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Self-regulation moderates the relationship between fine motor skills and writing in early childhood

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ABSTRACT

Learning to write is challenging for young children, as they must integrate their still-developing fine motor skills with an understanding of written language to produce a mark that has meaning. Complicating things more is the fact that children are often asked to produce a variety of written products with varying task demands (e.g., writing single letters vs. combining these letters to form entire words or sentences). Although theoretical models of writing highlight the importance of both self-regulation and fine motor skills for writing, our current understanding of how these two constructs interact to support writing remains incomplete. Thus, the current study examined the extent to which self-regulation moderates the relation between fine motor skills and early writing development – and whether this relation differs by writing task difficulty. To address this, two diverse cross-sectional samples of 3-5-year-old children from Head Start programs were assessed on fine motor skills, self-regulation, and a variety of writing tasks at the beginning ($N = 333$) and end ($N = 405$) of the preschool year. Hierarchical regression analyses were conducted to examine the potential moderating association between fine motor skill and self-regulation on early writing skills, with separate models fit for each writing task. After controlling for demographic factors, results indicated that self-regulation was important at the beginning of the year for children with higher levels of fine motor skills when completing a challenging writing task. Self-regulation was also important at the end of the school year for both 1) children with lower fine motor skills but only for the simpler writing tasks and 2) for children with higher fine motor skills on the more challenging writing tasks. Findings suggest that the relation between self-regulation and writing is dependent upon task difficulty and that self-regulation and fine motor skills may compensate for deficits in one or the other skill when children perform writing tasks.

1. Introduction

Even for young children, early writing is a complex task requiring the execution of a range of skills (Gerde et al., 2012). Widely-accepted theoretical frameworks model writing to incorporate multiple components such as transcription skills including handwriting (i.e., the forms of letters) and spelling (i.e., orthography), as well as text generation skills (i.e., generating ideas for composition; Berninger et al., 2002; Puranik & Lonigan, 2014; Rhyner, 2009). Beyond the cognitive-linguistic skills (e.g., letter knowledge; Puranik & Lonigan, 2012), empirical evidence has identified that behavioral skills like self-regulation (Puranik et al., 2019; Zhang et al., 2017) are also important for early writing development. As handwriting – a part of transcription – is dependent on well-developed fine motor muscles (Berninger & Rutberg, 1992; Graham et al., 1998; Son & Meisels, 2006), it is logical that fine motor skills would be essential for early writing. Indeed, automaticity of these fine motor skills is related to the length and quality of children's writing (Graham et al., 2012). The relation between self-regulation and writing is less clear, however, and behavioral skills are not always included in theoretical frameworks of writing (e.g., Rhyner, 2009). This opacity in the role of self-regulation may be due to the interrelatedness of self-regulation and fine motor skill development (Cameron et al., 2015; McClelland & Cameron, 2019). Moreover, young children are asked to write a variety of tasks that range in difficulty (e.g., their name, single letters, words) – each of which may recruit skills differently to execute the task. Drawing from socio-cognitive theories and the

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Not-so-Simple View of writing (Berninger & Winn, 2006), the purposes of this paper are: (1) to clarify the relation between fine motor skills, self-regulation, and early writing using a model that recognizes potential interrelations between fine motor and self-regulatory skills, and (2) to explore the extent to which these relations differ as a function of writing task difficulty.

1.1. Early writing is important

Early writing skills are important because they are concurrently related to other early literacy skills including letter knowledge, print concepts, and phonological awareness (Diamond et al., 2008) and lay the foundation for later writing and reading achievement (Kim et al., 2015; Levin et al., 2005). Moreover, early writing skills appear in national and state early learning standards (Tortorelli, Gerde, Rohloff, & Bingham) and are key features of early childhood curricula (e.g., *Tools of the Mind,* Bodrova & Leong, 2007) marking their value for early literacy development. Writing, even for young children, is conceptualized to include multiple skills including handwriting, spelling, and composing (Berninger et al., 2002; Puranik & Lonigan, 2014; Rhyner, 2009). As such, to elicit writing from children, researchers have utilized a variety of tasks which range in difficulty because they engage different orthographic skills. Writing tasks that are easier for preschool children, because they require more novice knowledge of print and limited orthographic knowledge, include writing one's name or writing individual letters (Gerde, Skibbe, et al., 2012; Levin et al., 2005; Puranik & Lonigan, 2012). More difficult tasks include those that require children to use advanced print knowledge and spelling such as word writing (Puranik et al., 2019) or require children to generate ideas (i.e., compose) in addition to transcribing such as writing a story (Thomas et al., 2020). Due to variation in the orthographic knowledge needed to execute each of these increasingly challenging tasks, it is essential to understand how children utilize motor and self-regulatory skills as they engage in multiple writing tasks.

1.2. The relation between fine motor skills and writing

Motor skill proficiency – specifically, fine motor skill proficiency – is integral to the development of early writing (Berninger & Rutberg, 1992; Berninger et al., 1992). Fine motor skills include behaviors like manipulating small objects, cutting with scissors, drawing, tracing, and copying figures, and these skills have been linked to writing such that children with higher levels of fine motor skill proficiency perform better on writing assessments than do their peers who are lower in fine motor skill proficiency (Daly et al., 2003; Gerde et al., 2012). Especially in a classroom context, fine motor skills feature prominently in young children's daily activities – in fact, an observational study of Head Start and kindergarten classrooms showed that between 27%-66% of the school day is devoted to fine motor activities (Marr et al., 2003). Mastery of fine motor skills can be framed in the context of the Theory of Automaticity, which posits that the more skilled an individual becomes at performing a particular task, the more "automatic" this process becomes – thus freeing up cognitive resources that would otherwise be used to focus on its execution (Logan, 1988; Savage, 2004).

In the context of fine motor skills and school performance, this means that a child who possesses higher levels of mastery of basic motor skills (i.e., grasping a pencil, writing letters) may be better able to focus his/her attention on higher-order concepts like spelling words correctly or composing sentences (Cameron et al., 2012; Medwell et al., 2009). In contrast, a child low in fine motor skills may struggle with these more basic classroom activities and thus be less able to allocate his or her attention to the content of lessons or the execution of more complex tasks. Difficulties with executing the fine motor skills associated with writing inherently limit both the amount of text that children can produce and the speed with which they can produce it (Berninger, 1999; Graham et al., 2012). Since writing is an integral part of children's early academic development, it is necessary to explore potential compensatory mechanisms that could be used to overcome deficits in fine motor skill proficiency – and one such potential compensatory mechanism is self-regulation.

