindergarten. Specifically, persistent gaps between boys and girls on mathematics achievement tests range from an effect size of 0.10 to 0.30 (Fryer Jr & Levitt, 2010; Robinson & Lubienski, 2011), and these gaps are more pronounced at the top of the score distribution (Penner & Paret, 2008; Robinson & Lubienski, 2011). What is less clear *is how and why* these gaps emerge.

Some research suggests that differences in how EF develops or works in girls and boys could influence how they engage in academic tasks. For example, research suggests that girls may develop some components of EF earlier or differently than boys. In a nationally representative sample of boys and girls between the ages of 5 and17, Naglieri and Rojahn (2001) found that girls with comparable demographic characteristics outperform boys on planning and attention – key cognitive skills strongly related to EF and task orientation. Planning and attention enable children to think deeply about tasks, resist distractions, and select the best method for solving a problem – skills that are foundational to children's ATLs. This literature suggests that girls may be stronger in EF skills that directly contribute to ATLs in preschool.

Other research suggests sex differences in the neural networks that underlie EF. For example, neuroscientists have found that working memory—an important component of EF—involves different neural network in adult males and females (Haier, Jung, Yeo, Head, & Alkire, 2005; Hill, Laird, & Robinson, 2014). In males, working memory activates regions of the brain related to spatial processing, whereas in females it activates brain regions involved in verbal processing (Haier et al., 2005; Hill et al., 2014 xxx), which shapes the strategies that girls and boys use to solve complex problems (Haier et al., 2005). On one hand, spatial processing is directly associated with mathematics learning (Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014). On the other hand, among preschoolers, girls may have an advantage in a classroom environment in which teachers engage girls in high quality interactions that support their development of mathematics concepts and skills (e.g., Early et al., 2007).

Children's task orientation could also relate to mathematics achievement in boys and girls in different ways. For example, some research suggests that gaps in academic grades can be explained by differences in teachers' reports of boys' and girls' effort and behavior. In late elementary and middle school, girls are more likely than boys to hold mastery over performance goals and to productively engage in the classroom (Kenney-Benson, Pomerantz, Ryan, & Patrick, 2006). Alternatively, task orientation among girls and boys could be interpreted differently by teachers in ways that could impact their learning and achievement. In one study using the nationally representative Early Childhood Longitudinal Study – Kindergarten Cohort of 1998, girls were only perceived by teachers as being as mathematically competent as similarly achieving boys when their teachers also reported that they worked harder, exhibited better social behavior, and showed a greater eagerness to learn than boys (Robinson-Cimpian et al., 2014). The above pattern of findings can result in teachers underrating the abilities of girls who are perceived as less highly engaged, which can contribute to gaps in mathematics achievement in the early grades (Robinson-Cimpian et al., 2014).

By examining the nature of the associations among fall EF, residualized change in task orientation, and mathematics achievement among boys and girls in pre-kindergarten, we are exploring a potential pathway that could contribute to differences in mathematics achievement over time. Given how little is known about sex differences in how EF, residualized change in task orientation, and mathematics achievement relate to one another in prekindergarten, we explore these associations to examine if they could contribute to sex differences in mathematics achievement that are well-documented in subsequent years of children's education.

The Current Study

The current study examines the associations among children's fall EF and changes in task orientation skills, their direct and indirect associations with mathematics achievement. We also explore whether associations between EF, changes in task orientation, and mathematics achievement differ for boys and girls.

Specifically, we examined the following research questions:

1. What are the direct associations between children's fall EF, growth in task orientation, and gains in mathematics achievement across the pre-kindergarten year?
2. To what extent does growth in children's task orientation mediate the association between their fall EF skills and mathematics achievement?
3. To what extent do these direct and indirect associations between EF, growth in task orientation, and mathematics achievement vary for boys and girls?

Methods

Recruitment and Participants

Data for this study come from a larger longitudinal study of prekindergarten children in a large, culturally and linguistically diverse school system in the United States (IES R305B170002 and R305N160021). Teachers were recruited in the fall of 2016 from publicly funded center-based classrooms that served children from low-income families. Participating teachers sent home consent forms and family demographic surveys to eligible children. Children were eligible for the larger study if they turned 4 by September 30th and did not have an IEP (other than for speech). Eighty percent of parents had children who were eligible to participate and consented to allow their child's participation, resulting in 1500 participating children from 138 classrooms. Children in the larger sample were 50% male and 55.01 months old at the start of the study (SD = 3.51). The parent study sample was ethnically diverse, comprised of 60% Hispanic/Latino, 17% Black, 10% White, 9% Asian, and 4% multiracial or other ethnicities. The majority of teachers were White (66%) and had approximately 16 years of teaching experience (SD = 10.11).

