SELF-REGULATION MODERATES THE RELATIONSHIP BETWEEN FINE MOTOR SKILLS AND WRITING IN EARLY CHILDHOOD

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Kinesiology—Doctor of Philosophy

2021

PUBLIC ABSTRACT

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For young children, learning to write is a challenging and complex process. Not only must they have an understanding of written language (i.e., be able to identify letters and their corresponding sounds), but they must also learn how to produce a specific mark for each letter. Writing tasks span a range of difficulty, from producing single letters to combining letters into words, and eventually combining these words into meaningful sentences. Two factors that contribute to children's writing development are fine motor skills and self-regulation. However, many questions still remain about the exact nature of these relationships – especially because fine motor skills and self-regulation are also related to each other. The purpose of this dissertation was to clarify the ways in which fine motor skills and self-regulation – and the interaction between the two – relate to writing tasks across a range of difficulty levels. Two large samples of preschool children from Head Start programs were assessed on fine motor skill level, self-regulation, and a variety of writing tasks at both the beginning (N = 333 children) and end (N = 405 children) of the school year. Results indicated that both self-regulation and fine motor skills were important predictors of writing performance at both the beginning and end of the school year – and that the two interacted with each other in a few key ways. On the more-challenging tasks, high self-regulatory skills appeared to bolster the performance of children who were higher in fine motor skills (and thus, more skilled at writing). On the less-challenging tasks, self-regulation bolstered the performance of children who were lower in fine motor skills. These findings suggest that the relation between self-regulation and motor skills may compensate for

deficits in one or the other skill. Such findings have considerable implications for practice, including in the design and implementation of future interventions designed to improve children's fine motor skills and/or self-regulatory abilities – which may, in turn, be associated with improvements in classroom performance.

ABSTRACT

SELF-REGULATION MODERATES THE RELATIONSHIP BETWEEN FINE MOTOR SKILLS AND WRITING IN EARLY CHILDHOOD

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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, this dissertation 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 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 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 motor skills, but only for the simpler writing tasks, and 2) for children with higher 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 motor skills may compensate for deficits in one or the other skill when children perform writing tasks.

ACKNOWLEDGMENTS

Completion of this dissertation – and this PhD – would not have been possible without the guidance, support, and encouragement of many people.

To my advisor, Dr. Matt Pontifex: Thank you for your thoughtful & patient mentorship and for believing in me every step of the way. I am a better scholar because of you. I hope to provide the same strength of support to my own students in the future, and I look forward to a lifetime of collaboration. Thanks also to Katie, Emerson, and Ava Pontifex for making me feel like a part of the family from the very beginning.

To my committee members – Dr. David Ferguson, Dr. Janet Hauck, and Dr. Hope Gerde: Each of you has contributed to my development in a unique and powerful way. Your perspective, insight, and encouragement have meant the world to me, and I know that I will continue to draw upon the lessons you have taught me as I progress in my own research career.

To the members of the Health Behaviors & Cognition Laboratory, past and present – Dr. Drew Parks, Dr. Katy Gwizdala, Dr. Amanda McGowan, Oksana Ellison, Lauren Bullard, and each of our undergraduate research assistants: Being a part of this team has been a privilege, and I am so thankful that we had the chance to work together.

To the members of the Early Language & Literacy Investigations Laboratory – I have learned so much from our work together, and I will be forever grateful to you all for welcoming me as one of your own.

To the MSU Kinesiology Department: I could not have chosen a better or more supportive environment in which to pursue a PhD. Thanks to the faculty, the staff, and all of my fellow graduate students for making this experience such a great one. Thanks also to Coach

Orlando and the staff of the MSU Tennis Center for giving me a home away from home in East Lansing.

To Drs. Jennifer Coffman and J. D. DeFreese: Thank you for being my original champions and mentors and for the support that has extended far beyond UNC. I am lucky to know you.

To the children, families, and teachers who participated in this study: Thank you for your willingness to contribute to this work. It is my sincere hope that these findings can be used to optimize children's development, both physically and in the classroom.

Finally, to my family: Thank you for providing me with the strongest of foundations through every stage of this journey and for your unconditional love and support. I hope I've made you proud.

The research reported here was supported by the Institute of Education Sciences, U. S. Department of Education, through Grant R305A150210 to Michigan State University. The opinions expressed are those of the author and do not represent views of the Institute or the U. S. Department of Education.

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KEY TO ABBREVIATIONS

ESI-R	Early Screening Inventory – Revised (Assessment of Fine Motor Skills)
HTKS	Head-Toes-Knees-Shoulders (Assessment of Self-Regulation)
ZPD	Zone of Proximal Development

CHAPTER 1

Introduction

Even for young children, early writing is a complex task requiring the execution of a range of skills (Gerde, Skibbe, 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 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. The purposes of this dissertation were: 1) to clarify the relation between motor skills, self-regulation, and early writing using a model that recognizes potential interrelations between motor and self-regulatory skills, and 2) to explore the extent to which these relationships differ as a function of writing task difficulty.

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 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 et al., 2012; 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.

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 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 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 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.

The Relation between Self-regulation and Writing

Self-regulation – a composite skill that develops rapidly during the preschool period (Diamond, 2002) – includes the ability to pay attention, switch focus, remember instructions, and execute self-control (McClelland et al., 2007b). In addition, it is strongly related to early academic success and school performance in a variety of domains such as reading and mathematics (Best et al., 2011; Blair et al., 2005; McClelland et al., 2014; Ponitz et al., 2009; Zelazo et al., 2003). The three components of self-regulation are also 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 (i.e., more predictive of writing performance) 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. Important to note is that as tasks become more automatic, they inherently require less self-regulation (Logan, 1988; Savage, 2004; Willingham, 1999). 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).

The Relationship between Fine Motor Skills, Self-regulation, and Writing

Recent research indicates that self-regulation and 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; Roebers et al., 2014). For example, if a child has low levels of 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. This interrelation between motor skills and self-regulation may play a role in how these skills relate to early writing. 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 dissertation examined children's performance at two time points in the preschool year: both at the beginning (when writing skill was less-well-developed) and again at the end (when writing skill for most children had 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).

Aims and Hypotheses

The purpose of this dissertation was to address the following aims:

Aim 1. To examine the extent to which self-regulation moderated the relation between fine motor skills and early writing development.

Hypothesis 1. Informed by the Theory of Automaticity, it was hypothesized that 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.

Aim 2. To examine whether the relationship between self-regulation and fine motor skills differed by writing task difficulty.

Hypothesis 2. It was also hypothesized that 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).

By establishing an understanding of the nature of the relationship(s) between self-regulation and motor skills as it relates to early writing, this dissertation study provides key insights into the ways in which self-regulation may differentially interact with fine motor skill proficiency – based both on children's skill level and the difficulty of the task. In the classroom context, this work could also help to inform future educational interventions to improve children's early writing development. Finally, from a public health perspective, this work highlights the importance of prioritizing children's physical – in addition to their cognitive – health in early childhood, and the role that self-regulation plays in optimal development.

CHAPTER 2

Review of Literature

To gain a fuller understanding of the relationship(s) between fine motor skills, self-regulation, and early writing, it is first necessary to review the existing literature surrounding each of these topics. In this chapter, information will first be provided on Head Start preschool programs to provide context about the sample utilized in this investigation. Next, a discussion of (1) fine motor skill development; (2) the development of self-regulation; and (3) the Not-So-Simple theoretical framework of writing development will be presented. In addition, a comprehensive overview of (4) the relationship between fine motor skills and self-regulation; and (5) the interrelationships between fine motor skills and self-regulation in the context of writing is included.

