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The Development of Self-Regulation across Early Childhood

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Abstract

The development of early childhood self-regulation is often considered an early life marker for later life successes. Yet little longitudinal research has evaluated whether there are different trajectories of self-regulation development across children. This study investigates the development of behavioral self-regulation between the ages of three and seven, with a direct focus on possible heterogeneity in the developmental trajectories, and a set of potential indicators that distinguish unique behavioral self-regulation trajectories. Across three diverse samples, 1,386 children were assessed on behavioral self-regulation from preschool through first grade. Results indicated that majority of children develop self-regulation rapidly during early childhood, and that children follow three distinct developmental patterns of growth. These three trajectories were distinguishable based on timing of rapid gains, as well as child gender, early language skills, and maternal education levels. Findings highlight early developmental differences in how self-regulation unfolds with implications for offering individualized support across children.

Keywords

Behavioral self-regulation; developmental trajectories; early childhood; longitudinal

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The Development of Self-Regulation Across Early Childhood The development of effective self-regulation is recognized as fundamental to an individual's functioning, with development during early childhood often considered an early marker for later life successes

Correspondence should be sent to Janelle J. Montroy, Children's Learning Institute, Department of Developmental Pediatrics, University of Texas Health Science Center at Houston, 7000 Fannin Street Suite 2373H, Houston, TX 77030, USA. Tel: +1 713 500 3831. Janelle.J.Montroy@uth.tmc.edu.

(Blair, 2002; Bronson, 2000; Calkins, 2007; Diamond, 2002; Gross & Thompson, 2007; Kopp, 1982; McClelland & Cameron, 2012; Mischel et al, 2011; Moffitt et al., 2011; Vohs & Baumeister, 2011; Zelazo et al., 2003). Research indicates that between ages three and seven a qualitative shift in self-regulation may take place when children typically progress from reactive or co-regulated behavior to more advanced, cognitive behavioral forms of *self*-regulation (e.g., Diamond, 2002; Kopp 1982) that likely require the integration of many skills such as executive functions and language skills (Calkins, 2007; Cole, Armstrong, & Pemberton, 2010). Likewise, past research suggests wide variation in the level of self-regulation skills children manifest during early childhood that consistently predicts a multitude of short- and long-term outcomes such as school readiness, academic achievement throughout primary school, adult educational attainment, feelings of higher self-worth, a better ability to cope with stress, as well as less substance use, and less law breaking, even among individuals at risk of maladjustment (McClelland, Acock, Piccinin, Rhea, & Stallings, 2013; Mischel et al., 2011; Moffitt et al., 2011).

However, despite mounting evidence that early childhood is an important time period for the development of self-regulation, little is known about how children's trajectories of development might vary across individuals over time (Bergman, Magnusson, & Khouri, 2002; Muthén & Muthén, 2000; Nagin, 1999). To address this gap, we examined the inter-individual variation in children's growth trajectories between preschool and early elementary school based on evidence that self-regulation requires the coordination and processing of multiple skills across several domains (Calkins, 2007; Cole et al., 2010). More specifically, we posit that there will be differences related to when the integration of these skills begin to manifest as well as differences in the patterns of how they are manifest as regulated behavior (Blair, 2010; Blair & Raver, 2012; 2015; Calkins, 2007; Clark et al., 2013). In the current study, we examined the development of behavioral self-regulation via the Head-Toes-Knees-Shoulders task (Cameron et al., 2008) between the ages of three and seven with longitudinal data involving up to eight measurement occasions for individual children across three samples. We evaluated possible heterogeneity in the developmental trajectories of children's behavioral self-regulation using growth mixture modeling (GMM; Grimm, McArdle, & Hamagami, 2007), and potential indicators of trajectory differences.

Defining Self-regulation

Self-regulation is a complex, multi-component construct (Blair & Raver, 2012; McClelland, Cameron Ponitz, Messersmith, & Tominey, 2010; Schunk & Zimmerman, 1997; Vohs & Baumeister, 2011) operating across several levels of function (e.g., motor, physiological, social-emotional, cognitive, behavioral and motivational), that in its broadest sense represents the ability to volitionally plan and, as necessary, modulate one's behavior(s) to an adaptive end (Barkley, 2011; Gross & Thompson, 2007). One approach to the complexity of self-regulation has been to view the multiple functions of self-regulation as hierarchically organized and, eventually, reciprocally integrated (Blair & Raver, 2012; Calkins, 2007). Ultimately self-regulation depends on the coordination of many processes across levels of function, with children's ability to draw on, integrate, and manage these multiple processes increasing across developmental time (McClelland & Cameron, 2012; McClelland et al., 2014).