For the current study, we selected children from the larger study who completed study assessments in English in the fall and spring and who were determined to be proficient in English (see more information in Procedures). Due to the cultural and ethnic diversity of the sample, all children were assessed for English language proficiency prior to administering direct assessments of mathematics and executive function skills. Children who scored above the cut-point for English language proficiency as determined by the language screening assessment (preLAS; Duncan & De Avila, 1998) were assessed in English in the fall and spring. Children who scored below the cut-point for English language proficiency *and* whose parents reported that their home language was Spanish participated in separate sessions in which mathematics and EF skills were assessed in English and Spanish (Woodcock, McGrew, & Mather, 2001; Woodcock & Sandoval, 1996). Forty-four percent of children in the sample received the Spanish assessments in the fall. In the spring, however, these children received the assessments only in English, which may or may not correspond with either the English or Spanish assessment in the fall.

Furthermore, the study did not have the capacity to assess all children who were not proficient in English in their home language. Children who did not score above the threshold for English language proficiency whose parents indicated that their home language was a language other than Spanish were given the direct assessments in English, even though the English version may not have accurately captured their skills. Thus, for the purposes of the present study, we focused children who completed all assessments in English in the fall and spring *and* who scored above the cut-point for English language proficiency.

Thus, of the original 1500 children in the parent study, 467 were eligible to participate in our study. On average, the 467 children in our sample were 53 months old at the start of pre—K, had parents with an average of 13 years of education, and were racially and ethnically diverse, (31% Hispanic/Latino, 35% Black, 8% White, 11% Asian, 15% multi-racial or other ethnicities). Children were nested in 115 classrooms (average 4 students/class), 27 of which were Head Start classrooms, 87 were public pre—K, and 1 was in a private pre-K center. Overall, the sub-sample reflected the larger study: classrooms were balanced in terms of the proportion of boys and girls (51% boys), consisted of mostly 4-year-olds (77%), and included a small proportion of students with special needs (8%). Teachers in these classrooms were largely White (60%) and averaged 17 years of education. See Table 1 for sample descriptive statistics, with model predictors, outcomes, and covariates stratified by child sex.

Procedures

Data were collected through parent surveys, teacher surveys, and direct assessments. Parents completed brief demographic questionnaires in the fall of pre-K. Teachers completed rating scales about each participating child in the fall and spring. Trained data collectors conducted direct assessments of children's skills in the fall (September–November) and spring (April–May). Data collectors completed a one-day training to learn the measures prior to assessing children and assessed children outside of the classroom in a quiet space, when possible. All procedures were approved by the Institutional Review Board at the University of Virginia and parents and teachers received a small stipend to thank them for their time.

Measures

PreLAS. We assessed children's English language fluency with 3 of the 5 parts of the preLAS: Part 1-Simon Says (receptive), Part 3: Art Show (expressive/productive) and Part 4: The Human Body (expressive/productive) (Duncan & De Avila, 1998). Students who received a score of 31–40 were assessed on the full battery in English (Duncan & De Avila, 1998). Students who scored 30 or below and had a home language of Spanish were assessed in English on the four WJ-III subtests and then in Spanish for BDS, HTKS, and PT. A subset of these students also received the Spanish version of the WJ-III, Bateria Estandar. Students who scored 30 or below and had a home language other than Spanish were assessed only on the four WJ-III subtests in English. However, in the spring, all children were assessed in English because prior analyses with this sample using the fall PreLAS indicated the fall assessment underestimated children's skills in English. Given the potential poor alignment of the fall language of assessment with children's language skills and given the change in language assessment from fall to spring for some students, we selected students who scored above 30 on the preLAS *and* who received the English language assessment in the fall and spring.

Table 1
Descriptive statistics for the study sample (n = 467).

Variable	Whole sample means (S.D.) and percentages	Groups means and percentages		Between-group differences	
		Boys	Girls	ANOVA F or Chi-Square*	*p*
Teacher characteristics					
Years of education	16.92 (1.53)				
Years of experience	16.48 (9.72)				
Non-White	40.00%				
Classroom characteristics					
Percent 3-year-olds	8.26 (10.10)				
Percent 4-year-olds	76.83 (14.65)				
Percent 5-year-olds	14.91 (11.48)				
Percent boy	50.79 (11.27)				
Percent special needs	7.58 (6.86)				
Child and family covariates					
PreLAS score	31.92 (5.55)	31.35 (5.96)	32.39 (5.15)	4.11	0.04
Male	45.60%				
Age (months)	53.41 (3.35)	53.40 (3.40)	53.42 (3.32)	0.00	0.95
Race/ethnicity				5.84	0.44
Black	35.10%	36.90%	33.60%		
White	8.33%	6.70%	9.70%		
Hispanic/ Latino(a)	30.81%	31.30%	30.40%		
Asian or Pacific Islander	11.36%	9.50%	12.90%		
Multi-racial	11.60%	11.20%	12.00%		
Other	2.80%	2.00%	0.80%		
Parent years of education	13.22 (1.82)	13.20 (1.87)	13.24 (1.78)	0.05	0.83
Income-to-needs ratio	1.01 (0.62)	0.99 (0.62)	1.04 (0.61)	0.61	0.44
Teacher reported closeness (Spring)	4.49 (0.59)	4.25 (0.72)	4.43 (0.64)	9.55	<0.001
Focal variables and predictors					
Executive function composite (Fall)	0 (0.75)	−0.07 (0.77)	0.06 (0.74)	3.83	0.05
PT (Fall)	10.32 (5.21)	9.67 (5.46)	10.86 (4.40)	6.16	0.01
HTKS (Fall)	25.71 (25.64)	22.08 (24.80)	28.74 (25.99)	7.90	0.01
BDS (Fall)	1.33 (0.66)	1.35 (0.69)	1.31 (0.64)	0.45	0.50
Child task orientation					
Fall	3.61 (0.93)	3.37 (0.97)	3.83 (0.85)	26.72	<0.001
Spring	3.79 (0.96)	3.51 (1.02)	4.02 (0.84)	31.26	<0.001
Math achievement					
WJ fall math reasoning	408.30 (17.61)	407.49 (17.40)	408.98 (17.79)	0.83	0.36
WJ spring math reasoning	421.96 (15.92)	421.08 (16.71)	422.71 (15.21)	1.14	0.29
WJ retest time (days)	186.93 (21.67)	188.25 (20.82)	185.80 (22.36)	1.39	0.24