1.3. The relation between self-regulation and writing

The term self-regulation is used to describe a wide range of concepts, and there remains a great deal of debate about its precise definition and how it relates to similar concepts such as executive function (Allan & Lonigan, 2011; Eisenberg et al., 2010; Garon et al., 2008). Here we define self-regulation, with a focus specifically on behavioral self-regulation, as the deliberate application of controlling, directing, and planning skills to behavioral responses to achieve social, academic, or personal goals (Vohs & Baumeister, 2016). Thus, we apply McClelland and Cameron's (2012) definition of self-regulation as the integration of executive functions, including the ability to pay attention, switch focus, remember instructions, and execute self-control, in support of behavioral responses like remembering to raise one's hand and waiting to be called upon instead of shouting out an answer (Cameron et al., 2008; McClelland et al., 2007). Indeed, this definition of self-regulation underlies the Head-Toes-Knees-Shoulders (HTKS) task (Gonzalez et al., in press) – the assessment of self-regulation used in the present investigation – which has been shown to relate to executive-function-related processes (McClelland et al., 2014). Self-regulation has been shown to be strongly related to early academic success and school performance in a variety of domains (Best et al., 2011; Blair et al., 2005; Zelazo et al., 2003), including as measured specifically by the HTKS (Cameron et al., 2008; McClelland et al., 2014).

According to the Not-so-Simple View of writing, multiple components of self-regulation are theoretically utilized during the writing process (Berninger & Winn, 2006). Writing taps cognitive flexibility as children shift their focus among composing, handwriting, and spelling, and requires working memory to recall and use letter sounds and shapes in word formation. Throughout the writing process, inhibitory control is also at work to keep children's attention on the task. A growing body of empirical evidence supports the association of self-regulation to writing. A longitudinal study by Kent et al. (2014) showed that a writing model including the attentional aspect of self-regulation was a better-fitting model than one that included only reading and spelling. This same study found that self-regulation was positively related to composition quality and fluency in kindergarten and first grade.

For younger children, however, the relation between self-regulation and writing is less clear. Some research has identified direct relations between self-regulation and writing (e.g., Gerde et al., 2012; Puranik et al., 2019), whereas others have found reading skills (e.g., phonological awareness and letter knowledge) to mediate the relation between self-regulation and writing (Zhang et al., 2017). Interestingly, work from Gerde et al. (2012) found that self-regulation was directly associated with preschoolers' name writing – however, work from Puranik et al. (2019) did not find a direct association between self-regulation and name writing in a sample of kindergartners.

1.3.1. Writing task difficulty and self-regulation

Task difficulty may be one explanation for these competing findings. Important to note is that as tasks become more automatic, they inherently require less self-regulation. For instance, children tend to be successful in writing their name before they

can write other words (Treiman et al., 2001), and writing an individual letter requires less skill than writing a word. Thus, specific writing tasks that have been mastered – and thus are easier for children – may not engage children's self-regulation, though self-regulation seems to be important when the task is sufficiently challenging. Accordingly, the six-month age difference between the samples of these two studies (Gerde et al., 2012; Puranik et al., 2019) resulted in general mastery of the name writing task, which may have reduced children's need for self-regulation to execute this specific task. Even for other writing tasks, some complexities in the relation between self-regulation and writing exist. For example, Puranik and colleagues (2019) found self-regulation to be associated with children's writing of dictated letters and words in preschool – however, in kindergarten, self-regulation was not related to letters but was instead related to the higher-level skills of word writing and composing. Collectively then, greater self-regulation may be needed when the task is "at the upper end, or beyond [a child's] zone of proximal development" (Puranik et al., 2019, p. 229).

1.4. The relationship between fine motor skills, self-regulation, and writing

Recent research indicates that self-regulation and fine motor skills are highly related and co-develop – and as such, this work hypothesizes that skill in one may make up for deficiencies in another (Cameron et al., 2015; McClelland & Cameron, 2019; Oberer et al., 2017; Roebers et al., 2014). In other words, if a child has low levels of fine motor skills but high levels of self-regulation, it may be that this higher level of self-regulation allows for the child to perform (on various academic assessments) at a level comparable to a child who is high in both. To illustrate: work from Cameron et al. (2015) showed that preschoolers with either strong fine motor skills or strong self-regulation learned as much in print knowledge as did children who were strong in both. This interrelation between fine motor skills and self-regulation, then, may also play a role in how these skills relate to early writing.

1.4.1. The Theory of Automaticity

One way to understand the relationship between fine motor skills and self-regulation in the context of writing is the Theory of Automaticity. This theory states that the more skilled an individual is at performing a particular task, the more automatic and the less cognitively-taxing this process becomes – and thus, the more cognitive resources are freed up to be able to focus on other tasks (Logan, 1988; Savage, 2004; Willingham, 1999). In the classroom context, this could play out in the following way: if a child becomes proficient in fine motor skills like writing, copying, tracing, and drawing, he/she then has more cognitive resources available for higher-order concepts like learning how to compose sentences, how to solve math problems, and how to read paragraphs for comprehension. On the other hand, a child who struggles just to write letters and numbers will have to devote more cognitive resources to this relatively low-level task and will therefore have less cognitive resources that he/she can devote to these more advanced concepts. Thus, in the context of early writing development especially, it has been speculated that the extent to which a child can achieve mastery – and thus, automaticity – of writing-related tasks may play a role in the amount of cognitive resources available to devote to other higher-order learning objectives (and the amount of self-regulation needed to overcome this fine motor skill deficiency) (Cameron et al., 2012).

1.4.2. The Zone of Proximal Development

The relation between fine motor skills, self-regulation, and writing can also be framed in terms of the Zone of Proximal Development (ZPD; Vygotsky, 1978), which essentially posits that for learning to occur (or, in this case, for self-regulation to come online), tasks that children perform must be within their own personal realm of difficulty. The task cannot be too easy – and thus, not engaging enough for the child to experience any meaningful growth opportunities – but it also cannot be too challenging, and thus outside the window within which children are able to eventually be successful given their current set of skills (Daniels, 2002). In an educational setting, it is important for teachers to keep this zone in mind for each student – coupled with the fact that depending on the difficulty of the task and the skillset of the individual student, the ZPD for each student will be slightly different and will change with time and experience. This concept is especially important in the context of this study, as our hypotheses center around the idea that the interaction of fine motor skills and self-regulation are dependent on where each task's level of difficulty is located relative to each child's ZPD. For example, if a child possesses a relatively high level of fine motor skill and is performing a relatively simple task like writing his name, self-regulatory processes may not need to be recruited in order to execute the task. However, if the task becomes more difficult – or if his fine motor skill proficiency were lower – he may need to employ higher levels of self-regulation in order to successfully complete it.

1.5. Purpose, aims, & hypotheses

Given the strong links between both fine motor skills and self-regulation and early writing outcomes, the relationship between these two factors presents a particularly interesting research area to explore – especially in the context of *when* and *how* these variables interact. Informed by the work of Puranik et al. (2019) suggesting that self-regulation may differentially affect children's writing performance as a function of task difficulty, this study examined children's performance at two time points in the preschool year: both at the beginning (when writing skill is less-well-developed) and again at the end (when writing skill for most children has improved) using writing transcription tasks that varied in difficulty, from easier (i.e., writing one's own name, writing individual letters), to more challenging (i.e., writing whole words, writing a story). Accordingly, the purpose of the present investigation was to address the following research questions: (1) To what extent does self-regulation moderate the relationship between fine motor skill and the development of early writing? and (2) Does this relation differ by writing task difficulty? Informed by the Theory of Automaticity, it was hypothesized that (1) self-regulation would serve a compensatory role in the development of early writing, such that children who were lower in fine motor skill proficiency – and thus, whose writing skills were not yet automatized – but higher in self-regulation would outperform their lower-self-regulated peers on writing outcome measures. It was also hypothesized that (2) task difficulty would play a role in this relationship, such that self-regulation would serve a compensatory role only when children were performing a writing task that was within their Zone of Proximal Development (i.e., not too challenging, yet also not too simple).