Head Start Preschool Programs

The Head Start preschool program, founded in 1965 as a part of President Lyndon B. Johnson's War on Poverty initiative (Ludwig & Phillips, 2008), today provides close to 700,000 children with access to free early educational programming across the United States ("National Head Start Fact Sheets"). Head Start programs are federally-funded and serve children ages 3-5, targeting three primary areas: early learning, health, and family well-being (*Head Start Programs | ECLKC*). As a part of Head Start, children are provided with a variety of opportunities throughout the school day including educational activities, healthy snacks and meals, time to play with peers both indoors and outdoors, and even some free medical and dental care services (*Head Start and Early Head Start | Childcare.Gov*). The primary eligibility criteria for nearly all Head Start programs is having a family income level at or below the federal poverty line – but regardless of income, all children from families receiving public assistance

(e.g., from the Temporary Assistance for Needy Families or Supplemental Security Income programs), all children in foster care, and all homeless children are eligible for Head Start (*How to Apply | ECLKC*). Participation in Head Start programs has been linked to higher performance on academic achievement measures later in children's educational careers (e.g., Currie & Thomas, 1993), as well as an increased likelihood of completing high school and attending college (Garces et al., 2002; Ludwig & Miller, 2007) – and even a reduction in health problems such as depression and obesity (Carneiro & Ginja, 2014).

Fine Motor Skill Development

Early childhood is perhaps the most intensive time for the development of fine motor skills, which include things like manipulating small objects, cutting with scissors, drawing, tracing, and copying figures (McHale & Cermak, 1992). A large proportion of time during the day in early childhood classrooms is spent engaging in fine motor activities: for example, a study of 10 Head Start preschool and 10 kindergarten classrooms found that on average, children in Head Start spent between 27-46% and children in kindergarten spent between 36-66% of the school day engaged in fine motor activities (Marr et al., 2003). Specific to writing, children's fine motor development occurs in relative sequence from least complex to most complex, and can be conceptualized using four overarching categories: *whole arm* control, *whole hand* control, *pincher* coordination, and *pincer* coordination (Carvell, 2006). Many teachers in early childhood classrooms recognize the importance of developing these fine motor skills, and so integrate various activities throughout the school day to promote each of these four stages. For example, to promote *whole arm* skills, teachers may have students stir a large pot of dry pasta with a wooden spoon. To promote *whole hand* skills, they may have students use a sponge to transfer water from one container to another. For *pincher* skills, teachers may instruct students in how to use

tongs, and then have them pick up various items and sort them into groups. And finally, to promote *pincer* skills (those requiring the most finesse), teachers may show students how to use keys to open various types of locks (all examples adapted from Huffman & Fortenberry, 2011). In experimental settings, fine motor skills are most commonly measured using one of two standardized assessments: The Beery Developmental Test of Visual-Motor Integration (Beery, 2004; McCrimmon et al., 2012) and the Early Screening Inventory – Revised (ESI-R; (Meisels et al., 1997)), both of which include measures such as copying, tracing, drawing, and grasping small objects.

Interestingly, fine motor skills have been linked to academic achievement such that children with higher levels of fine motor skill proficiency perform better on measures of writing, mathematics, and reading than do their less-skilled peers (Cameron et al., 2012; Grissmer et al., 2010; Son & Meisels, 2006). The underlying mechanism for this phenomenon has not been conclusively identified – but experimental work points to a few possibilities. For example, compelling evidence from research in the realm of handwriting shows that following an exercise in which five-year-old children were asked to write letters by hand – as opposed to simply typing or tracing the letters – the children displayed increased activation in neural areas associated with reading (e.g., the interior frontal gyrus, the left anterior cingulate cortex, and the fusiform gyrus) when presented with letters in an MRI scanner (James & Engelhardt, 2012). In essence, the hypothesis that has been most commonly presented to explain the motor skill-achievement link is that the act of writing itself links visual processing with motor experience – thus strengthening the connections in children's brains, and facilitating superior performance on related academic assessments (e.g., recognizing letters after performing a letter-writing task) (James, 2017). Other hypotheses to explain this link center on the idea that fine motor skills are essential for

functioning within a classroom context: children must learn to successfully manipulate scissors, tie their shoes, and grasp writing utensils that will eventually be used compose sentences, write numbers to solve equations, and explain their rationale in scientific lab reports. If children do not have mastery of these basic fine motor skills, then they less likely to be able to progress from simpler tasks to more complex ones – thus affecting their development (and success) in the classroom (McHale & Cermak, 1992).

Fine motor skills can even be used as a predictor of school readiness or academic achievement: for example, higher levels of fine motor skill in preschool relate to superior kindergarten achievement in the areas of letter-word identification, reading comprehension, vocabulary, phonological awareness, and mathematics performance (Becker et al., 2014; Cameron et al., 2012; Son & Meisels, 2006). Even several years later, this relationship is still observed: fine motor skills in preschool predict reading performance in 2nd (Dinehart & Manfra, 2013) and 3rd (McPhillips & Jordan-Black, 2007) grades. Interestingly, some data suggest that higher levels of fine motor skill may be especially beneficial for students who struggle in the classroom (e.g., Kindergartners with low-to-average English grades (Milne et al., 2018)) or for students who are economically disadvantaged (Dinehart & Manfra, 2013). In fact, those students who are low in fine motor skills at the beginning of kindergarten are particularly vulnerable to difficulties not only in academic subject areas but also in areas like social and emotional adjustment to school – and without intervention, may be at risk of falling behind their peers (Bart et al., 2007). A large proportion of children (anywhere from 10-24%) experience fine motor skill difficulties – but fortunately, meta-analytic evidence does show that interventions to improve these skills are largely successful in doing so (Strooband et al., 2020).

The Development of Self-Regulation

"Self-regulation" refers to a composite measure of skills, including 1) the ability to hold information and manipulate it as a part of *working memory*; 2) the ability to pay *attention* for a sustained period of time; and 3) the ability to exercise restraint or control over a particular behavior or response (*inhibitory control*) (McClelland & Cameron, 2011). Like fine motor skills, self-regulatory skills develop most rapidly in early childhood: specifically, between the ages of 3-7, but especially in the preschool years (Montroy et al., 2016). Also in a similar manner to the relationship between fine motor skills and academic achievement, children with higher levels of self-regulation have been shown to out-perform their lower self-regulated peers in subject areas such as: print knowledge and phonological awareness (Purpura et al., 2017), vocabulary (McClelland et al., 2007b), reading (Duncan et al., 2007), and mathematics (Mazzocco & Kover, 2007). In a classroom context, all three components of self-regulation are drawn upon on a regular basis: having to pay *attention* to a teacher's instructions for a particular assignment or task; holding these instructions in *working memory* as the child prepares to execute the task; and exercising *inhibitory control* by suppressing the desire to get up out of their seat or talk to their friends instead of completing their assignment. As early as preschool, higher levels of self-regulation are related to superior performance in the classroom (Blair & Razza, 2007) – and gains in self-regulation have been shown to predict subsequent gains in math, literacy, and vocabulary (e.g., over the course of the preschool or the kindergarten year; McClelland et al., 2007a; Ponitz et al., 2009). This relationship is also observed longitudinally, predicting school success into adolescence and even early adulthood. For example, four-year-olds with attention levels one standard deviation above the average were 48.7% more likely to complete college by the age of 25 (McClelland et al., 2013). This relationship between self-regulation and