*p < .05; **p < .001.

Executive Function. Based on evidence suggesting that EF is best represented as a unitary construct during the preschool period (e.g., Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Fuhs & Day, 2011; Nelson, James, Chevalier, Clark, & Espy, 2016), we constructed a composite of children's executive function skills based on measures of working memory, attentional focus, and inhibitory control in the fall of the academic year. To create the composite, we standardized the raw score or total number of correct responses for each scale and calculated an average of the three standardized scores. Recent research suggests that compositing individual EF measures to create a mean score represents EF better than creating a latent EF factor score (see Kuhn et al., 2016 for a discussion of conceptual, pragmatic, and statistical evidence for compositing EF measures).

Backward Digit Span. Working memory was assessed with the Backwards Digit Span (BDS; Carlson, 2005), which asks children to repeat sequences of random numbers in reverse that increase in length. First, the child practices repeating two consecutive numbers in reverse (1,2). The administrator has the child practice at least twice – after each incorrect trial, the administrator demonstrates the correct response and then they try again until they get it correct up to 6 trials. The official assessment begins with three sets of two random numbers (e.g., 1, 5), then three sets of three random numbers (e.g., 6, 4, 1), and so on, up to three sets of 5 numbers (e.g., 4, 2, 1, 3, 5). The administrator circles all sequences that the child receives correct and crosses out any that were incorrect. At the end of the full trial, the highest number of digits that the child was able to repeat in reverse is their score on the assessment. For example, if a child answered 1 or up to 3 sets of 5 numbers correct, they would receive a score of 5, etc. (0 to 5; $\alpha = 0.60$).

Pencil Tap. Inhibitory control was assessed with the Pencil Tap task (PT; Smith-Donald, Raver, Hayes, & Richardson, 2007). This assessment asks children to tap once when the assessor taps twice and vice versa. Similar to BDS, the administrator has the child practices for at least two and up to six trials, demonstrating the correct response after any incorrect responses. Children complete 16 trials, the number of times they tap their pencil is recorded, and the total number of "correct" reverse taps is the final score. Pencil Tap has shown good concurrent and construct validity (Smith-Donald et al., 2007). The internal consistency in the current sample was excellent ($\alpha = 0.94$).

Head-Toes-Knees-Shoulders. The Head-Toes-Knees-Shoulders assessment (HTKS; McClelland et al., 2007) measures a combination of working memory, inhibitory control, and attentional focus by asking children to do the opposite of what the data collectors asked (e.g., the child touches their toes when the data collector instructs the child to touch their head). The administrator has the child practice before they begin – after each incorrect trial, the administrator explains the correct response and then they try again until they get it correct or up to three times. Correct (i.e., opposite) responses are scored "2," incorrect (i.e., same) responses that the child catches and self-corrects are scored "1," and incorrect responses that the child does not catch are scored "0." The score on the scale is the total points after 10 trials. Internal consistency was good ($\alpha = 0.89$).

Task Orientation. Students' task orientation was assessed with the task orientation sub-scale of the Teacher Child Rating Scale (Hightower, 1986). The sub-scale includes six items about the quality of children's academic involvement in the classroom, including the extent to which a child completes their work, is well organized, functions well with distractions, and works well without adult support, and is a self-starter (e.g., "Please rate the following items according to how well they describe the child… Completes work, Functions well even with distractions"). Teachers responded to these items on a 5-point Likert scale (1 = *not at all*, 3 = *moderately well*, 5 = *very well*) on rating scales they completed in the fall of the academic year (α = 0.92). Teachers rated task orientation in the fall and the spring. For this study, we regress task orientation in the fall onto task orientation in the spring in order to estimate residual change in task orientation as the mediator.

Mathematics achievement. Children's mathematics achievement was assessed in the fall and spring with the Math Reasoning score of Woodcock Johnson III Psychoeducational Battery (WJ-III; Woodcock et al., 2001). Math Reasoning is a combination of Applied Problems and Quantitative Concepts subtests. The Applied Problems subtest required children to perform basic math calculations in response to orally presented problems (e.g., "Show me two fingers"; α = 0.93). The Quantitative Concepts subtest required children to identify number patterns (e.g., "How many houses are there?" [child is shown an image with 2 identical houses]; α = 0.91). Together, Math Reasoning is an aggregate measure of problem solving, analysis, reasoning, and vocabulary. For the purposes of this study, we used the W scores, which are suggested for use in analyses that measure growth over time (see Jaffe, 2009). To capture growth in mathematics reasoning over preschool, we controlled for children's scores in the fall when predicting their scores in the spring and we controlled for the time between math assessments.