2. Method

2.1. Participants

Participating children were recruited from Head Start preschool programs in one midwestern and one southern U.S. state, representing high levels of ethnic and cultural diversity. Eligibility criteria ensured that children were in a classroom participating in a larger study of teacher writing practices, between 3-5 years old,

and attending the preschool program regularly to minimize missing data. All children were eligible for Head Start – and thus, family income for the vast majority of children was at or below the federal poverty level (Department of Health and Human Services, 2015). In addition, this was the first year attending Head Start for all participating children (i.e., most, if not all, had no prior preschool experience). Analyses were conducted on only those children with complete data for the measures of interest in this investigation (fine motor skills, self-regulation, and four writing tasks) – as such, the current study included 333 children at the beginning of the preschool year (i.e., September-October) and 405 children at the end of the preschool year (i.e., April-May). These cross-sectional samples were used to assess children's self-regulation, fine motor skills, and writing at two distinct time points – thus allowing for the examination of task-difficulty-dependent relationships among these variables and replicating the approach of Puranik et al. (2019). Two hundred seventy-two of these children were assessed at both time points.

At the beginning of the preschool year, participating children were between 37 and 71 months old (M = 51.7, SD = 6.5) and 45% were female. Most children were African-American (61.3%), with smaller numbers of White (15.6%) and multiracial (8.7%) children. Children spoke predominantly English as their first language (78.7%). Mothers/female guardians reported their highest level of education, with 59.7% attaining a high school diploma or less, 26.7% attaining a college degree, and 3.9% attaining a graduate degree.

At the end of the preschool year, participating children were between 41 and 76 months old (M = 57.5, SD = 6.4) and 46.2% were female. Most children were African-American (67.4%), with smaller numbers of White (14.6%) and multiracial (6.7%) children. Children spoke predominantly English as their first language (84.4%). Mothers/female guardians reported their highest level of education, with 66.5% attaining a high school diploma or less, 23.7% attaining a college degree, and 3.6% attaining a graduate degree.

2.2. Procedure

Children were recruited from classrooms participating in a study of early writing approaches (Gerde, Bingham, Bowles, Meier, & Zhang, 2019). Teachers invited parents of all children to participate by sending home informational fliers and talking with parents at arrival/pick up. Parents or legal guardians signed informed consent to register their child for participation in the study and completed a survey of demographic information about their family. Data were collected during the fall and spring of the 2017-2018 school year. At both time points, children were assessed on fine motor skills, self-regulation, and writing. Trained research assistants assessed children individually for approximately 15-20 minutes during the school day in a quiet space within their respective preschool. Research assistants were rigorously trained to administer each assessment accurately by reviewing the test materials and passing a quiz on assessment instructions, watching training videos, practicing administering the assessments with adults, and then, with children under supervision. Once research assistants administered the test accurately with no errors with three children, they were "passed" for data collection. Assessments were audited in the field by a peer and again during data filing in the lab.

2.2.1. Measurement of fine motor skills

Children's fine motor skills were assessed using the Motor subtest of the Early Screening Inventory – Revised (ESI – R; Meisels et al., 2007). Previous work has used this well-established, standardized developmental screener to identify preschool and kindergarten children who may be at risk for school failure (Kimmel, 2001; Paget, 2001) and to assess motor development for research purposes (e.g., Son & Meisels, 2006). The task consists of a block building item (using five blocks to build a gate – 1 point for imitation, 2 points for build on own), four shape copying items (circle, cross, square, triangle – 1 point each), and a person-drawing item (0 points for less than 3 body parts, 1 point for 3-4 body parts, 2 points for 5+ body parts). Scores on the Motor subtest ranged from 0 to 8. Meisels et al. (1997) found test-retest reliability for the ESI – R to be .89 (Meisels et al., 1997). Inter-item reliability for the visual motor subscale was .57 (*ECLS-K Base Year Public-Use Data Files and Electronic Codebook*, 2001).

2.2.2. Measurement of self-regulation

The Head-Toes-Knees-Shoulders task (HTKS; McClelland et al., 2014) was used as a direct measure of self-regulation (including working memory, attention, inhibitory control, and task persistence). The HTKS, which has been linked to literacy achievement in preschool (McClelland et al., 2007; Smith et al., 2008), consists of three sections. In the first section, children were taught two oral commands ('touch your head,' and 'touch your toes'). They were then asked to do the opposite of what the researcher said. For example, if the researcher instructed the child to touch his/her head, the child had to do the opposite and touch his/her toes. In the second section, two additional opposing commands were added ('touch your knees,' and 'touch your shoulders,'). In the third section, children continued to perform the opposite movement from the researcher's instruction, but the rules were switched such that head was paired with knees, and shoulders was paired with toes. An additional section in which children are instructed to verbalize – rather than physically execute – the opposite command (i.e., 'say head when I say toes') was included *only* for children who responded inaccurately to all practice items prior to engagement in the first section; these children continued on to the first section if they scored 4 or above. Responses for each of the sections were scored as 0 = incorrect, 1 = self-correct (i.e., the child changed an incorrect response to a correct one with no help from the administrator), or 2 = correct. Each of the three main sections contained ten items and the additional "drop-back" section contained seven items. Children who successfully passed the practice items (i.e., did not need to engage in the drop-back section) earned the full amount of points for this section. Higher scores on this task indicate higher levels of self-regulation, and children's scores ranged from 0 – 74. Research demonstrates strong reliability and validity of the HTKS (Cameron et al., 2008, 2009).

2.2.3. Measurement of writing outcomes

Children's writing skills were assessed using four writing tasks based on previous work by Diamond and colleagues (2008), Gerde, Bingham, and Pendergast (2015), and Thomas et al. (2020). The coding for each task (described below) reflects typical development of very young children's writing (Bloodgood, 1999; Diamond et al., 2008; Puranik et al., 2011; Rowe & Wilson, 2015) and permits discrimination at the lower end of the system by separating scribbles (children's earliest marks) from drawing (an attempt to communicate meaning through print) and linear scribbles that reflect children's burgeoning concepts of linearity and/or directionality (Puranik et al., 2011), which is important given the nature of the sample (i.e., some children are quite young; all are from Head Start programs). The writing tasks also reflect a developmental progression, as name writing is an easier task than word writing or story writing for children across orthographies (e.g., Levin et al., 2005). The tasks proceeded in the order listed below:

2.2.3.1. Name writing. The researcher instructed the child to write their name with a marker on a blank 8.5" x 11" sheet of paper. Scores on this task ranged from 0 to 8: name writing was

coded 0 = refusal, 1 = scribbling, 2 = drawing, 3 = linear scribble, 4 = letter-like forms, 5 = at least one letter, 6 = all letters/partial name, 7 = all letters in name out of order, 8 = name spelled correctly.