achievement has been demonstrated across a variety of samples and in a variety of domains – even after controlling for factors like age, IQ, ethnicity, and parental education level (Duncan et al., 2007). In addition, it appears to be especially meaningful in the context of low-income/at-risk children. For example, a study of 157 at-risk children showed that self-regulation partially mediated the relationship between early reading skills and later reading performance – suggesting that self-regulation plays an important role in the development of reading competence (Smith et al., 2008). Like fine motor skills, self-regulatory skills are also often integrated into early childhood curricula – for example, as outlined in the *Tools of the Mind* approach (Bodrova & Leong, 2007), which includes information about ways in which teachers can be intentional about scaffolding classroom activities to develop children's self-regulatory abilities. To illustrate: teachers may have preschool students engage in games of "Simon Says" or "Duck-Duck-Goose" to teach them about how to both follow instructions (e.g., only perform an action if Simon says so) and to learn to physically control their bodies (e.g., stay seated unless you are tapped on the head when someone says, "Goose!") (Bodrova & Leong, 2007). These types of skills, if mastered early in development, have considerable downstream effects in terms of children being able to thrive socially, emotionally, and academically (Bodrova & Leong, 2007). In experimental settings, self-regulation is often measured using tasks like the Day-Night Stroop Task (Gerstadt et al., 1994) or the Head-Toes-Knees-Shoulders assessment (McClelland et al., 2014), which require children to hold a set of instructions in their *working memory*, pay *attention* to changing task demands, and *inhibit* a prepotent response to make the correct choice. As it was the task used in the present investigation, more information about the Head-Toes-Knees-Shoulders assessment is provided in the Methodology section.

The Relationship Between Fine Motor Skills and Self-Regulation

Interestingly, there are also data to suggest that fine motor skills and self-regulation are related to each other: specifically, such that higher levels of motor skills are related to higher levels of self-regulation, and vice-versa (McClelland & Cameron, 2019; Oberer et al., 2017). This link between fine motor skills and self-regulation manifests in the context of achievement as well: for example, 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 – suggesting a potential compensatory relationship (Cameron et al., 2015).

The mechanism through which this relationship occurs is not necessarily known – however, there is speculation that it has to do with the overlapping involvement of a few key brain areas. Involved most heavily in the execution of fine motor skills are the cerebellum and the prefrontal cortex – the area of the brain which is also most heavily involved in self-regulation (Diamond, 2000; Willingham, 1999). In fact, evidence from neuroimaging studies suggest that during certain cognitive and motor tasks, the prefrontal cortex, cerebellum, and connecting structures such as the basal ganglia are often concurrently activated (Diamond, 2000). Thus, one prominent assertion is that the relationship between these skills has to do with enhanced connectivity or communication between the neural networks involved in both fine motor skill execution and self-regulation, and that development of each one contributes positively to the development and functioning of the other (Diamond, 2000).

Compelling evidence to support this hypothesis is also demonstrated in studies comparing children with dyslexia or other language/reading impairments to typically-developing readers: often, those with language or reading impairment also have comorbid motor or self-regulatory deficits (e.g., they perform more poorly on finger-tapping or motor timing tasks, or on

tasks of inhibitory control) – providing further support for a link between these cognitive and motor areas of the brain and related processes (Savage, 2004; Viholainen et al., 2006).

One study in particular, investigating the link between fine motor skills and self-regulation, has introduced several questions regarding the exact nature of this relationship. Roebers and colleagues (2014) measured fine motor skills, non-verbal intelligence, and self-regulation in a sample of N = 169 five- and six-year-old preschool children, then followed up with subsequent measurements of academic achievement when children were in kindergarten and first grade. At all three of these time points, fine motor skills, non-verbal intelligence, and self-regulation were related to each other – and at the later time points, it was found that children's initial levels of fine motor skills and non-verbal intelligence were predictive of later school achievement (Roebers et al., 2014). However, when self-regulation was added into the regression model, fine motor skills and non-verbal intelligence were no longer significant predictors of academic performance (Roebers et al., 2014) – identifying self-regulation as an important component in the link between fine motor skills and academic achievement, and presenting several interesting questions about the nuance(s) present in this relationship.

Early Writing Development: The Not-So-Simple Theoretical Framework

For children, learning to write is a complex and multi-faceted process. Not only must they learn to identify letters, remember which sounds each one makes, and then combine those letters to form meaningful words and sentences, but they must also learn how to grasp and manipulate writing utensils in order to do so. The development of writing can be conceptualized using a theoretical framework that includes several key component, the most all-encompassing of which is referred to as the "Not-So-Simple View" (Berninger et al., 2009). The Not-So-Simple View places text generation – including words, sentences, and more complex forms of

writing such as discourse – as the outcome variable of interest, visualized in a model schematic as the top point of a triangle (Berninger et al., 2009). Components that relate to text generation are included as the bottom two points of the triangle in this schematic diagram: transcription skills (i.e., handwriting, keyboarding, and spelling) on one side, and executive functions (i.e., self-regulation of attention, goal setting, planning, reviewing, revising, and self-monitoring) on the other (Berninger et al., 2009). In the middle of the triangle are dynamic cognitive processes including components of working memory (e.g., the phonological loop for remembering sounds, the orthographic loop for remembering the visual aspects of letters), and a more general construct that enables children to fluidly integrate their self-regulatory processes with their fine motor skills and their knowledge of letters, sounds, and words to produce a mark that has meaning (Berninger et al., 2009). By considering such a complex model – as opposed to a simpler model that includes only the most essential elements involved in text generation – writing can be examined through a multitude of lenses, and a variety of components can be targeted by teachers in order to improve it (Berninger et al., 2009). For example, a program called Self-Regulated Strategy Development (SRSD) targets these executive-functioning-related components of writing, and has been successfully employed in schools to improve older elementary school children's writing outcomes (Graham & Harris, 2003; Harris et al., 2019). The Not-So-Simple View of writing is particularly appropriate to be used as the theoretical framework in this dissertation, as both motor skills and self-regulatory processes – and the dynamic interplay between the two – are the main focus as potential predictors of text generation outcomes.

Fine Motor Skills and Self-Regulation in the Context of Early Writing

In addition to being related to superior academic achievement in areas like reading and mathematics, fine motor skills and self-regulation are also related to superior performance on measures of early writing. Specifically, children with higher levels of fine motor skills (Gerde, Skibbe, et al., 2012) and/or higher levels of self-regulation (Puranik et al., 2019) evidence superior writing performance as compared to their less-skilled peers. Early writing skills – specifically, learning how to produce letters, words, and sentences –are of the utmost importance in childhood. For young children, much early instruction is focused on teaching handwriting, spelling, and composing (Berninger et al., 2002; Puranik & Lonigan, 2014; Rhyner, 2009), all of which are related to fluent written communication skills and subsequent academic success. Proficiency in these skills is related to other early literacy skills including letter knowledge, print concepts, and phonological awareness (Diamond et al., 2008), helping to lay the foundation for later writing and reading achievement (Kim et al., 2015; Levin et al., 2005). In experimental settings, researchers use a variety of tasks – spanning a range of difficulty levels – to assess children's writing proficiency. The easiest writing tasks for young children, because they require a less-advanced knowledge of various print concepts, are writing one's own name (e.g., "Madison") or writing individual letters (e.g., "M," "S," "U") (Gerde, Skibbe, et al., 2012; Puranik & Lonigan, 2012; Treiman et al., 2001). More difficult tasks, because they require a higher level of spelling knowledge and a larger vocabulary, including writing entire words (Puranik et al., 2019) or composing ideas in the context of a story (Thomas et al., 2020). Because we know that motor skills and self-regulation are also related to each other, understanding how both might be *interrelated* – especially in the context of writing – is of particular interest, and may be due to a number of factors.