Covariates. In order to increase the precision of the estimated associations between EF, task orientation, and mathematics achievement and the moderating role of child sex, we controlled for relevant child and family covariates that were available in the data (Cohen, 2001).

Child and Family Demographics. The school district provided information about students' sex and ethnicity. At the start of the school year, parents reported their child's age, race/ethnicity, the language spoken at home, and their years of education and income-to-needs ratio on demographic questionnaires.

Closeness. We included teacher report of closeness in the spring with the child in order to control for teachers' positive bias in reporting positive classroom behavior of children with whom they share a close relationship. Closeness was assessed with the Student–Teacher Relationship Scale (Hamre & Pianta, 2001). Teachers reported on nine items about their relationship with each participating child, based on a 5-point scale (e.g., "I share an affectionate, warm relationship with this child," "It is easy to be in tune with what this child is feeling"; 1 = *definitely does not apply*, 3 = *neutral, not sure,* 5 = *definitely applies*), which assess the extent to which teachers felt a warm and affectionate relationship with the child (α = 0.82).

Analytic strategy

To address the study objectives, we first assessed if there were significant associations between EF in the fall, residualized change in children's task orientation, and their mathematics achievement in the spring, when controlling for fall math achievement and relevant covariates in a series of linear regression analyses (Baron & Kenny, 1986). We then ran a path analysis to examine the mediation model, followed by multi-group analysis to explore moderation by child sex. Notably, the lagged dependent variable model predicted both the direct effect of children's EF in the fall on children's mathematics achievement in the spring while controlling for their mathematics achievement in the fall, and the indirect effect of the residualized change in their task orientation.

To assess whether we should use cluster-robust standard errors because children's task orientation and math achievement are related to their homeroom teacher, we assessed the intraclass correlation (ICC) of children's mathematics achievement and task orientation with their teacher. The ICC for task orientation is 0.17 for the fall and 0.19 for the spring; the ICC for math reasoning in the spring, is 0.03, both of which are comparable to the range of ICC's seen in an educational context (see Hedges & Hedberg, 2007). As a robustness check, we ran the models with and without robust clustered errors. Similar to other measurement work showing that the level of ICCs may not contribute to differences between MLM and OLS point estimates (Mundfrom & Schultz, 2001), results from both types of models were nearly identical. Given the ICC for task orientation (a teacher-report) reflects sufficient nesting to warrant cluster-robust standard errors, we adjusted for children's classroom membership using robust clustered standard errors and report those findings in this paper (Diggle et al., 2002).

Parameter estimates and goodness-of-fit statistics were computed with M*plus* 8.0 (Muthén & Muthén, 1998-2017). The robust maximum likelihood estimator option was specified (MLR) with TYPE = COMPLEX, which produces model parameter estimates and standard errors that are robust to model assumption violations (e.g., non-normality in the outcome, heterogeneity, dependence in subjects). We evaluated whether the models were a good fit for the data using criteria suggested by Hu and Bentler (1999) (SRMR <0.08, RMSEA <0.06, and CFI > 0.90–0.95; we also include the model chi-square, though it tends to be significant in larger samples). We also compared the whole group and multi-group models with the Akaike Information Criteria (AIC; Akaike, 1974) and the Bayesian Information Criterion (BIC; Raftery, 1995), with lower values indicating better fit.

To address the question of the mediating role of task orientation in predicting children's mathematics achievement from their executive function skills, we fit a mediation model (depicted in Fig. 1) that estimated residualized change of task orientation from the fall to the spring in order to isolate the unique contribution of executive function (i.e., if executive function and task orientation in the fall are highly correlated, then there should be nothing left over for executive function to explain). The mediation model incorporated covariates in order to control for the influences of children's age, race, socioeconomic status (parent years of education and income-to-needs ratio), closeness with their teacher, and mathematics achievement in the fall on their mathematics achievement in the spring. Specifically, in order to account for the possibility that mathematics achievement (the outcome) and task orientation (the mediator) have common causes (Judd & Kenny, 2009), we included the same covariates in the a and c′ paths in the analysis (see Fig. 1).[1] According to standard practice (e.g., Fairchild & MacKinnon, 2009), we examined the mediating effect of task orientation on the associations between executive function and mathematics achievement by examining the significance of the ab path in the model with the Sobel Test (using the "model INDIRECT" command in Mplus). Finally, we used "CINTERVAL" in the OUTPUT commands to produce confidence intervals in order to assess asymmetric sampling distribution of the ab parameter estimates.