2.2.3.2. Letter writing. The researcher dictated 10 letters (T, B, H, M, S, A, D, C, J, and P) one at a time, and children were instructed to write each letter. Letter writing was coded 0 = refusal, 1 = scribbling, 2 = drawing, 3 = linear scribble, 4 = letter-like form, 5 = non-target letter, 6 = target letter. The score for each letter was summed to create a total score (range 0 – 60; α = .76).

2.2.3.3. Word writing. The researcher dictated 5 consonant-vowel-consonant words (sad, hug, lip, net, and job) one at a time, and children were instructed to write each word, a typical procedure for eliciting word writing (Thomas et al., 2020). Word writing was coded 0 = refusal, 1 = scribbling, 2 = drawing as writing, 3 = scribble writing, 4 = letter-like form, 5 = at least one letter, 6 = letters with one sound represented, 7 = letters with two sounds represented, 8 = word spelled correctly. The score for each of the five words was summed to create a total score (range 0 – 35; α = .82).

2.2.3.4. Name writing. A story writing task (Gerde & Bingham, 2013), including a picture of two raccoons with a dialogue bubble above the larger raccoon, was used to elicit story writing from children. Children were told, "In books, text bubbles include words that characters say or think," then asked, "What do you think Mama Raccoon might be saying or thinking in the picture?" The researcher recorded the child's response verbatim, then instructed the child to write what they had said in the speech bubble. When the child finished, the researcher asked, "Can you tell me what you wrote so I can remember?" and recorded the child's response. In alignment with word writing and previous work (Thomas et al., 2020), children's story writing was coded for the highest form of transcription (handwriting/spelling) they produced: 0 = refusal, 1 = child name as story, 2 = drawing/scribbling, 3 = letter-like forms, 4 = at least one letter, 5 = beginning and salient sounds, 6 = advanced phonological spelling.

2.3. Coding early writing

Three research assistants were trained to use the above coding system through the use of a training manual which includes master-coded examples of children's early name, letter, word, and story writing. Coders initially read the coding manual containing coding instructions, code definitions, and example coded writing samples of each type of writing and discussed the process with a master coder (second author). The coders then completed three rounds (15 samples each) of practice scoring followed by debriefing meetings with the master coder. Next, coders scored three sets of five master-coded writing sample packets for a total of 15 writing sample packets. Coders were considered reliable when they achieved 90% agreement with master codes across three sets of writing sample packets. Reliable coders double-coded a randomly-selected 20% of all writing samples to ascertain ongoing interrater reliability; kappa ranged from .87-1.00 for all codes used in analyses.

2.4. Statistical analysis

All analyses were conducted in R Version 4.0.3 (R Core Team, 2019) using the stats (R Core Team, 2019), fmsb (Nakazawa, 2019) psychometric (Fletcher, 2010), lm.beta (Behrendt, 2014), Rmimic (Pontifex, 2020), jtools (Long, 2021), and interactions (Long, 2020) packages with an alpha level of p = 0.05. Separate cross-sectional analyses were conducted at each time point (the beginning of the preschool year and the end of the preschool year). Only those children with complete data for all measures (fine motor skill, self-regulation, name writing, letter writing, word writing, and story writing) were included: N = 333 children at the beginning of the preschool year and N = 405 children at the end of the preschool year, representing 86% and 95% of the children tested at each time point, respectively. Bivariate correlations were conducted to examine the relation(s) between fine motor skill, self-regulation, and each of the writing outcomes. Hierarchical regression analyses were then conducted to examine the potential moderating association(s) between fine motor skill and self-regulation on early writing skills. Due to the nested structure of the data (i.e., children within classrooms within schools), a cluster-robust standard error approach was employed at the level of the classroom (McNeish et al., 2017).

Four separate regression models were fit for each of the writing outcome measures. In the first step, a hierarchical approach using a stepwise model selection based on Akaike Information Criteria (Akaike, 1974) was performed to determine which of four demographic factors (Age in Months; Sex; Race/Ethnicity [0 = White, 1 = Nonwhite]; and Geographic Site [0 = Southern Site, 1 = Northern Site]) – bidirectionally introduced in a stepwise fashion and compared against a model including just a constant – were significant predictors of each of the writing outcome variables. Those demographic factors that improved the model fit were then included in each of the subsequent analysis steps, which remained the same for each of the variables at both time points. In the second model, fine motor skills were entered as the sole independent variable; in the third, both fine motor skills and self-regulation were entered into the model; and the fourth model included fine motor skills, self-regulation, and the interaction between the two. Analysis of variance tests (ANOVAs) were then conducted to compare model fits, the results of which are reported below. Given the sample size and analytical strategy – and assuming a beta of 0.20 (i.e., 80% power) – the present investigation theoretically had sufficient sensitivity to detect an R^2 increase exceeding an effect size (Cohen's f^2) of 0.03, as computed using G*Power statistical software (Faul et al., 2007).

3. Results

In this section, results are presented first for the Beginning of the Preschool Year, followed by results for the End of the Year. Each of the sections is organized in the following way: (1) Descriptive statistics about children's general task performance (i.e., means and standard deviations), (2) Results from the hierarchical regressions for each of the writing tasks, which proceeded in the following way:

Model 1: Demographic factors
Model 2: Demographic factors + fine motor skills
Model 3: Demographic factors + fine motor skills + self-regulation
Model 4: Demographic factors + fine motor skills + self-regulation x fine motor skills

For all tasks, the results of Model 1 are presented first (i.e., the demographic factors that improved the fit of the regression model above and beyond a constant as well as their standardized beta coefficients, t-values, p-values, effect sizes, and the adjusted R^2 value). Next, statistics are presented from the highest-level model containing the factors (i.e., fine motor skills and/or self-regulation and/or the interaction between the two) that improved the model fit. As an example, for the Name Writing regression analysis at the beginning of the year, Model 3 (demographic factors + fine motor skills + self-regulation) improved the model fit as compared to

Table 1
Participant demographic characteristics and fine motor skill, self-regulation, and writing outcome measures at the beginning of the preschool year (mean ± SD).

Measure	All Participants	[Range]
N	333 (150 female)	
Age (months)	51.7 ± 6.5	[37 – 71]
Ethnicity (%)	African-American = 61% Asian American = 2% Latino/Hispanic = 2% Multiple ethnicity = 9% White = 16% Other = 2% Missing or Unreported = 8%	
ESI-R Score (Fine Motor Skill)	2.9 ± 2.3	[0 – 8]
Head-Toes-Knees-Shoulders (HTKS) Score (Self-Regulation)	18.1 ± 15.0	[0 – 70]
Name Writing Score	4.6 ± 2.1	[0 – 8]
Letter Writing Score	33.2 ± 17.3	[3 – 60]
Word Writing Score	11.1 ± 9.3	[0 – 38]
Story Writing Score	2.7 ± 1.0	[0 – 6]

Note. Only participants with complete data for all fine motor skill, self-regulation, and writing outcome variables included in analysis.

Model 2 – but because Model 4 did not improve the fit as compared to Model 3, the statistics from Model 3 are presented.