The Theory of Automaticity

One way to understand the relationship between fine motor skills and self-regulation in the context of writing could be via 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 then 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 reserves available to devote to other higher-order learning objectives (and the amount of self-regulation needed to overcome this motor skill deficiency) (Cameron et al., 2012).

The Role of Task Difficulty & The Zone of Proximal Development

Whereas the relations between self-regulation and achievement in reading and mathematics are relatively clear-cut (i.e., higher self-regulation corresponds with higher achievement levels essentially across the board), the link is a bit less clear in the realm of early writing – and findings in this area have been equivocal. Some research has identified direct relations between self-regulation and writing (e.g., Gerde et al., 2012; Puranik et al., 2019), but

others have found that there is not a direct link, instead showing a mediated relationship between self-regulation and writing through other skills like phonological awareness and letter knowledge (Zhang et al., 2017). Interestingly, work from Gerde et al. (2012) shows 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. Important to note here is the six-month age difference between these two samples – and the fact that name writing is likely more challenging for younger children, as they have not yet had as much experience writing their own names as would have children entering kindergarten. Along this same line of logic, Puranik and colleagues (2019) found self-regulation to be associated with children's letter- and word-writing in preschool – but in kindergarten, self-regulation was no longer related to letters and was instead related to word writing and composing (which require higher levels of writing skill).

As tasks become more automatic, they inherently require less self-regulation – and so it may be that task difficulty also plays a role in the relationship between self-regulation and writing performance. This phenomenon can be framed in terms of the Zone of Proximal Development (ZPD; Vygotsky, 1978), which essentially states 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 dissertation 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 individual 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.

CHAPTER 3

Methodology

Participants

Participating children were recruited from Head Start preschool programs – one in Flint, Michigan and one in Atlanta, Georgia – both 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 line (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). Of note, instruction for all children began and ended at the same time (i.e., the school year period comprised the same months, regardless of which classroom the child was in). 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.

Procedure

Children were recruited from classrooms participating in a study of early writing approaches. 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, behavioral 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.

Measurement of fine motor skills

Children's visual 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).

Measurement of self-regulation

The Head-Toes-Knees-Shoulders task (HTKS; McClelland et al., 2014) was used as a direct measure of behavior regulation (including working memory, attention, inhibitory control, and task persistence). The HTKS, which has been linked to literacy achievement in preschool (McClelland et al., 2007b; 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 Ponitz et al., 2008; Ponitz et al., 2009).

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 tasks proceeded in the order listed below:

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. See Figure 1 for an example name writing response.

Figure 1. A child's response to the name writing task. Despite one backwards letter, this response would have earned a score of 8, indicating that the name was spelled correctly.

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; $\alpha = .76$). See Figure 2 for an example letter writing response.

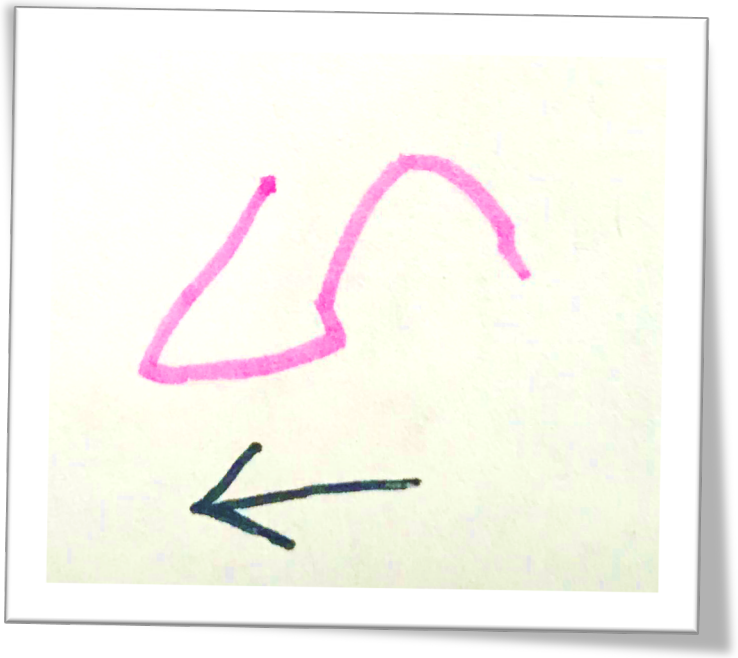

Figure 2. A child's response when asked to write the letter 'S.' This response would have earned a score of 4, indicating a letter-like form.

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). See Figure 3 for an example word writing response.

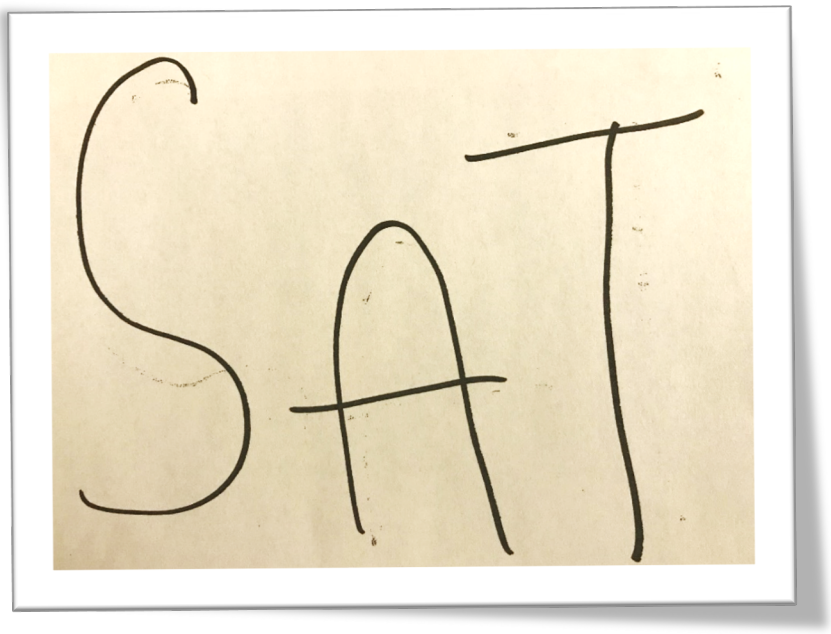

Figure 3. A child's response when asked to write the word 'sad.' This response would have earned a score of 7, indicating that letters were used and that two sounds were represented.

Story 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. See Figure 4 for an example story writing response.

Figure 4. A child's response when asked to write what Mama Raccoon might be saying to her baby. As this child indicated that the text was supposed to say, "I love you," this response would have earned a score of 5, indicating that beginning and salient sounds were represented.

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. 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.

Statistical Analysis

All analyses were conducted in R Version 3.6.3 (R Core Team, 2019) using the stats (R Core Team, 2020), fmsb (Nakazawa, 2019), psychometric (Fletcher, 2010), lm.beta (Behrendt, 2014), and Rmimic (Pontifex, 2020) packages with an alpha level of $p = .05$. 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 between fine motor skill and self-regulation on early writing skills. 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 = Georgia, 1 = Michigan]) – 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. The 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).