To test for the moderating effect of children's sex, we ran a multi-group analysis that simultaneously tested for group differences in the pathways of interest for boys and girls. Specifically, the multi-group analysis compared the mediation model where the paths are constrained to be equal across boys and girls to a mediation model where the paths varied by student sex. In this way, the multiple group analysis allowed us to examine which specific paths of the mediation model

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[1] As a robustness check, we also ran models that included children's preLAS score as a covariate. While the preLAS score was used to select our study sample, variability in English language skills could influence the validity of the direct assessment of children's EF and math skills and could influence associations among EF, ATL, and math achievement. The size and significance of the results with the preLAS as a covariate were comparable to when the preLAS was not included and the model fit was reduced, so we chose not to include the preLAS as a covariate in the analysis.

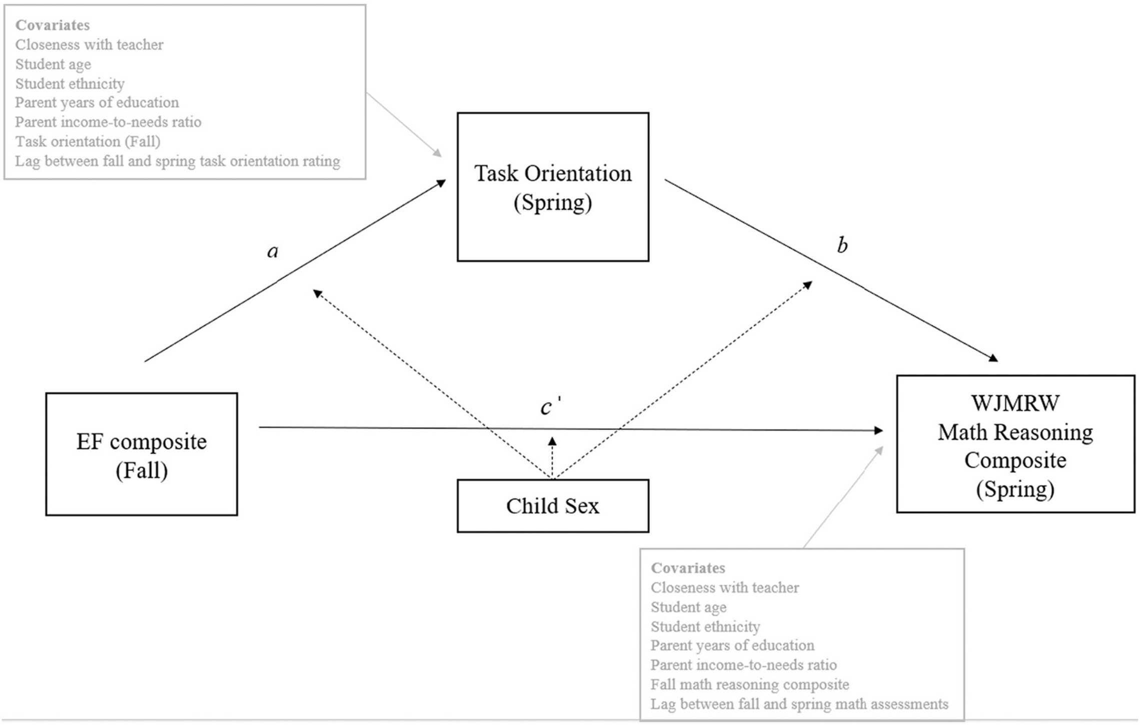

Fig. 1. Moderated mediation model illustrating the hypothesized paths between EF in the fall, residualized change in task orientation, and math achievement in the spring while taking mathematics achievement in the fall into account, assessing the moderating role of child sex.

differed between boys and girls and whether there was a significant difference in the indirect effect of executive function on mathematics achievement through task orientation for boys and girls.

We used multiple criteria to assess the moderated mediation model. First, we assessed differences in the indirect effect across children's sex and we assessed sex differences in the specific direct paths as explanatory evidence of moderation within the mediation model. Second, we used the Wald chi-square test to formally assess whether differences in the indirect effect or path coefficients of the mediation model between boys and girls were statistically significant (Little, Card, Bovaird,

Table 2
Pearson bivariate correlations between model predictors and outcomes.