For clarity, each Model Number is referred to when it is presented in the sections that follow. Tables containing a full breakdown of these analyses (i.e., all four models at both time points for all four tasks) can be found in the Supplementary Material (Tables S1-S4).

3.1. Beginning of the preschool year

At the beginning of the preschool year, data from 333 children were analyzed; see Table 1 for full demographic and overall task performance information about this sample. In the fall of the school year, children's writing scores across the four tasks varied widely. On average, children wrote their name using letter-like forms ($M = 4.6$, $SD = 2.1$), but some children used scribbles and others wrote all letters; no child wrote their name accurately. Typically, children wrote letters using linear scribbles ($M = 33.2$, $SD = 17.3$) though some wrote letters and others scribbled. For words, children primarily drew illustrations ($M = 11.1$, $SD = 9.3$); however, some children used letter-like forms and others scribbled. Generally, children depicted their story through drawing/scribbling ($M = 2.7$, $SD = 1.0$); however, some children wrote letter-like forms. Both fine motor skill and self-regulation were positively related to children's performance on all four of the writing outcome measures (r's ≥ 0.36, p's $< .001$; see Table 2). The results of the hierarchical regression modeling for each writing outcome measure are reported below, presented using change statistics to reflect the difference in variance explained as compared to the models including only demographic factors:

3.1.1. Name writing

Age, site, sex, and race/ethnicity were significant predictors of name writing performance (Model 1) ($F(4, 328) = 43.45$, $f^2 = 0.52$; $R^2_{adj} = 0.34$, $p < 0.001$). Beyond these demographic factors, both fine motor skills and self-regulation (Model 3) explained a statistically significant amount of variance in name writing performance: ($F(6, 326) = 49.43$, $p < 0.001$, $f^2 = .89$; $\beta_{fine\ motor\ skills} = 0.38$, $t = 7.7$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.15$, $t = 3.0$, $p < 0.001$; $R^2_{change} = 0.13$; $R^2_{adj} = 0.47$).

3.1.2. Letter writing

Age, site, and sex were significant predictors of letter writing performance (Model 1) ($F(3, 329) = 53.97$, $f^2 = 0.47$; $R^2_{adj} = 0.32$, $p < 0.001$). Beyond these demographic factors, fine motor skills (Model 2) explained a statistically significant ($F(4,328) = 75.93$, $p < 0.001$, $f^2 = 0.89$; $\beta_{fine\ motor\ skills} = 0.47$, $t = 9.7$, $p < 0.001$) amount of variance in letter writing performance ($R^2_{change} = 0.15$; $R^2_{adj} = 0.47$).

3.1.3. Word writing

Age, sex, and site were significant predictors of word writing performance (Model 1) ($F(3, 329) = 33.61$, $f^2 = 0.30$; $R^2_{adj} = 0.23$, $p < 0.001$). Beyond these demographic factors, both fine motor skills and self-regulation (Model 3) explained a statistically significant amount of variance in word writing performance ($F(5, 327) = 37.95$, $p < 0.001$, $f^2 = 0.56$; $\beta_{fine\ motor\ skills} = 0.39$, $t = 7.10$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.13$, $t = 1.91$, $p = 0.06$; $R^2_{change} = 0.13$, $R^2_{adj} = 0.36$).

3.1.4. Story writing

Age was a significant predictor of story writing performance (Model 1) ($F(1, 331) = 82.66$, $f^2 = 0.25$; $R^2_{adj} = 0.20$, $p < 0.001$). Both fine motor skills and self-regulation explained a statistically significant amount of variance in story writing performance, over and above age (Model 3) ($F(3, 329) = 49.45$, $p < 0.001$, $f^2 = 0.43$; $\beta_{fine\ motor\ skills} = 0.33$, $t = 6.73$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.14$, $t = 2.06$, $p = 0.04$; $R^2_{change} = 0.10$; $R^2_{adj} = 0.30$).

3.2. End of the preschool year

At the end of preschool, data from 405 children were analyzed; see Table 3 for full demographic and overall task performance information about this sample. Similar to the beginning of the year, at the end preschool children's writing varied widely across the four tasks. Children wrote their name using letters and letter-like forms, on average ($M = 5.4$, $SD = 1.9$); some children spelled their name correctly and still others scribbled to represent their name. For letters, typically, children wrote letter-like forms ($M = 39.1$, $SD = 17.6$), but some children scribbled and others wrote accurate letters. When writing words, children drew illustrations in general ($M = 12.4$, $SD = 10.4$); however, some children used letters and spelled words correctly and others scribbled. For story writing, on average, children used letter-like forms in their writing ($M = 3.2$, $SD = 1.2$), although some children used advanced invented spelling

Table 2
Bivariate correlations between fine motor skill proficiency, self-regulation level, and writing outcome measures at the beginning of the preschool year.

Variable	ESI-R Score (Fine Motor Skill)	HTKS Score (Self-Regulation Level)	Name Writing	Letter Writing	Word Writing	Story Writing
ESI-R Score (Fine Motor Skill)	–					
HTKS Score (Self-Regulation)	0.43**	–				
Name Writing	0.59**	0.44**	–			
Letter Writing	0.64**	0.38**	0.68**	–		
Word Writing	0.52**	0.36**	0.54**	0.64**	–	
Story Writing	0.46**	0.36**	0.57**	0.54**	0.56**	–

Note. * denotes correlation was significant at $p \leq .05$. ** denotes correlation was significant at $p \leq .001$.

Table 3
Participant demographic characteristics and fine motor skill, self-regulation, and writing outcome measures at the end of the preschool year (mean ± SD).

Measure	All Participants	[Range]
N	405 (187 female)	
Age (months)	57.5 ± 6.4	[41 – 76]
Ethnicity (%)	African-American = 67% Asian American = 3% Latino/Hispanic = 2% Multiple ethnicity = 7% White = 15% Other = 3% Missing or Unreported = 4%	
ESI-R Score (Fine Motor Skill)	4.2 ± 2.3	[0 – 8]
Head-Toes-Knees-Shoulders (HTKS) Score (Self-Regulation)	27.6 ± 20.2	[0 – 74]
Name Writing Score	5.4 ± 1.9	[1 – 8]
Letter Writing Score	39.1 ± 17.6	[3 – 60]
Word Writing Score	12.4 ± 10.4	[0 – 40]
Story Writing Score	3.2 ± 1.2	[0 – 6]

Note. Only participants with complete data for all fine motor skill, self-regulation, and writing outcome variables included in analysis.

Table 4
Comparison of fine motor skills, self-regulation, and performance on the four writing tasks at the beginning and end of the preschool year.