The current study focuses on self-regulation in relation to its role in successful classroom functioning (McClelland & Cameron, 2012; McClelland, Morrison, & Holmes, 2000; Nesbitt et al., 2015). Effective self-regulation in the classroom requires that the child seamlessly coordinate multiple aspects of top down control (i.e., executive function) such as attention, working memory, and inhibitory control along with motor or verbal functions to produce overt behaviors, such as remembering multi-step directions amidst distractions (Cameron Ponitz et al., 2008; McClelland et al., 2007). This form of self-regulation is therefore typically termed behavioral self-regulation (c.f., emotional self-regulation; Gross & Thompson, 2007). To evaluate individual differences in development of self-regulation across multiple years, we used a well validated direct assessment of behavioral self-regulation, the Head-Toes-Knees-Shoulders task (HTKS, Cameron et al., 2008) that captures variations in behavioral self-regulation throughout the entire range of early childhood, making it possible to accurately assess developmental change on a common scale across time (Cameron Ponitz et al., 2008; Connor et al., 2010; McClelland et al., 2007; Skibbe et al., 2012). The HTKS is a short, game-like task where children are asked to 'do the opposite' in regards to a set of paired rules. For example, if the child is asked to touch their head, instead they must touch their toes. This task taps three executive function skills (McClelland et al., 2014) in order to make a gross motor response: 1. attention (ability to focus on instructions and current stimuli), 2. working memory (ability to process the current trial while holding a rule or set of rules in mind), and 3. inhibition (ability to ignore a well learned response in order to respond in a counter-intuitive way).

Executive functions help an individual understand, monitor, and control their own reaction to the environment, as well as problem solve regarding desired future behaviors and/or outcomes. Put another way, the coordination of these skills often forms the basis of a child's ability to respond adaptively within the classroom. Notably a distinction has been made in recent years between executive functions at the service of abstract or decontextualized environments, and executive functions at the service of adapting to environments that require the regulation of affect and motivation (e.g., Hongwanishkul et al., 2005). Sometimes referred to as 'cool' executive functions and 'hot' executive functions within cognitive traditions (e.g., Zelazo & Carlson, 2008), these skills can be considered as necessary (although not entirely sufficient; Ursache & Blair, 2011) for behavioral and emotional aspects of self-regulation, respectively (Zhou & Chen, 2008). Both hot and cool aspects are important for development; hot aspects are usually more associated with socio-emotional health and outcomes, while cool aspects are more associated with cognitive and academic outcomes (Kim et al, 2013). The HTKS task generally draws on cool aspects of executive function, although in reality no task is entirely free of an emotional context, with distinctions generally being a matter of degree (Manes et al, 2002).

The Development of Behavioral Self-regulation

The development of self-regulation begins in infancy, with many of the skills that are important for behavioral self-regulation developing first as separate domains, then becoming organized and integrated over time (Barkley; 2011; Corrigan, 1981; Diamond et al., 1997; Kopp, 1989; Stifter & Braungart, 1995). Previous work indicates that not only do separate facets of self-regulation appear to develop at different times and rates (such as emotional self-regulation generally preceding the development of behavioral self-regulation; Howse et al., 2003) but also the underlying skills may also develop at different times. For example, the ability to delay a response (an outcome most strongly associated with developing inhibitory control) appears to develop earlier than other executive skills (Lengua, et al., 2015). However, despite differences across individual facets and skills associated with self-regulation, previous research consistently indicates that children younger than three have difficulty simultaneously coordinating and utilizing multiple executive function skills to create a behavioral response that also requires a motor or verbal action (Carlson, Moses, & Breton, 2002; Diamond, 2002; Zelazo et al., 2003). However, after age three and during early childhood, the individual skills that support behavioral self-regulation (e.g., see Cole et al., 2010; Diamond et al., 1997 or Rothbart et al., 2006), as well as behavioral self-regulation itself as an integration of those skills, rapidly develop(s), signifying a qualitative shift in children's regulatory abilities (Best & Miller, 2010; Garon et al., 2008; Kopp, 1982; Zelazo et al., 2008).

Specifically, cross sectional work with a multitude of tasks indicates a rapid increase or "leap" in performance on tasks that require the integration of several executive function skills into behavior, such as the HTKS task, the Dimensional Change Card Sort, The Day/Night, Bear/Dragon, Fish Flanker, and Luria's tapping task (Diamond, 2002; Gerstadt et al., 1994; Rothbart et al., 2006; Rueda et al., 2004; Zelazo et al., 2003). For example, there are large group differences in accuracy on a fish flanker task (see Rueda et al., 2004 for a description of the task) between four year olds and six year olds, but by about age seven, children's accuracy gains level off as performance becomes similar to adults (although reaction time continues to improve; Rothbart et al., 2006; Rueda et al., 2004). In addition, recent work explicitly evaluating behavioral self-regulation longitudinally (Cameron Ponitz et al., 2008), as well as several studies of underlying executive function skills (Chang, Shaw, Dishion, Gardner & Wilson, 2014; Clark et al., 2013; Diamond et al., 1997; Wiebe, Sheffield & Espy, 2012) indicate non-linear growth with rapid gains followed by a decelerating rate of gain in performance.