#	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		r (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)
1	Child gender														
2	Parent years of education	−0.01 (0.83)													
3	Income-to-needs ratio	−0.04 (0.44)	0.30 (0.00)												
4	Child age	−0.00 (0.95)	−0.04 (0.41)	−0.05 (0.31)											
5	Closeness with teacher (spring)	−0.15 (0.00)	−0.07 (0.20)	−0.01 (0.87)	0.13 (0.01)										
6	Task Orientation (fall)	−0.24 (0.00)	0.08 (0.15)	0.02 (0.71)	0.27 (0.00)	0.28 (0.00)									
7	Task Orientation (spring)	−0.27 (0.00)	−0.01 (0.80)	−0.00 (0.93)	0.24 (0.00)	0.40 (0.00)	0.75 (0.00)								
8	PreLas score	−0.09 (0.04)	0.18 (0.00)	0.12 (0.02)	0.20 (0.00)	0.21 (0.00)	0.32 (0.00)	0.27 (0.00)							
9	WJ Math Reasoning (fall)	−0.04 (0.36)	0.16 (0.00)	0.09 (0.09)	0.32 (0.00)	0.13 (0.01)	0.35 (0.00)	0.36 (0.00)	0.60 (0.00)						
10	WJ Math Reasoning (spring)	−0.05 (0.29)	0.15 (0.00)	0.09 (0.09)	0.28 (0.00)	0.19 (0.00)	0.39 (0.00)	0.41 (0.00)	0.57 (0.00)	0.79 (0.00)					
11	WJ retest time	0.06 (0.24)	−0.03 (0.52)	0.00 (0.93)	−0.01 (0.86)	0.09 (0.06)	−0.03 (0.50)	0.02 (0.66)	0.04 (0.40)	0.04 (0.38)	0.11* (0.03)				
12	EF composite (fall)	−0.09 (0.05)	0.158 (0.00)	0.07 (0.19)	0.27 (0.00)	0.16 (0.00)	0.29 (0.00)	0.32 (0.00)	0.46 (0.00)	0.65 (0.00)	0.61 (0.00)	0.08 (0.10)			
13	Pencil Tap z-score (fall)	−0.11 (0.01)	0.15 (0.00)	0.08 (0.14)	0.26 (0.00)	0.16 (0.00)	0.29 (0.00)	0.31 (0.00)	0.41 (0.00)	0.55 (0.00)	0.50 (0.00)	0.03 (0.55)	0.78 (0.00)		
14	HTKS z-score (fall)	−0.13 (0.01)	0.15 (0.00)	0.10 (0.04)	0.21 (0.00)	0.13 (0.01)	0.26 (0.00)	0.25 (0.00)	0.41 (0.00)	0.49 (0.00)	0.50 (0.00)	0.10 (0.03)	0.79 (0.00)	0.48 (0.00)	
15	BDS z-score (fall)	0.03 (0.50)	0.05 (0.28)	−0.03 (0.51)	0.15 (0.00)	0.09 (0.08)	0.12 (0.02)	0.18 (0.00)	0.23 (0.00)	0.42 (0.00)	0.40 (0.00)	0.04 (0.35)	0.71 (0.00)	0.29 (0.00)	0.32 (0.00)

Preacher, & Crandall, 2007). Finally, we also consider improvements in model fit to support that the model is better represented by incorporating the moderating effect of child sex. We dealt with missing data (which averaged 6% across all variables and ranged from 0% to 19% on any given variable) by applying the full information maximum likelihood method in M*plus* (Schafer & Graham, 2002), which allowed us to use all available data.

Results

Descriptive Statistics

Descriptive statistics for all study variables are presented in Table 1. Analyses of Variance (ANOVAs) and Chi-Square tests reveal that girls and boys do not differ in terms of key demographic characteristics (e.g., English fluency, parent years of education, race, or ethnicity), or regarding their mathematics achievement in fall or spring. There were, however, significant differences in teacher reported closeness and task orientation in the fall and spring, with girls scoring significantly higher on these variables. Table 2 includes bivariate correlations among the variables of interest. Results show a strong positive correlation between fall EF and spring mathematics achievement ($r = 0.61$) and a moderate positive correlation between fall task orientation and spring mathematics achievement ($r = 0.41$).

Associations between EF, ATL, and Mathematics

In a series of linear regressions testing the associations between EF, ATL, and mathematics achievement (when including the list of covariates previously described), we found that children's EF in the fall of preschool predicts both their mathematics score in the spring ($\beta = 0.16$, $p < .001$) and the residualized change in their task orientation ($\beta = 0.11$, $p = .001$). Also, residualized change in task orientation predicts mathematics test scores in the spring ($\beta = 0.14$, $p = .001$).

Table 3 presents results from model examining the direct and indirect associations among EF, ATL, and children's spring mathematics achievement. Results from this model reveal that children who entered pre-k with stronger EF skills demonstrated greater gains in mathematics achievement across the school year ($\beta = 0.15$, $p < .001$). Notably, these results relate children's baseline EF skills in the fall with change in academic achievement from fall to spring. Moreover, children with stronger fall EF skills also showed greater change in task orientation in the classroom from the fall to the spring ($\beta = 0.11$, $p = .001$). Finally, children with stronger change in task orientation demonstrated greater gains in mathematics achievement across the year ($\beta = 0.11$, $p = .003$).

Task orientation as a mediator

Overall, the mediation model shows evidence of good fit to the data (RMSEA = 0.066 (0.048, 0.085), SRMR = 0.034, CFI = 0.95). In the mediation model, the indirect effect of residualized task orientation, when controlling for relevant covariates, is statistically significant ($\beta = 0.01$, $p = .006$; see a and b paths in Fig. 1, Table 3). The direct effect of fall EF on mathematics achievement in the spring, while controlling for fall math achievement and a comparable set of covariates, remains statistically significant ($\beta = 0.15$, $p < .001$; see c′ path in Fig. 1, Table 3). Therefore, the effect of fall EF on math achievement is partially mediated by changes in children's task orientation from fall to spring. Specifically, the proportion of the effect of fall EF on children's math achievement from fall to spring that is mediated is 7.5% (proportion of mediated effect = 1 – the direct effect (c') / the total effect ($c = c' + ab$); Baron & Kenny, 1986).