CHAPTER 4

Results

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.

Table 1. Participant demographic characteristics and 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 Level)	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 motor skill, self-regulation, and writing outcome variables included in analysis.

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).

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 Level)	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 $p \leq .001$

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:

Name writing. Age, site, sex, and race/ethnicity were significant predictors of name writing performance ($F(4, 328) = 43.5$, $f^2 = 0.53$ [95% CI: 0.36 to 0.75]; $R^2_{adj} = 0.34$, $p < 0.001$). Beyond these demographic factors, both fine motor skills and self-regulation explained a statistically significant amount of variance in name writing performance: ($F_{change}(6, 326) = 40.5$, $p < .001$, $f^2 = .20$ [95% CI: 0.09 to 0.34]; $\beta_{fine\ motor\ skills} = 0.38$, $t = 7.8$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.15$, $t = 3.1$, $p = 0.002$; $R^2_{change} = 0.13$; $R^2_{adj} = 0.47$).

Letter writing. Age, site, and sex were significant predictors of letter writing performance ($F(3, 329) = 54.0$, $f^2 = 0.49$ [95% CI: 0.33 to 0.70]; $R^2_{adj} = 0.32$, $p < 0.001$). Beyond these demographic factors, fine motor skills explained a statistically significant ($F_{change}(4, 328) = 95.4$, $p < 0.001$, $f^2 = 0.23$ [95% CI: 0.11 to 0.37]; $\beta_{fine\ motor\ skills} = 0.47$, $t = 9.8$, $p < 0.001$) amount of variance in letter writing performance ($R^2_{change} = 0.15$; $R^2_{adj} = 0.47$).

Word writing. Age, sex, and site were significant predictors of word writing performance ($F(3, 329) = 33.6$, $f^2 = 0.31$ [95% CI: 0.19 to 0.46]; $R^2_{adj} = 0.23$, $p < 0.001$). Beyond these demographic factors and novel to the present investigation, self-regulation was found to moderate the relationship between fine motor skills and word writing performance ($F_{change}(6, 326) = 24.2$, $p < .001$, $f^2 = 0.18$ [95% CI: 0.09 to 0.30]; $\beta_{fine\ motor\ skills} = 0.27$, $t = 3.5$, $p < 0.001$; $\beta_{self\text{-}regulation} = -0.03$, $t = -0.3$, $p = 0.8$; $\beta_{interaction} = 0.23$, $t = 2.0$, $p = 0.042$; $R^2_{change} = 0.14$, $R^2_{adj} = 0.36$). 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 5).

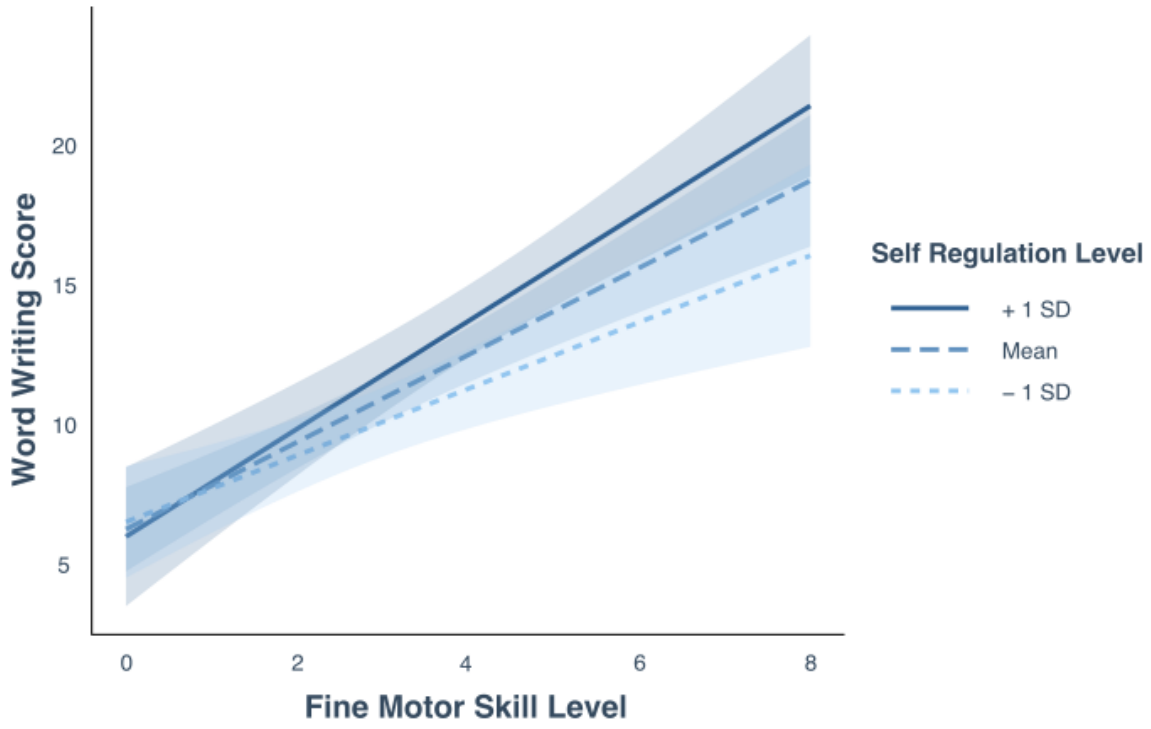

Figure 5. Visualization of the significant interaction between fine motor skills and self-regulation for word writing performance at the beginning of the preschool year.

Story writing. Age was a significant predictor of story writing performance ($F(1, 331) = 82.7, f^2 = 0.25$ [95% CI: 0.14 to 0.38]; $R^2_{adj} = 0.20$, $p < 0.001$). Both fine motor skills and self-regulation explained a statistically significant amount of variance in story writing performance, over and above age: ($F_{change}(3, 329) = 26.5$, $p < .001$, $f^2 = .14$ [95% CI: 0.06 to 0.24]; $\beta_{fine\ motor\ skills} = 0.33$, $t = 6.2$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.14$, $t = 2.6$, $p = 0.01$; $R^2_{change} = 0.11$; $R^2_{adj} = 0.30$).

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

Table 3. Participant demographic characteristics and 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 Level)	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 motor skill, self-regulation, and writing outcome variables included in analysis.

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).

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]	< .001**
HTKS Score (Self-Regulation Level)	18.4 ± 15.2	29.8 ± 20.9	11.5	0.60 [0.49 to 0.72]	< .001**
Name Writing	4.7 ± 2.0	5.6 ± 1.9	7.4	0.43 [0.31 to 0.54]	< .001**
Letter Writing	34.8 ± 17.0	40.9 ± 17.3	8.1	0.36 [0.27 to 0.45]	< .001**
Word Writing	11.9 ± 9.6	13.4 ± 10.8	2.7	0.15 [0.04 to 0.26]	.006**
Story Writing	2.8 ± 1.1	3.2 ± 1.2	7.0	0.42 [0.30 to 0.55]	< .001**

Note. * denotes significance at $p < .05$. ** 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.

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 ≥ 0.38, p's $< .001$; see Table 5).