In summary, theory and research both provide evidence of rapid gains in the ability to regulate behavior that are likely linked to the integration of multiple processes, but particularly processes considered under the umbrella of executive function, such as attention, working memory and inhibition (Cameron Ponitz et al., 2008; Chang et al., 2014; Diamond, 2002; Rothbart, et al., 2006). Based on these findings, we expect that the development of behavioral self-regulation in early childhood is likely best represented by a nonlinear function (Diamond, 2002). Specifically, we expect that between the ages of three and seven years, gains in self-regulation will increase rapidly as multiple processes become more coordinated, followed by later decelerated growth (e.g., Cameron Ponitz et al., 2008; Chang et al., 2014; Wiebe et al., 2012).

Heterogeneity in behavioral self-regulation development

Several prominent theories suggest the possibility of multiple self-regulation growth trajectories across early childhood (see Blair, 2010; Blair & Raver, 2012; 2015; Calkins, 2007; Lerner & Overton, 2008). Specifically, theories drawing on psychobiological or dynamic systems models (Blair & Raver, 2015; Lerner & Overton, 2008) indicate a back and forth developmental relationship between children's biological traits and their experiences. These theories contend that how children learn to regulate their behavior can vary widely given that biological predispositions such as temperament and early environmental experiences greatly vary. However, few studies have fully tested whether there are underlying trajectory differences in self-regulation such that children develop behavioral self-regulation in differing ways (i.e., process differences) and/or at different rates (Posner & Rothbart, 2000; Rothbart, Ellis, Rueda & Posner, 2003). The majority of work in this area has noted mean differences in the amount of self-regulation children are able to exert at a given age during early childhood; only recently have studies begun to focus on growth in self-regulation and predictors thereof. Of these studies, few have accounted for systematic inter-individual differences across time (but see Vallotton & Ayoub, 2011; Wanless et al., 2016; Willoughby et al., 2016).

Instead, the majority of studies evaluating self-regulation growth have focused on utilizing child and environmental aspects to predict aggregate variation around a general slope and/or rate mean (e.g., Blandon et al., 2008; Cameron Ponitz et al., 2008; Clark et al., 2013), without further consideration for whether this variation may indicate qualitatively distinct developmental change. This makes it is difficult to conclude whether there actually are subgroups of children with systematic differences in how self-regulation processes unfold (Rogosa, 1988). Likewise, findings at the aggregate level do not necessarily describe the relationship among variables for a single individual or subgroup of individuals (von Eye & Bergman, 2003). This makes it equally difficult to accurately map out predictive relations between children's individual traits and environments and their self-regulation development.

Only one study to date has evaluated multiple trajectories across children in behavioral self-regulation (Wanless et al., 2016). This studied focused specifically on a Taiwanese sample of children and indicated two distinct behavioral self-regulation trajectories: an "increasing" developers trajectory with children rapidly gaining in self-regulation and then leveling off across early childhood, and a "steady-then-increasing" trajectory with children demonstrating few regulatory gains between ages 3 – 5 years and rapid gains after 5 years of age. However, this study only includes a relatively small sample, and focuses on a homogenous population in Taiwan.

The current study builds upon and extends this previous work by directly examining the possibility of qualitatively different behavioral self-regulation growth trajectories between the ages of three and seven in a large heterogeneous population. We focus specifically on behavioral self-regulation as theoretical considerations indicate that the regulation of behavior is expected to include multiple trajectories during early childhood given that the multiple executive function inputs that support it are sensitive to not only genetic inputs but experiential inputs and that these inputs are rapidly developing and differentiating during this time period (Blair & Raver, 2012; Lonigan & Allan, 2014). As part of investigating potential trajectories, we also evaluate one rough environmental proxy and two child level predictors in order to validate potential trajectory differences, and better understand patterns of how and, possibly when, these factors matter for self-regulation development across children.

Child factors

There are several early characteristics that previous studies have identified as having an association with the development of behavioral self-regulation (Blair et al., 2011; Calkins, Dedmon, Gill, Lomax, & Johnson, 2002; Cole et al., 2010; Matthews et al., 2009). The current study focuses on children's gender and language skills as these attributes are fairly consistently linked to individual differences in self-regulation (Bohlmann et al., 2015; Matthews et al., 2009; Ready et al., 2005), and potentially trajectory differences (Vallotton & Ayoub, 2011).