Moderation and moderated mediation by child sex

Having established the focal associations of interest in the full sample, we next estimated multi-group path models to assess whether these associations operated differently for boys and girls. Results from these analyses revealed some preliminary evidence of potential differences among boys and girls in the relation between EF, task orientation, and mathematics achievement. As mentioned above, we first compared a model in which the mediation effect was constrained to be equal across boys and girls with a model in which the paths were allowed to vary across these groups. The multi-group model had good fit to the data (RMSEA = 0.030 (0.000, 0.061); SRMR = 0.015; CFI = 0.994). The AIC and BIC indices also decreased, which indicates that the data is better represented in the multi-group model (AIC = 19,645.22; BIC = 20,938.88) than the whole group model (AIC = 20,346.57; BIC = 21,043.15). The chi-square for both the multi-group [X^2 (62, N = 254, 213) = 962.700, $p < .001$)] and whole group [X^2 (21, N = 467) = 63.495*, p < .001)] is significant.

Sex differences in direct associations

Analyses revealed that child sex does not moderate the independent associations between EF, residualized change in task orientation, and mathematics achievement. While the sub-group analyses showed differences in which paths were significant for girls and boys, the sex difference itself is not statistically significant (see Fig. 1, Table 3 for an overview of all sex differences results). Specifically, the standardized model results for that girls' fall EF predicts their mathematics achievement (the c′ path; $\beta = 0.16$, $p = .006$) and the residualized change in task orientation (*a* path; $\beta = 0.15$, $p = .001$), and their residualized task orientation predicts their math achievement (*b* path; $\beta = 0.12$, $p = .005$). In contrast, whereas boys' mathematics achievement is predicted by both their fall EF (c' path; $\beta = 0.13$, $p = .01$) and residual change in task orientation (*b* path; $\beta = 0.11$, $p = .04$), residualized task orientation is not significantly related to boys' EF in the fall (*a* path; $\beta = 0.06$, $p =$

Table 3
Standardized regression coefficients for the relation between EF and mathematics achievement as mediated by residualized change in task orientation.

	Whole sample mediation			Multi-group moderated mediation								
				Girls			Boys			Wald Test		
	B	SE	*p*	*B*	SE	*p*	*B*	SE	*p*	*Est*	SE	*p*
Path a	0.11	0.03	0.001	0.15	0.05	0.001	0.06	0.05	0.228	0.01	0.02	0.538
Path b	0.11	0.04	0.003	0.12	0.04	0.005	0.11	0.06	0.043	0.46	1.08	0.672
Path c′	0.15	0.04	0.000	0.16	0.06	0.006	0.13	0.05	0.012	0.05	0.05	0.247
Indirect effect	0.01	0.01	0.028	0.02	0.01	0.034	0.01	0.01	0.332	0.02	0.49	0.562
CI (95%) of indirect effect	0.001, 0.026			0.001, 0.036			−0.006, 0.018					
RMSEA	0.066 (0.048, 0.085)			0.030 (0.000, 0.061)								
CFI/TLI	0.946			0.994/0.986								
SRMR	0.034			0.015								
AIC	20,346.57			19,645.224								
BIC	21,043.15			20,938.879								
Chi-Square	63.495 (21) $p = .000$			962.700 (62) $p = .000$								

.228). The Wald Chi-Squared tests reveal, however, that these differences are not statistically significant, resulting in no moderation by child sex (see Table 3).

Sex differences in mediating effect of task orientation

Similarly, child sex does not moderate the mediating effect of residualized task orientation. In the multi-group model, the indirect effect was significant for girls ($\beta = 0.05$, $p = .005$), but not significant for boys ($\beta = 0.01$, $p = .332$). However, the difference in the indirect effect between boys and girls was not statistically significant (Wald $= -0.29$, $p = .56$).

Discussion

Despite an increased focus on supporting early mathematics, many children continue to enter kindergarten without foundational mathematics skills needed to succeed (Garcia & Weiss, 2015). Furthermore, gaps in mathematics achievement among boys and girls emerge early in elementary school and persist throughout later years of schooling and affect STEM education and labor force participation (Else-Quest et al., 2010; Fryer Jr & Levitt, 2010; Robinson & Lubienski, 2011). Given the importance of children's mathematics achievement, the current study sought to examine: 1) the associations among fall EF, growth in task orientation, and mathematics achievement in pre-kindergarten; 2), whether growth in task orientation mediated the relations between EF and mathematics achievement, and 3) whether these associations varied as a function of child sex.

Direct and indirect associations among EF, task orientation, and mathematics gains

Results support prior research suggesting a positive association between early EF, ATL, and mathematics skills (Blair & Razza, 2007; Sung & Wickrama, 2018; Ursache, Blair, & Raver, 2012; Vitiello & Greenfield, 2017). They add to growing empirical research suggesting children's EF skills and learning behaviors may be ways to support children's mathematics achievement in the early years (e.g., Jacob & Parkinson, 2015; Vitiello & Greenfield, 2017). Specifically, the results suggest that targeting EF skills before or at the start of pre-kindergarten might be particularly effective at supporting math achievement, and that the strongest instructional approaches might combine supports for children's EF, learning behaviors, and mathematics knowledge and skills throughout pre-kindergarten (e.g., Blair & Raver, 2014; Jitendra et al., 2007).