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

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:

Name writing. Age, site, and sex were significant predictors of name writing performance at the end of the preschool year ($F(3, 401) = 43.2$, $f^2 = 0.32$ [95% CI: 0.21 to 0.46]; $R^2_{adj} = 0.24$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and name writing ($F_{change}(6, 398) = 36.2$, $p < 0.001$, $f^2 = 0.21$ [95% CI: 0.12 to 0.33]; $\beta_{fine\ motor\ skills} = 0.50$, $t = 6.8$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.38$, $t = 3.6$, $p < 0.001$; $\beta_{interaction} = -0.31$, $t = -2.3$, $p = 0.02$; $R^2_{change} = 0.16$, $R^2_{adj} = 0.40$) 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 6).

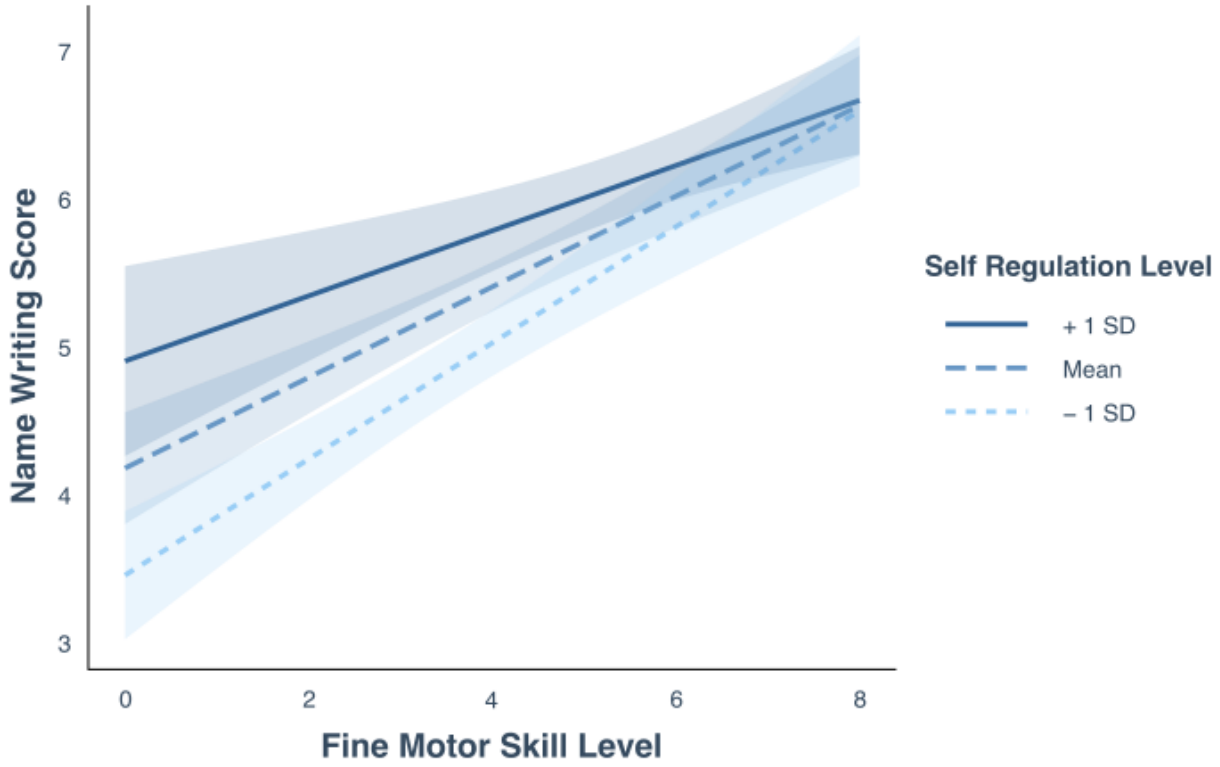

Figure 6. Visualization of the significant interaction between fine motor skills and self-regulation for name writing performance at the end of the preschool year.

Letter writing. Age, site, and sex were significant predictors of letter writing performance ($F(3, 401) = 62.2$, $f^2 = 0.47$ [95% CI: 0.32 to 0.64]; $R^2_{adj} = 0.31$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and letter writing ($F_{change}(6, 398) = 58.7$, $p < 0.001$, $f^2 = 0.31$ [95% CI: 0.19 to 0.46]; $\beta_{fine\ motor\ skills} = 0.53$, $t = 7.9$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.50$, $t = 5.4$, $p < 0.001$; $\beta_{interaction} = -0.36$, $t = -3.1$, $p = 0.002$; $R^2_{change} = 0.21$, $R^2_{adj} = 0.52$) 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 impact of self-regulation was attenuated for children with higher levels of fine motor skills (see Figure 7).

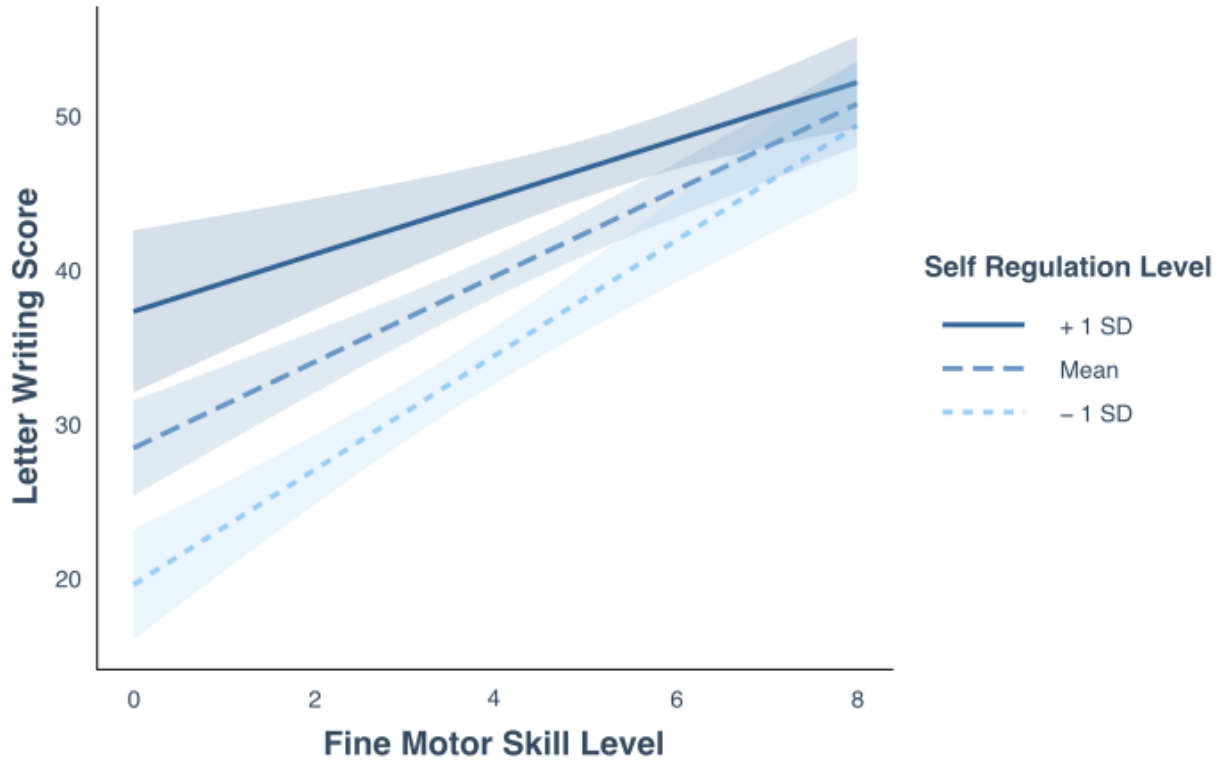

Figure 7. Visualization of the significant interaction between fine motor skills and self-regulation for letter writing performance at the end of the preschool year.