Gender—Previous findings generally indicate that boys have lower levels of self-regulation than girls (Kochanska et al., 2001; Matthews et al., 2009, 2014; McClelland et al., 2007), with gender differences often increasing across time (Matthews et al., 2014). It is not well understood why such gender differences occur (though see Entwistle, Alexander, & Olson, 2007), although recent work suggests gender differences may in part relate to cultural beliefs and expectations (von Suchodoletz et al., 2013; Wanless et al., 2016). However, there is evidence that, from an early age, gender is associated with what type of self-regulation developmental trajectory a child is likely to follow (Vallotton & Ayoub, 2011). For example, during toddlerhood, boys' self-regulation generally dips around age two then rises, while girls' self-regulation rises steadily, resulting in gender differences at ages two and three favoring girls. Additional research focused on kindergarteners suggests that a subset of boys persist in demonstrating very low levels of behavioral self-regulation (Matthews et al., 2009), potentially signifying these boys not only continue to developmentally lag behind girls, but that they may also not be acquiring self-regulation in the same way that peers are. Given these past findings, we expected that boys may be more likely to follow a potentially lagged trajectory.

Language—Language is another child attribute that affects developing self-regulation, and may be an important factor for understanding potential self-regulation trajectory differences across children. Theoretically, language is thought to give children "mental tools" to help them organize and modify their thoughts and behaviors (Vygotsky, 1934/1986). During early childhood, expressive language in particular may be important as it enhances the ability of the child to both name their own current state and manipulate that state in relation to a specific context (Cole et al., 2010). It also seemingly enhances children's ability to hold task requirements in mind (Karbach, Eber, & Kray, 2008). Research evaluating how expressive language helps toddlers to self-regulate suggests that trajectories of self-regulation vary between children based on the child's observed expressive vocabulary skills (Vallotton & Ayoub, 2011). Likewise, early expressive language skills are also associated with higher levels of early self-regulation, with greater language gains across preschool and the transition to kindergarten associated with greater self-regulation gains (Bohlmann, Maier, & Palacios, 2015). This suggests that children with higher levels of expressive language develop self-regulation faster compared to children with lower levels of language. We also expected expressive language to be related to self-regulation growth on the HTKS because children use both expressive and receptive language when completing the task (and can answer verbally if needed/verbalize actions). Based on these previous findings, the pattern of associations between expressive language at the start of schooling and potential self-regulation trajectories should follow a similar pattern such that lower levels of expressive language are associated with a distinct, potentially lagged trajectory compared to higher levels of expressive language.

Mother education

In addition to child attributes and competencies, past research consistently demonstrates that children's environments affect developing behavioral self-regulation (Blair, 2010; Grolnick & Farkas, 2002; Landry et al., 2006). One particularly salient aspect of children's environments that may affect developing self-regulation is their mothers' education levels (e.g., see Miech, Essex, & Goldsmith, 2001). Mother education often serves as a rough yet important proxy of family socioeconomic status and resources (Bradley & Corwyn, 2002; Hoff, Laursen & Tardif, 2002). Low maternal education levels have been linked to lower socioeconomic resources and higher stress levels that, over time, can affect children's developing neuroendocrine processes (e.g., such as cortisol levels). These processes are theorized to directly shape developing self-regulatory response patterns (see Blair & Raver, 2015). Maternal education levels are also associated with distinct parenting profiles that include mothers' warmth, responsiveness, use of rich language inputs, and ability to maintain their children's attention (Guttentag, Pedrosa-Josic, Landry, Smith & Swank, 2006), all factors that predict individual differences in children's self-regulation levels (see Grolnick & Farkas, 2002). Thus, mother education levels are also expected to serve as indicator of valid differences in children's developing self-regulation patterns.

Current Study

Past theory and research indicate that behavioral self-regulation rapidly develops during early childhood with possible heterogeneity of early self-regulation trajectories (e.g., Blair & Raver, 2015; Vallotton & Ayoub, 2011; Wanless et al., 2016). To better understand behavioral self-regulation development and heterogeneity across children, we used the HTKS measure to assess and evaluate development via latent growth curve modeling. We then directly focused on potential trajectory differences in early childhood utilizing growth mixture modeling. We hypothesized that most children would demonstrate rapid gains in their behavioral self-regulation trajectory (e.g., Cameron Ponitz et al., 2008; Matthews et al., 2009), compared to peers, with these gains occurring early in schooling (Blair & Raver, 2015). However, we hypothesized a subset of children would demonstrate a lagged behavioral self-regulation trajectory across early childhood as they are not ready to integrate the multiple processes required by advanced behavioral self-regulation when they first reach school (Wanless et al., 2016; Willoughby et al., 2016). As part of trajectory validation, we utilized multiple diverse samples that included the same measure of behavioral self-regulation within similar age ranges, and with similar data collection procedures in order to evaluate whether trajectory findings replicate across a diverse population of children in different areas of the United States. We then further validated trajectories in relation to predicted associations between three characteristics: gender, language ability, and maternal education levels. We expected that these factors would distinguish what trajectory a child was likely to follow, with patterns of association matching previous findings, offering evidence indicating that trajectories capture meaningful individual difference as well as increasing our understanding how these characteristics relate to individual differences in development over time.