In this study, we hypothesized, based on prior research (e.g., Nesbitt et al., 2015; Sung & Wickrama, 2018; Vitiello et al., 2011), that ATL, specifically, residualized change in children's task orientation in the classroom, would mediate the link between children's fall EF skills and their growth in mathematics achievement across the pre-K year. We found some evidence that children's task orientation from fall to spring partially mediated this association, although it accounted for only 7.5% of the total association. To date, only a handful of studies have examined whether children's EF may promote learning behaviors which can facilitate academic achievement, and findings have been somewhat mixed. Sung and Wickrama (2018) found both direct associations between EF, ATLs, and mathematics achievement, and also an indirect association between EF and academic achievement through ATLs. However, others who have examined these pathways have not found these indirect associations (e.g., Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Brock et al., 2009). Discrepancies in these findings could be due to varying ways and timing of measuring both EF and ATLs. In our analyses, we examined residualized change of task orientation, which enabled us to isolate the unique contribution of executive function, thereby addressing concerns about the correlation between children's executive function and task orientation.

That said, although this study contributes to the evidence base suggesting that learning behaviors may be a mechanism through which EF is associated with mathematics achievement, our results underscore the need for further research on this and other mechanisms that may play a role in explaining the associations between early EF skills and mathematics achievement. For example, some researchers have suggested that the primary mechanism through which EF is associated with achievement may be through underlying cognitive processes like information processing (Vitiello & Greenfield, 2017), which also relate to children's classroom engagement. Studies that employ neuroimaging techniques may provide insight into neurodevelopmental processes that underlie associations among EF and achievement (Shanmugen & Satterthwaite, 2016).

Moderation by child sex

Importantly, we did not find statistically significant sex differences in the direct and indirect associations among EF, ATLs, and mathematics gains across the pre-K year. More research is needed to know if and how significant sex differences emerge in kindergarten or elementary school, when differences in mathematics achievement become prevalent and continue to increase over time.

There were, however, other sex differences among these variables that are worth noting. First, the girls and boys in our study did not differ in their mathematics achievement in the fall or spring. These results are promising, given some extant research showing that gaps in mathematics achievement emerge early and can persist if unaddressed (Fryer Jr & Levitt, 2010; Robinson & Lubienski, 2011; Robinson-Cimpian et al., 2014). Girls in our sample, however, exhibited significantly higher teacher report of their task orientation than boys. This finding relates to other research that shows that positive classroom behavior and showing an eagerness to learn is more important for teachers' perceptions of competence in girls than in boys (Garcia & Weiss, 2015; Robinson-Cimpian et al., 2014). Our research could suggest that girls are more engaged in learning tasks than boys, that teachers are more focused on or notice girls' classroom orientation, that girls are receptive to feedback or indications from their teachers that their orientation in class is meaningful or consequential, and/or that girls' classroom orientation is particularly related to their mathematics achievement. Teachers also reported that they felt significantly closer to the female than the male students in their classes. Despite including teacher-reported closeness as a covariate in the analyses, teachers' sense of closeness could play a significant role in how girls' task orientation relates to their math achievement if it reflects increased engagement with teachers on math-related learning tasks.

Limitations and future directions

There are a number of limitations in the current study that warrant discussion. First, the sample size was small and consisted of children from a single school system. A larger and more nationally representative sample could provide a more accurate assessment of the associations between EF, ATLs, and mathematics achievement among pre-kindergarten students. In particular, future research could include or examine differential associations in pathways for English Language Learners (ELLs). There is some research to suggest that ELLs exhibit greater EF skills in pre-k compared to native English speakers (Halle, Hair, Wandner, & Chien, 2012). Our study is also limited by having used teacher report of task orientation. Although teacher perceptions of ATLs are associated with children's learning and achievement and are important to understand, it could be helpful to examine how children's task orientation—as measured directly through observation or physiological assessment like portable electroencephalography (EEG)—relates to EF and mathematics achievement. Furthermore, our measure of EF could be too general to capture sex differences in pre-kindergarten. Extant research on sex differences in EF or how EF could relate to mathematics achievement focus on components of EF, like working memory and attention (Haier et al., 2005; Hill et al., 2014; Naglieri & Rojahn, 2001). Future research could examine whether there are sex differences in specific components of EF. It could also be useful to examine whether differences in observed task orientation relate to motivational differences that shape the emotional, cognitive, behavioral, and social quality of children's orientation and mathematics achievement. Finally, future research could examine the impact of features of the classroom environment or learning tasks that relate to differences in how EF shapes student orientation.

CRediT authorship contribution statement

Tara L. Hofkens: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Jessica Whittaker:** Conceptualization, Writing – original draft. **Robert C. Pianta:** Funding acquisition, Supervision, Writing – review & editing. **Virginia Vitiello:** Writing – review & editing. **Erik Ruzek:** Methodology, Writing – review & editing. **Arya Ansari:** Writing – review & editing.

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