Word writing. Age, site, and race/ethnicity were significant predictors of word writing performance ($F(3, 401) = 34.6$, $f^2 = 0.26$ [95% CI: 0.16 to 0.38]; $R^2_{adj} = 0.20$, $p < 0.001$). Beyond these demographic factors, self-regulation was found to moderate the relationship between fine motor skills and word writing ($F_{change}(6, 398) = 45.0$, $p < 0.001$, $f^2 = 0.25$ [95% CI: 0.15 to 0.37]; $\beta_{fine\ motor\ skills} = 0.12$, $t = 1.6$, $p = 0.11$; $\beta_{self\text{-}regulation} = -0.09$, $t = -0.9$, $p = 0.37$; $\beta_{interaction} = 0.50$, $t = 3.8$, $p < 0.001$; $R^2_{change} = 0.20$, $R^2_{adj} = 0.40$). 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 8).

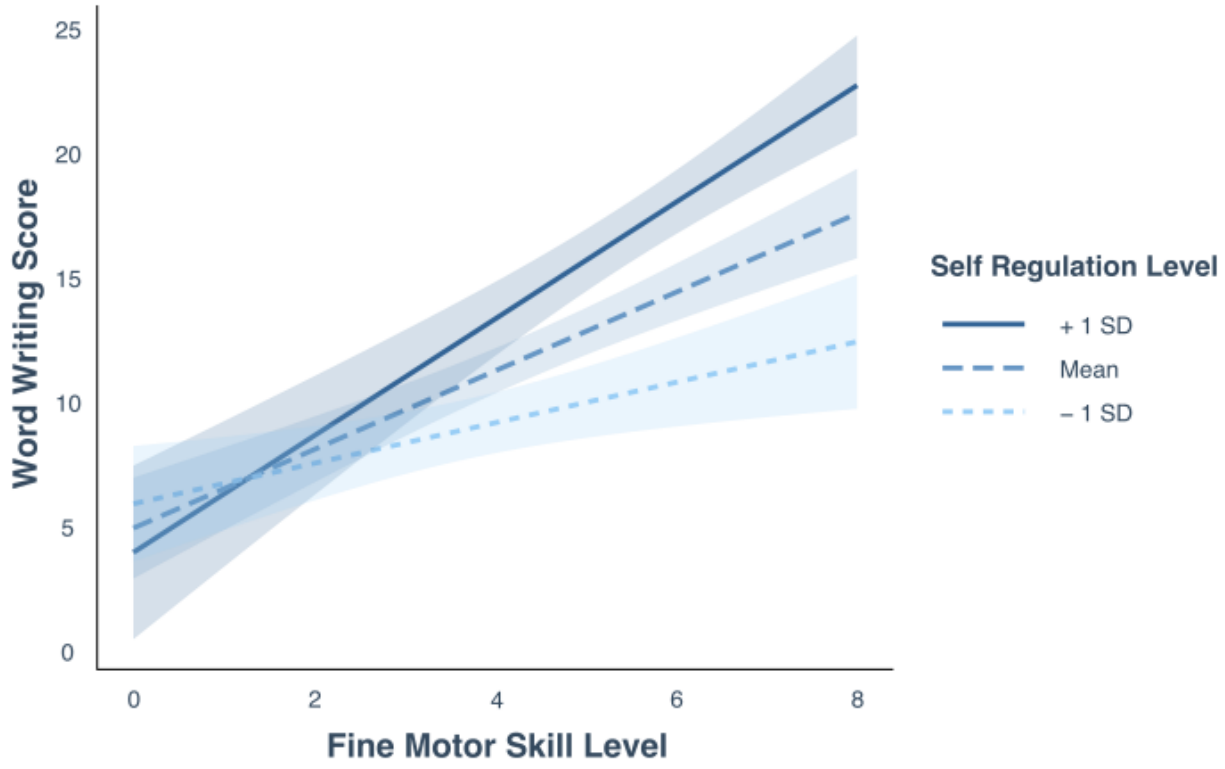

Figure 8. Visualization of the significant interaction between fine motor skills and self-regulation for word writing performance at the end of the preschool year.

Story writing. Age, site, and sex were significant predictors of story writing performance ($F(3, 401) = 32.1$, $f^2 = 0.24$ [95% CI: 0.14 to 0.35]; $R^2_{adj} = 0.19$, $p < 0.001$). Beyond these demographic factors, both fine motor skills and self-regulation – but not the interaction between the two – explained a statistically significant amount of variance in story writing: ($F_{change}(5, 399)$

= 33.2, $p < 0.001$, $f^2 = 0.14$ [95% CI: 0.07 to 0.23]; $\beta_{fine\ motor\ skills} = 0.33$, $t = 6.4$, $p < 0.001$; $\beta_{self\text{-}regulation} = 0.12$, $t = 2.4$, $p = 0.017$; $R^2_{change} = 0.12$, $R^2_{adj} = 0.30$.

CHAPTER 5

Discussion

The aim of this dissertation 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 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 this dissertation, self-regulation interacted with fine motor skills for several tasks measuring early writing proficiency in a sample of preschool children. These findings identify the interrelation between 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. These findings also help to clarify the reason(s) why some of the relationships observed in the investigation by Roebers et al. (2014) may have seemed inconsistent. In that investigation, cross-lagged models were used in which children's levels of fine motor skills and self-regulation in preschool were used to predict academic performance in kindergarten and first grade. Fine motor skills on their own were predictive of academic performance – however, when self-regulation was added to the model, fine motor skills were no longer a significant predictor (Roebers et al., 2014). As demonstrated in the present investigation, the relationship between fine motor skills and self-regulation in an achievement context is dynamic, changing as children improve in their skill development even throughout the course of a single school year (i.e., from fall to spring). It could be, then, that the findings observed by Roebers et al. (2014) – captured across a period of three distinct school years – are an indication of this very phenomenon: that fine motor skills and self-regulation are related to academic performance in a task-dependent manner, ever-changing based on improvements in skill level as children grow and develop.

At the beginning of the school year, this dissertation 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 motor skills – but not self-regulation – were a predictor. Novel to this study, a significant interaction was observed between self-regulation and motor skills in the context of the word-writing task, manifesting such that children with higher levels of motor skills and higher levels of

self-regulation outperformed children with higher levels of motor skills but lower levels of self-regulation. This relationship was not observed for children with lower levels of motor skills, suggesting that for these children, there may have been a sort of "floor" effect wherein self-regulation could not come online because the task was simply too challenging. While it may seem counterintuitive that an interaction was observed for the harder – but not the easier – tasks at the beginning of the school year, the concept of a floor effect may also help to explain this phenomenon. In other words, because performance on all tasks was relatively low at the beginning of the year (i.e., no child wrote his/her name accurately; most of the writing observed in the other tasks was in the form of letter-like forms, drawings, or scribbles), the only group within which self-regulation was able to come online as a compensatory mechanism was children with high levels of fine motor skill – presumably the most adept at completing the most challenging task. As will be detailed in the following paragraphs, it was not until the end of the school year – when both 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 ≥ 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 motor skills – on the simpler writing tasks (name writing, letter writing). For those children with higher levels of 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 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 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.