Variable	Beginning of the Preschool Year	End of the Preschool Year	t	d_{rm} [95% CI]	p
ESI-R Score (Fine Motor Skill)	3.1 ± 2.3	4.5 ± 2.2	12.1	0.61 [0.49 to 0.72]	< 0.001**
HTKS Score (Self-Regulation)	18.4 ± 15.2	29.8 ± 20.9	11.5	0.60 [0.49 to 0.72]	< 0.001**
Name Writing	4.7 ± 2.0	5.6 ± 1.9	7.4	0.43 [0.31 to 0.54]	< 0.001**
Letter Writing	34.8 ± 17.0	40.9 ± 17.3	8.1	0.36 [0.27 to 0.45]	< 0.001**
Word Writing	11.9 ± 9.6	13.4 ± 10.8	2.7	0.15 [0.04 to 0.26]	0.006**
Story Writing	2.8 ± 1.1	3.2 ± 1.2	7.0	0.42 [0.30 to 0.55]	< 0.001**

Note. * denotes significance at $p < 0.05$. ** denotes significance at $p < .001$. These data reflect comparisons of the children ($N = 272$) who were tested at both the beginning and the end of the preschool year.

Table 5
Bivariate correlations between fine motor skill proficiency, self-regulation level, and writing outcome measures at the end of the preschool year.

Variable	ESI-R Score (Fine Motor Skill)	HTKS Score (Self-Regulation Level)	Name Writing	Letter Writing	Word Writing	Story Writing
ESI-R Score (Fine Motor Skill)	–					
HTKS Score (Self-Regulation)	0.48**	–				
Name Writing	0.55**	0.43**	–			
Letter Writing	0.62**	0.54**	0.69**	–		
Word Writing	0.57**	0.51**	0.51**	0.72**	–	
Story Writing	0.51**	0.38**	0.48**	0.61**	0.62**	–

Note. * denotes correlation was significant at $p \leq 0.05$. ** denotes correlation was significant at $p \leq 0.001$.

(multiple sounds represented) and others drew illustrations to reflect their ideas.

Importantly, children's performance on all measures of interest – fine motor skills, self-regulation, name writing, letter writing, word writing, and story writing – was significantly better at the end of the preschool year than at the beginning of the preschool year (see Table 4 for comparison data from the 272 children who were tested at both time points).

Bivariate correlations were conducted to examine the relationship(s) between fine motor skill, self-regulation, and each of the writing outcomes. Both fine motor skill and self-regulation were positively related to performance on all four of the writing outcome measures (r's $\geq$ 0.38, p's $< .001$; see Table 5). The same hierarchical regression analyses as for the beginning of the preschool year data were conducted at the end of the preschool year to examine the potential moderating association between fine motor skill and self-regulation on emergent writing skills. The results of this hierarchical regression modeling for each writing outcome measure are reported below:

3.2.1. Name writing

Age, site, and sex were significant predictors of name writing performance at the end of the preschool year (Model 1) ($F(3, 401) = 43.25$, $f^2 = 0.32$; $R^2_{adj} = 0.24$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and name writing (Model 4) ($F(6, 398) = 45.45$, $p < 0.001$, $f^2 = 0.67$; $\beta_{fine\ motor\ skills} = 0.50$, $t = 6.33$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.38$, $t = 3.62$, $p < 0.001$; $\beta_{interaction} = -0.31$, $t = -2.19$, $p = 0.03$; $R^2_{change} = 0.16$, $R^2_{adj} = 0.40$) such that higher levels of self-regulation were associated with enhanced name writing performance in children with lower levels of fine motor skills, but the impact of self-regulation was attenuated for children with higher levels of fine motor skills (see Figure 1).

3.2.2. Letter writing

Age, site, and sex were significant predictors of letter writing performance (Model 1) ($F(3, 401) = 62.21$, $f^2 = 0.45$; $R^2_{adj} = 0.31$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and letter writing (Model 4) ($F(6, 398) = 73.91$, $p < 0.001$, $f^2 = 1.08$; $\beta_{fine\ motor\ skills} = 0.53$, $t = 7.83$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.50$, $t = 5.48$, $p < 0.001$; $\beta_{interaction} = -0.36$, $t = -3.86$, $p < 0.001$; $R^2_{change} = 0.21$, $R^2_{adj} = 0.52$) such that higher levels of self-regulation were associated with enhanced letter writing performance in children with lower levels of fine motor skills, but the

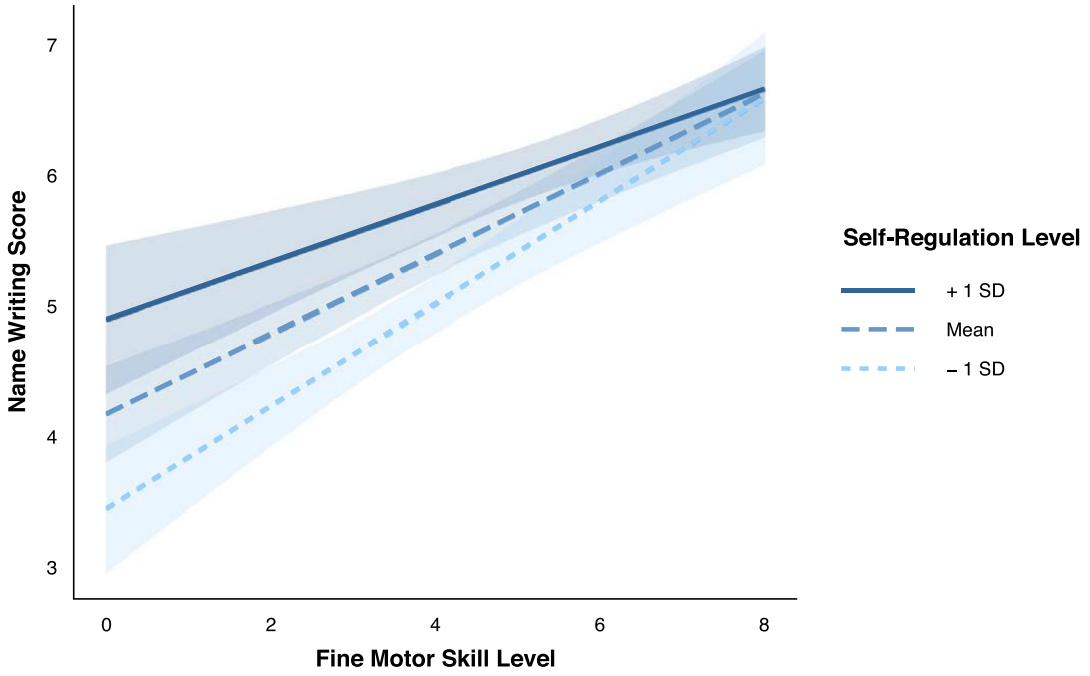

Fig. 1. Visualization of the significant interaction between fine motor skills and self-regulation for name writing performance at the end of the preschool year.