Methods

Participants

Participants consisted of 1,386 children across three samples that had at least two assessments of self-regulation between the ages of three and seven. Children were administered the same direct assessment of behavioral self-regulation in all three studies (the Head-Toes-Knees-Shoulders Task; Cameron Ponitz et al., 2008). The samples are described below.

Michigan longitudinal sample—The first sample was collected in predominantly middle- to upper-SES suburban area with a range of ethnic diversity in southeast Michigan. Participants included 351 (51% female) children followed from preschool through second grade as part of the "Pathways to Literacy" longitudinal study evaluating children's socio-emotional and cognitive development (e.g., ***; blinded for review; 32 of the full sample of 383 were not included due to having fewer than 2 assessments of self-regulation). Students attended 314 classrooms located within 16 schools in a single suburban school district. All schools within this district that included at least one preschool classroom were represented and preschool classrooms included Head Start classrooms (n = 49) as well as those that charged tuition. On average, children were 48.16 months (SD = 7.35) old at the start of the study: just over four years of age. The bulk of parents who provided information about their child's ethnicity (n =257) reported that their child was White/Caucasian (80%). The remainder of children were described as African-American (4%), Asian/Indian (*5%*), Hispanic (1%), and Multi-racial (3%). Several parents (8%) noted that another ethnicity would describe their child best. Most (n = 278) families noted that their child's native language was English, although some families (n = 73) did not respond to this question[1]. Median household income was high (i.e., $115,000; *Range* = $11,000 to $650,000) as were parent education levels, with over 75% of mothers (n = 233) reporting that they had earned at least a bachelor's degree.

Families were recruited via flyers sent home in children's backpacks at the beginning of the school year(s). Children's self-regulation was evaluated in the fall and spring of each year that the child was in the study until they finished first grade (up to 8 times) as part of a battery of measures administered by trained research assistants. Language assessments were administered during the fall of children's first preschool year. Parents also filled out demographic information including child gender and information related to education level in the fall of their child's first preschool year.

MLSELD preschool sample—The second sample consisted of 642 (51% female) preschool aged children from middle-SES communities with data waves collected over four

[1]In the Michigan longitudinal sample, > 7 languages other than English were reported as children's primary language, the largest language sub-group consisted of Arabic (n=4). For the MLSELD preschool sample, 18 languages other than English were reported, the largest language sub-groups consisted of Spanish, and Korean speakers (n = 8).

years in Michigan as part of the Michigan Longitudinal Study of Early Literacy Development (MLSELD preschool sample; ***; blinded for review). Children were drawn from 78 classrooms across six schools: two in central Michigan and four in western Michigan. Schools in central Michigan were accredited by the National Association for the Education of Young Children. One was associated with a university and the other was a joint public/university preschool that also had a population of Head Start eligible children (less than 5% of the current sample). The four schools in western Michigan were part of the area's public schools. In western Michigan, families were recruited for participation at a parent information night, while at the central Michigan schools families were recruited via flyers sent home in children's backpacks. Children were on average approximately four years of age at the start of the study (M = 47.74, SD = 7.02). Most parents who provided information about their child's ethnicity (n = 479) reported that their child was White/Caucasian (81%). Children who were African American (2%), Hispanic (3%), Asian (7%), multi-racial (4%), and those from 'other' (3%) ethnicities also participated in the present work. Among families reporting primary language spoken at home, almost all reported English (n = 443) although some families did not respond to this question (n = 158). Over half of mothers (n = 374) reported that they had earned at least a bachelor's degree. Household income levels were not collected as part of this study.

Children's self-regulation was collected in the fall and spring of each year by a trained research assistant in a quiet setting; self-regulation was also collected two additional times in winter (about a month and a half apart) in two years of the study, and one additional time in the winter in one year of study (i.e., in the first two years of study self-regulation was assessed four times, year three it was assessed three times, and it was assessed twice in year four). Children's language skills were tested in the fall of their first year of preschool and parents filled out demographic information including child gender and information related to education level at this time as well. Some children (n = 160) participated in the study over the course of two years and a small subset of children (n = 13) were included in the study for three years. Thus these children had their self-regulation evaluated more frequently. Across the larger MLSELD study (n = 888), 246 children either had only one self-regulation assessment (n = 133) or no assessments (n = 113; by design, only half of the sample had self-regulation assessed in year 4).