Of note regarding the story writing task is that there was not a wide distribution of children's scores on this task: most performed at about the same level (i.e., scores of 2 or 3). Statistically speaking, it may be that an interaction between fine motor skills and self-regulation was not observed because there was not enough variation in the sample for an interaction to be observed. Equally probable is this task was simply too challenging for children, drawing upon composition skills they had not yet mastered. An interesting follow-up research question to these particular considerations is whether or not a motor skill/self-regulation interaction would

observed using this same story-writing task in older or more-skilled samples, which would be in alignment with the theoretical interpretation of the results from this investigation.

This study certainly contributes to the theoretical literature on early writing development, providing important context surrounding the complex interplay between children's skill level, task difficulty, and the role of self-regulation in successful writing task performance. It also contributes to the public health literature, highlighting the importance of children's fine motor skills in the context of not only physical literacy but also in the context of optimal cognitive and academic 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.

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 motor (Son & Meisels, 2006) and self-regulatory development across the early

years (McClelland et al., 2007b), 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 et al., under review). 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 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.

Public Health Significance

When discussing the public health significance of the findings from this dissertation, it is helpful to consider a concept from the kinesiology literature known as "physical literacy." The concept of physical literacy primarily includes movements associated with larger muscle groups (e.g., jumping, throwing, running, balancing) as opposed to smaller ones, but highlights the importance of mastering motor skills in the pursuit of optimal human development. Generally speaking, a physically literate person is considered to be one who moves with confidence in a variety of challenging situations and is able to adapt to and anticipate various situations based on their mastery of these foundational movement skills (Whitehead, 2001). For example, a physically-literate child will feel comfortable in a variety of situations, maybe being inclined to participate in sports or activities that promote engagement in physical activity and healthy social development. In much the same way, fine motor skills are perhaps equally as important as these larger, gross motor skills when it comes to optimizing all forms of development, cognitive and academic included. If children are given the opportunity to bolster their fine motor skills like writing when they are young, they will be set on a trajectory towards success in increasingly complex subject matter, from composing sentences to solving complex mathematics equations to performing experiments in a scientific laboratory. Just as physical education curricula in many schools focuses on developing children's gross motor skills, evidence from this dissertation highlights the importance of providing continued opportunities to hone fine motor skills in the classroom as well. For example, interventions such as the Primary Movement Program (Brown, 2010), which has been shown to improve children's fine motor skills over the course of a school

year, could be employed. Similarly, programs like the Children's Health Activity Motor Program (CHAMP; Palmer et al., 2019) – which has been shown to significantly improve children's gross motor skills after a period of just 5 weeks – could be designed to target fine motor skills instead of (or in addition to) the gross motor skills that are already included.

Ensuring optimal development of self-regulation, too, is an important part of children's overall well-being – and thus contributes to public health. Children with higher levels of self-regulation in preschool are almost 50% more likely to have completed college by age 25 than their lower-self-regulated peers (McClelland et al., 2013). Research in young children also shows that toddlers with poorer self-regulation are at a higher risk of displaying behavioral problems later in school (Lonigan et al., 2017), and also at higher risk of becoming overweight/obese than are their more-highly-self-regulated peers (Graziano et al., 2010). Close to one-quarter of preschool children in the United States are overweight or obese (Ogden et al., 2015), with children from lower socioeconomic groups – such as those enrolled in Head Start programs, as were the children who participated in the present investigation – often at an even higher risk (Williams et al., 2018). Therefore, findings from this study add to a growing body of evidence underscoring the importance of bolstering children's self-regulatory abilities as a part of their schooling – with downstream benefits spanning not only aspects of academic achievement like reading, writing, and math, but also educational attainment, behavior in the classroom, and even aspects of physical health.

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 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. 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). Such work with older children could establish whether there exists a ceiling (or, similarly, work with even younger children could test for the existence of a floor) – above or below which this interaction between self-regulation and motor skills does not occur. It would seem consistent with the findings from this dissertation if for children whose motor skills were not-yet-developed-enough – or, conversely, too-well-developed – self-regulation did not play as central of a role in interacting with motor skills to influence task performance outcomes. Another interesting direction in which to take this research would be to examine whether this same interaction between fine motor skills and self-regulation occurs in the context of subject areas other than writing – for example, in reading, mathematics, or science. Because writing is an academic subject area that is so inherently so dependent on fine motor skills, determining the task-dependent nature of this relationship in other domains – with perhaps less of an overt need for manual dexterity, such as reading – is certainly an area worth exploring. Finally, interventional studies – in which self-regulation and/or fine motor skills (or both) are targeted – would provide experimental evidence about this

compensatory relationship, showing the ways in which *improvement* in each of these skills may impact writing performance.

Conclusions

Taken together, findings from this dissertation provide compelling evidence to clarify the nature of 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) – asserting that this relationship may, in fact, manifest via an interaction with children's existing levels of fine motor skills.

APPENDICES

APPENDIX A: IRB Approval Letter

MICHIGAN STATE
UNIVERSITY

Initial IRB Application Determination *Exempt*

June 15, 2015

To: Hope Gerde
552 W Circle Drive

Re: **IRB# x15-623e** Category: Exempt 2
Approval Date: June 15, 2015

Title: Development and Feasibility of the Improving Writing Resources and Interactions in Teaching Environments through Professional Development (IWRITE PD) for Teachers of Economically Disadvantaged Children (CGA 138194)

The Institutional Review Board has completed their review of your project. I am pleased to advise you that **your project has been deemed as exempt** in accordance with federal regulations.

The IRB has found that your research project meets the criteria for exempt status and the criteria for the protection of human subjects in exempt research. **Under our exempt policy the Principal Investigator assumes the responsibilities for the protection of human subjects** in this project as outlined in the assurance letter and exempt educational material. The IRB office has received your signed assurance for exempt research. A copy of this signed agreement is appended for your information and records.

Renewals: Exempt protocols do not need to be renewed. If the project is completed, please submit an ***Application for Permanent Closure***.

Revisions: Exempt protocols do not require revisions. However, if changes are made to a protocol that may no longer meet the exempt criteria, a new initial application will be required.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to the human subjects and change the category of review, notify the IRB office promptly. Any complaints from participants regarding the risk and benefits of the project must be reported to the IRB.

Follow-up: If your exempt project is not completed and closed after three years, the IRB office will contact you regarding the status of the project and to verify that no changes have occurred that may affect exempt status.

Please use the IRB number listed above on any forms submitted which relate to this project, or on any correspondence with the IRB office.

Good luck in your research. If we can be of further assistance, please contact us at 517-355-2180 or via email at IRB@msu.edu. Thank you for your cooperation.

Sincerely,

H. McGee

Harry McGee, MPH
SIRB Chair

Office of Regulatory Affairs
Human Research Protection Programs

Biomedical & Health Institutional Review Board (BIRB)

Community Research Institutional Review Board (CRIRB)

Social Science Behavioral/Education Institutional Review Board (SIRB)

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APPENDIX B: Dissertation Funding Sources

Dissertation Funding Sources

1. **Grant R205A150210, Institute of Education Sciences**
   U. S. Department of Education
   Awarded to Michigan State University
   Use: Study funding source.

2. **Dissertation Completion Fellowship – 2020/2021**
   The Graduate School, Michigan State University
   Funded - $7,000
   Use: Partial teaching release to allow time for analysis, writing, and defense preparation.

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