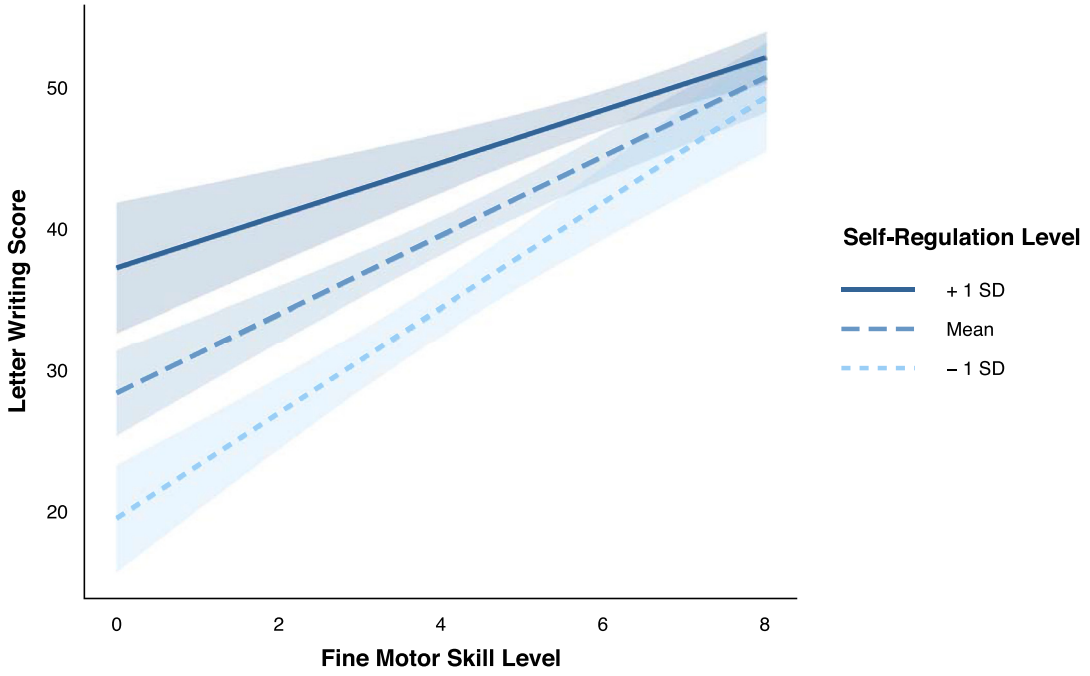

Fig. 2. Visualization of the significant interaction between fine motor skills and self-regulation for letter writing performance at the end of the preschool year.

impact of self-regulation was attenuated for children with higher levels of fine motor skills (see Fig. 2).

3.2.3. Word writing

Age, site, and race/ethnicity were significant predictors of word writing performance (Model 1) ($F(3, 401) = 34.59$, $f^2 = 0.25$; $R^2_{adj} = 0.20$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and word writing (Model 4) ($F(6, 398) = 45.51$, $p < 0.001$, $f^2 = 0.67$; $\beta_{fine\ motor\ skills} = 0.12$, $t = 1.81$, $p = 0.07$; $\beta_{self\text{-}regulation} = -0.09$, $t = -1.01$, $p = 0.31$; $\beta_{interaction} = 0.50$, $t = 4.75$, $p < 0.001$; $R^2_{change} = 0.20$, $R^2_{adj} = 0.40$). Higher levels of self-regulation were associated with enhanced word writing performance in children with higher levels of fine motor skills, but the impact of self-regulation was attenuated for children with lower levels of fine motor skills (see Figure 3).

3.2.4. Story writing

Age, site, and sex were significant predictors of story writing performance (Model 1) ($F(3, 401) = 32.07$, $f^2 = 0.23$; $R^2_{adj} = 0.19$, $p < 0.001$). Beyond these demographic factors, both fine motor skills and self-regulation (Model 3) – but not the interaction be-

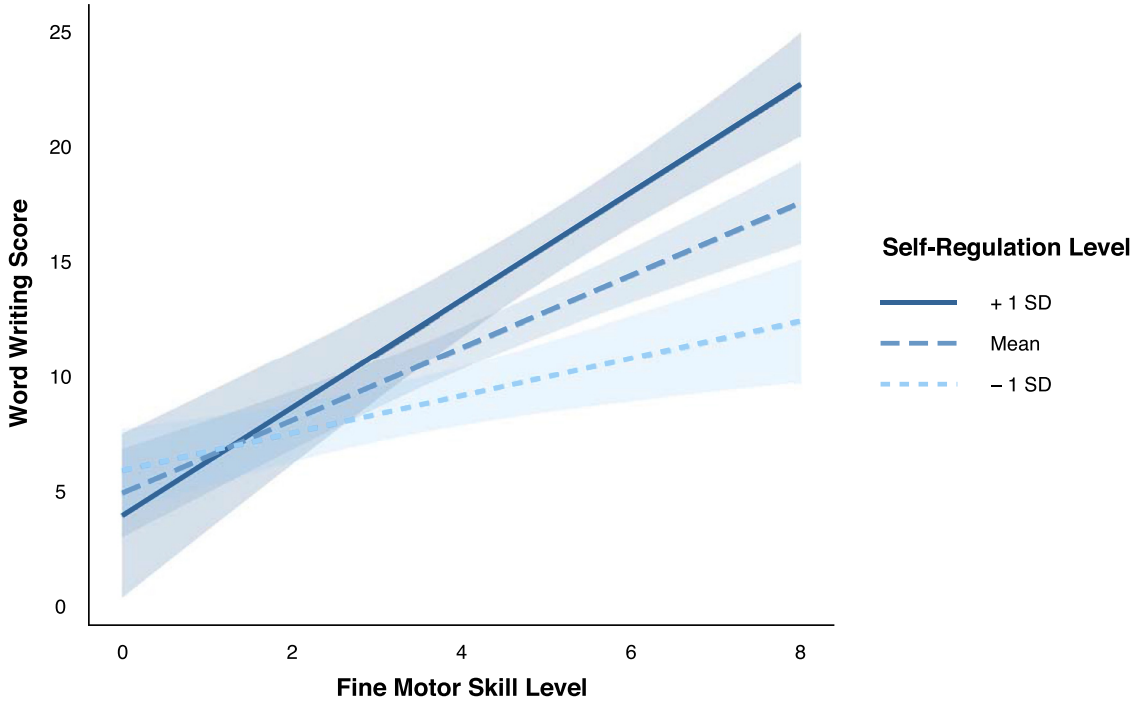

Fig. 3. Visualization of the significant interaction between fine motor skills and self-regulation for word writing performance at the end of the preschool year.

tween the two – explained a statistically significant amount of variance in story writing: ($F(5, 399) = 35.61$, $p < 0.001$, $f^2 = 0.43$; $\beta_{fine\ motor\ skills} = 0.33$, $t = 7.65$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.12$, $t = 2.01$, $p = 0.05$; $R^2_{change} = 0.11$, $R^2_{adj} = 0.30$.

4. Discussion

The aim of the present investigation was to explore the extent to which self-regulation moderates the relationship between fine motor skill proficiency and early writing – more specifically, to begin to illuminate the nature of these relations by clarifying how these variables interact at two different points in children's development. To answer this research question, children were assessed both at the beginning and at the end of the preschool year using writing transcription tasks that spanned a range of difficulty, from easier (i.e., name writing, letter writing), to more challenging (i.e., writing whole words, writing in the context of a story). In line with theories of writing development including the Not-so-Simple View (Berninger & Winn, 2006) and previous empirical research, both self-regulation and fine motor skills were related to young children's performance on a range of writing tasks (Gerde et al., 2012; McClelland & Cameron, 2019; Puranik et al., 2019; Zhang et al., 2017). Consistent with our *a priori* hypothesis and novel to the present investigation, self-regulation interacted with fine motor skills for several tasks measuring early writing proficiency in a sample of preschool children. As proposed, these findings identify the interrelation between fine motor skills and self-regulation to be important – and compensatory – for children in the context of particular tasks at particular times.