Oregon sample—The third sample was recruited from a mixed-SES rural site in Oregon and consisted of 393 (50% female) children followed from preschool through kindergarten as part of a measurement study focused on improving measures of school readiness and self-regulation (***; blinded for review; 38 of the full sample of 431 were not included due to having fewer than 2 assessments of self-regulation related to study attrition). Children were drawn from 37 classrooms in 17 schools, with 54% (n = 209) of children in Head Start programs. Children were on average over four and a half years old at the start of the study (M = 56.14, SD = 3.65). Most parents who provided information about their child's ethnicity (n = 354) reported that their child was White/Caucasian (63%), or Hispanic (19%). Children who were African American (1%), Asian/Pacific Islander (4%), multi-racial (13%), and those from 'other'(1%) ethnicities also participated in the present work. Families reported that English was the primary language spoken at home for most children (n = 297); however this sample also included a subsample of children whose primary language was Spanish (n = 60) who were tested in Spanish (all Spanish speakers were enrolled in Head Start). On average, mothers reported having attended some college, but only 43% reported that they had earned a bachelor's degree or higher. Of respondents, 58% indicated that their families qualified for public assistance such as WIC or food stamps in the past four years.

Families were recruited through letters sent home with an enrollment packet sent during the summer before the beginning of the preschool year. Self-regulation was assessed each year in the fall and spring by trained research assistants (up to four time points). Language skills were assessed in the fall of children's preschool year, and parents filled out demographic surveys at this time.

Measures

Self-regulation—Children's self-regulation was measured directly using the Head-Toes-Knees-Shoulders task (Cameron Ponitz et al., 2008; Connor et al., 2010; Matthews, et al., 2009). During the task, children are provided with paired behavioral rules (e.g., touch your head/touch your toes) and asked to do the opposite of what they were instructed to do. For example, when a child is asked to touch her toes, she should complete the opposite action (touch her head). The first ten items include one paired rule (e.g., head/toe). If children respond correctly to four or more items, they are given ten additional items with two paired rules (e.g., head/toes, knees/shoulders). Children earned two points for each correct response, one point for each self-correction (i.e., an initial movement to the incorrect response, but ultimately ending with the correct response), and zero points for each incorrect response. Scores ranged from 0–40, with higher scores indicating higher self-regulation. In the first year of the Michigan longitudinal sample data collection, when all children were in preschool, only the first half of the HTKS was administered, as the second half had not yet been developed. We therefore used a Rasch measurement approach to extrapolate an expected score on the entire 40 item task (details are provided in Bindman, Hindman, Bowles, & Morrison, 2013).

The HTKS has good construct and predictive validity within many culturally diverse samples, and across languages (Cameron Ponitz, McClelland, Matthews, & Morrison, 2009; McClelland et al., 2007; von Suchodoletz et al., 2013; Wanless, et al., 2011). Scores on this measure are significantly correlated with reported self-regulation in the classroom, parental reports of attention (Cameron Ponitz et al., 2009; McClelland et al., 2007) and other measures of self-regulation and executive function tasks. The HTKS also loads well onto a self-regulation factor with other similar measures (Allan & Lonigan, 2014). In addition, past evidence indicates that growth in HTKS performance does not appear to be a function of practice effects (Cameron Ponitz et al., 2008).

In terms of predictive validity, the HTKS consistently predicts academic achievement across diverse sample populations (McClelland et al., 2007; Montroy et al., 2014; von Suchodoletz et al., 2013; Wanless et al., 2011). Notably, evidence suggests HTKS scores and growth are generally stronger predictors of growth in academic achievement than other self-regulation and executive function measures, particularly measures that mostly capture one skill versus an integration of skills (Lipsey et al., 2014; McClelland et al., 2014).

The HTKS has strong reliability (Cameron Ponitz et al., 2008; Matthews et al., 2009; Montroy, et al., 2014; Wanless, et al., 2011). Past studies consistently report high levels of inter-rater reliability (kappa > .90; Cameron Ponitz et al., 2008), and internal consistency estimates above .80 (Montroy et al., 2014; Wanless et al., 2011). Within the current study internal consistency was also good, with Cronbach's alpha values ranging from .85–.94 across samples.

Language—Language skills were assessed across all three samples. In the Michigan longitudinal sample and the Oregon sample, the Picture Vocabulary subtest of the Woodcock Johnson III was used as an indicator of language (Woodcock & Mather, 2001), while the Test of Preschool Early Literacy picture vocabulary subtest (TOPEL; Lonigan, Wagner, Torgeson, & Rashotte, 2007) was used in the MLSELD preschool sample. Both the TOPEL and WJ vocabulary tests have been well validated and extensively used in the literature as indicators of expressive vocabulary (Bohlmann et al., 2015; Pence, Bojczyk & Williams, 2007; Wilson & Lonigan, 2009; Vallotton & Ayoub, 2011).

The Woodcock Johnson picture vocabulary subtest is an untimed picture naming task where children are shown a series of pictures and are asked to verbally identify the image. Children speaking Spanish in the Oregon sample were administered the Picture Vocabulary subtest of the Spanish version of the Woodcock-Johnson, the Bateria III Woodcock-Munoz. Picture Vocabulary has strong evidence of reliability (e.g., split half reliability between 0.76–0.81 for English speaking children and 0.88–0.89 for Spanish speakers) and validity. We used W-scores, a Rasch-type measure of ability, for all analyses. This type of score ensures measurement on an equal-interval scale and takes into account the level of item difficulty in relation to a children's age.

The TOPEL picture vocabulary subtest consists of 35 items including various untimed picture naming tasks where children name pictures (1 point) and then describe aspects or functions associated with the picture presented to them (e.g., What are they for? 1 point)[2]. Thus raw scores range from 0–70. Test-retest reliability for this subtest is .81 and test developers indicated that scores were strongly related to the Early One-Word Picture Vocabulary Test ($r = .71$, Brownell, 2000). The TOPEL was administered only in years 2 and 3 of the study. The remaining $n = 77$ in year 1 and $n = 113$ in year 4 were not administered by design.

Mother education and gender—Across samples, demographics questionnaires were provided to parents including information regarding the child's gender and parent education levels. For the Michigan longitudinal and the Oregon sample, mothers were asked to report education in terms of the number of years of schooling they had completed, while the MLSELD preschool sample was asked to report education levels via an 11-point survey question where education level categorically increased with 1 = *less than a high school level education,* 7 = *a bachelor's degree,* and 11 = *an advanced graduate degree (e.g., Ph.D or*

[2]We also ran analyses with only points for naming an object correctly included (i.e., excluding the points received for describing functions). The results were similar with both scoring methods, thus we present findings using the total (naming and functions) score as this is commonly how the subtest is scored and used in previous studies.

M.D). For comparability across samples, data from the Michigan longitudinal and Oregon sample were converted to the 11-point scale used by the MLSELD sample.

Analytic Approach

Analyses were done in two parts to (1) describe the general growth trajectory of self-regulation and (2) evaluate heterogeneity in self-regulation trajectories across children. First, we used latent growth curve models (Bowles & Montroy, 2013; McArdle, 1986; Meredith & Tisak, 1990; Singer & Willett, 2003) to examine the general trajectory of development of self-regulation. These models provide information about the average values of children's self-regulation (level of self-regulation) at a specified time, how rapidly their skills increase or decrease (i.e., slope), and whether this change is constant or might accelerate or decelerate (i.e., linear versus nonlinear growth). The general equation for the latent growth curve models we used was:

$$Self-reg[t]_n = Level_n + Slope_n \cdot A[t] + u[t]_n,$$

where $Self\text{-}reg[t]_n$ is the HTKS score for child *n* at age *t; A[t]* or the basis coefficient(s), are a function defining the shape of the growth trajectory, determining both the precise interpretation of the *Level* and the *Slope*, and the nature of change; $Level_n$ represents child *n's* predicted level of self-regulation at the point where *A[t]* is 0; and $Slope_n$ generally reflects child *n's* predicted rate of growth on the HTKS per unit of the basis coefficients. We considered five models for the trajectory: linear, quadratic, exponential, logistic, and the latent basis model. Due to variation in what age children received assessments and the time between assessments, scores were grouped by child age into three month windows in each dataset[3]. To evaluate what model optimally described the general growth trajectory of behavioral self-regulation, we utilized the Akaike Information Criterion (AIC) and the Adjusted Bayesian Information Criterion (aBIC) fit indices.

Next, we utilized growth mixture modeling (GMM; Muthén, 2001) to evaluate if there were multiple growth trajectories of early childhood behavioral self-regulation. In GMM, the trajectory classes are formed based on the growth factor means and variances (e.g., *Level* and *Slope* means and variances) with each class defining a different growth trajectory (Muthén, 2001). GMM also captures individual variation around these growth curves by estimating the growth factor variances within each class (Muthén & Muthén, 2000). Within the GMM models, we chose to restrict trajectory shape to the shape indicated by the latent growth curve models. This is common practice in the GMM literature when there is not a strong theory regarding shape of trajectory differences across the population. However, slope and rate parameters (but not functional form) were ultimately allowed to vary across trajectories, thus providing information regarding different developmental progressions and patterns. In all models, errors were specified to be uncorrelated. We determined best model fit based on AIC and aBIC indices (Tofighi & Enders, 2007), entropy, and bootstrapped likelihood ratio tests (BLRT) which compares the fit of the estimated model with k classes to

[3]In years one and two of the MLSELD preschool study, most children had two assessments within three months. To ensure local independence within the three month windows, only one assessment was included, chosen at random.

the same model with one less class (k-1), with p-values less than .05 indicating that the estimated k class model fits better than the k-1 model (Grimm, Ram & Estabrook, 2010). Note, BLRTs can only test differences in relation to what number of classes fits best, they provides little information when comparing within class solutions with differing parameters (e.g., whether a solution with constrained random effects versus variable random effects fit best). In addition we also considered whether results were interpretable and meaningful, and we took into account estimation parameters as well as estimation history as these are all relevant indicators of model comparison and selection (Grimm et al., 2010). To evaluate the predictors of trajectory classes, we assigned each child to the class with the highest probability, and used logistic regression based analyses to predict class membership[4]. All analyses were completed with Mplus version 7.2 (Muthén & Muthén, 1998–2010), utilizing full information maximum likelihood to account for missing data. In all analyses, year of study was included as a saturated covariate given its relationship with missing data in all samples, and the MLR estimator was used as this estimator provides the most accurate parameter estimates when missing data are present (Enders, 2010; Graham, 2003).