Results from this investigation are consistent with research from (Puranik et al., 2019), suggesting that the relationship between self-regulation and writing may indeed be task-dependent. In other words, self-regulatory processes may need only come online for tasks that are adequately challenging for children – but not for tasks that are too easy or too difficult. Because the act of writing is by its nature a fine motor task, the present investigation also builds upon the assertion from McClelland & Cameron (2019) to support the notion that the relationship between self-regulation and writing may manifest via an interaction with children's fine motor abilities – and that skill in one may help to compensate for deficiencies in another.

At the beginning of the school year, the present investigation showed that beyond demographic factors (i.e., age, sex, race/ethnicity, and geographic site) self-regulation and fine motor skills are both important variables involved with performance on several writing tasks, evidenced by the fact that each of these variables was associated with a significant amount of variance in writing performance. This was the case for all outcome variables with the exception of letter writing, for which fine motor skills – but not self-regulation – were a predictor. As will be detailed in the following paragraphs, it was not until the end of the school year – when both fine motor skill and writing performance had increased – that any sort of striation in accordance with self-regulation levels for the easier tasks was observed.

At the end of the preschool year, children improved in their performance on all four writing tasks as well as their fine motor skill and self-regulation levels (see Tables 1 & 3 for means and standard deviations and Table 4 for *t*-test comparisons of scores on each variable from the 272 children who participated at both time points). Indeed, overall scores for all of the variables in this investigation were significantly higher at the end of the preschool year than at the beginning: $t's \geq 2.7$, $p's \leq .006$. Interestingly and in line with previous research, for tasks that were "easier" – and thus, more automatic – for children (i.e., name writing, letter writing), self-regulatory processes appeared to come online for those children who struggled to execute the task: in this case, for children with lower levels of fine motor skills. To illustrate: self-regulation appeared to play a compensatory role for those children with lower levels of fine motor skills – in some cases allowing them to perform at the same level as children with higher levels of fine motor skills – on the simpler writing tasks (name writing, letter writing). For those children with higher levels of fine motor skills – presumably, those for whom these more basic tasks were not as difficult – this interaction with self-regulation was not observed.

Also at the end of the preschool year (and consistent with the finding from the beginning of the year), an opposite relationship was observed in the context of the more-challenging word writing task. Instead of self-regulation coming online for those children with low levels of fine motor skills, it appeared to matter more for children with higher levels of fine motor skills. This is again in line with the findings from (Puranik et al., 2019), who posited that the relationship between self-regulation and fine motor skills is task- or difficulty-dependent: because writing words is more complex than just writing letters (Cabell et al., 2013; Puranik et al., 2011), those children with higher levels of fine motor skills are more likely to be able to perform this task successfully. In this case, children with higher levels of fine motor skills and higher levels of self-regulation outperformed their lower-self-regulated peers on this word writing task.

This study certainly contributes to the theoretical literature on early writing development, providing important context surrounding the complex interplay between children's fine motor skill level, task difficulty, and the role of self-regulation in successful writing task performance. The findings help to solidify and explain self-regulation's role in young children's writing development, aligning and extending theoretical frameworks of writing that include self-regulation (e.g., Berninger & Winn, 2006). Importantly, for young children the role of self-regulation is dynamic; it is available when the task is challenging.

4.1. Implications for practice

Beyond advancing theory, however, these findings have considerable practical implications as well. While previous work has identified that even early writing is a complex task requiring children to enact multiple skills from cognitive, physical, and socioemotional domains (Gerde et al., 2012), the findings of this study reiterate the interrelations between these skills. Providing opportunities to exercise fine motor muscles and develop self-regulation will benefit children's writing development. In fact, intervention work promoting the self-regulation of older writers with learning disabilities (Graham & Harris, 2003; Mathematica Policy Research, 2017) has demonstrated improvements in children's writing. While writing is one way to engage these skills in tandem, multiple experiences for exercising small hand muscles and focusing attention should be available throughout the day. In addition, because children vary widely in their fine motor (Son & Meisels, 2006) and self-regulation development across the early years (McClelland et al., 2007), children should be given opportunities to write messages using any form of transcription (e.g., scribbles, drawing, letter-like forms), an idea that aligns with developmentally appropriate practices (Copple & Bredekamp, 2009) and early learning standards for writing (Tortorelli, Gerde, Rohloff, & Bingham). Further, because task difficulty plays a role in children's use of skills, children should be provided a range of writing opportunities within the curriculum. Young children need opportunities to write their name, a practice often observed in preschool classrooms (Gerde et al., 2015). Also, however, children are capable of and need opportunities to write for a range of purposes (Duke et al., 2006; Gerde et al., 2012) including in their play (Bingham et al., 2018) and in their curricular opportunities like science experiences (Gerde et al., 2020).

The findings of this study also highlight where strengths in one skill can support weaknesses elsewhere (Cameron et al., 2015; Chung et al., 2018). In a school setting, it is important for teachers to understand the ways in which children can leverage their strengths. Teachers who recognize when a child has the self-regulation skills to persist in a task may make better decisions regarding the types of supports they provide or when to let a child engage in productive struggle. In addition, it is important to recognize that children who may be less-skilled at performing particular tasks – especially fine-motor-dependent tasks like writing – may be able to compensate for these deficits (i.e., through work to increase their levels of self-regulation). These findings also underscore the tremendous value of occupational therapists and other professionals who aid in the development of children's fine motor skills – as this work makes clear that physical skill development does not occur in a vacuum, and in fact may be an integral part of both cognitive and academic development. Finally, efforts to target fine motor skills, self-regulation, or both – while keeping task difficulty in mind – could help to inform researchers in developing future educational interventions to improve children's early writing.

4.2. Limitations & future directions

The present investigation provided evidence from a large, diverse sample of preschool children – using a range of transcription tasks spanning varying levels of writing skill – that self-regulation and fine motor skills are related in the context of early writing performance. By examining performance at two distinct time points in the school year, this cross-sectional comparison allowed us to explore the ways in which self-regulation may differentially interact with fine motor skill proficiency based on children's skill level and/or the difficulty of the task. Importantly, however, this study was not a longitudinal investigation – and future work should examine the ways in which the *development* of these skills relates to change in writing performance over time. While our analytic approach was driven by current theories of writing development, we recognize the complexity of the relations between these variables and recommend future work considering more complex models (e.g., bidirectional). Future work should also examine the trajectory over which these relationships persist: in other words, extending beyond samples of preschool children and into the early elementary school years, wherein writing proficiency continues to advance (e.g., in more-advanced areas than transcription such as composition).

5. Conclusions

Taken together, findings from the present investigation provide compelling evidence to further illuminate the complex interrelationship(s) between self-regulation and writing as initially investigated by Gerde et al., (2012), Puranik et al., (2019), & Zhang et al. (2017) – and asserts that this relationship may manifest via an interaction with children's existing levels of fine motor skills.

Disclosure

None

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ecresq.2021.06.010.

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