Results

Descriptive Statistics of Behavioral Self-regulation

On average, children demonstrated gains in behavioral self-regulation as measured by the HTKS between the ages of three and seven; see Table 1 for a comparison of average gains across samples. Individual observed trajectories for a random subset of 25 children's scores per sample are presented in Figure 1. In all samples, there were substantial individual differences, and periods of acceleration and deceleration in growth both within and across children. Correlations are provided in the supplementary materials.

The Development of Behavioral Self-regulation

Fit statistics for the five latent growth curve models are reported in Table 2 by sample. In all samples, both AIC and aBIC suggested that the changes and between person differences in early childhood behavioral self-regulation development were best described by an exponential curve; see Figure 2. Across samples patterns varied such that: in the MLSELD preschool sample, children's growth accelerated across preschool. However, in the Oregon and Michigan longitudinal samples that followed children across early elementary grades, children demonstrated faster gains early in preschool with gains slowing in early elementary school[5].

Heterogeneity in Behavioral Self-regulation Development

Growth mixture modeling allows for the estimation of different trajectories with the possibility of every estimated parameter differing across groups (e.g., means, variances,

[4]We also ran the 3-step approach discussed in Asparouhov & Muthen (2014). However, this approach results in listwise deletion of missing data at the predictor level. Thus, in addition to the initial 3-step approach models we also used multiple imputations of missing predictor level data and re-ran all 3-step approach models. The pattern of results was the same in all cases.

[5]In order to rule out the possibility that the exponential shape was a product of floor and ceiling effects across time points, all analyses were re-ran utilizing Tobit growth curve models (Wang, Zhang, McArdle & Salthouse, 2009), which can account for floor or ceiling effects. In all samples, an exponential model still fit best compared to other models, even when accounting for floor or ceilings.

covariances, and basis coefficients; Grimm et al., 2007; McArdle & Bell, 2000; McArdle & Nesselroade, 2003). Currently, there is no generally accepted strategy for how GMMs should be evaluated in terms of which constraints to relax first (Grimm et al., 2007). However, similar to past studies, we evaluated models based on the principles of factorial invariance studies (e.g., Grimm et al., 2007), followed by an examination of models with different constraints related to within trajectory variation patterns (e.g., Kreuter & Muthén, 2008). Specifically, we evaluated fit across separate datasets starting with a two growth trajectory model where only level and slope means were allowed to vary across trajectory groups. In all models, the exponential shape indicated by the latent growth curve analyses was specified for all classes. Rate of acceleration/deceleration within the exponential trajectory(ies) was initially constrained to be the equal across curves (i.e., only timing differences were allowed with identical developmental form and rate of change). This would offer strong evidence that variation in behavioral self-regulation trajectory growth across children is similar, but with differences in developmental timing. All within curve variations (random effects) were also initially constrained (Kreuter & Muthén, 2008). We then allowed rates of acceleration/deceleration to vary in order to evaluate possible differences in how children develop self-regulation across early childhood. Specifically across different class/trajectory solutions, one could potentially see changes in the sign for rate of change indicating whether rate was accelerating or decelerating across the specific study time period, as well as differences in rate parameter magnitude (i.e., it was possible for a non-significant rate parameter to be found, which would be similar to if a linear trajectory was specified). Additional growth trajectories were then added to determine what number of trajectories best fit the data. Once number and trajectory rate of change differences were determined, we progressively relaxed within trajectory level and growth variances and covariances to investigate how closely individual children followed group trajectories.

Results indicated that the three trajectory solution fit best in all samples based on the evaluation of global fit statistics in association with bootstrapped LRTs, iteration history, convergences, estimated parameters, and entropy values; see Table 3 for a summary of fit statistics across the different models and samples. In all samples, the three trajectory solution was also interpretable such that children generally demonstrated timing differences in early childhood self-regulatory gains but with some variation in rate across trajectories. As seen in Figure 3, children demonstrated either early gains, intermediate gains, or later gains relative to sample peers. In general, children's individual self-regulation trajectories also conformed closely to the three trajectories. Specifically, the models where within trajectory level, slope or rate variations were constrained to zero fit best for all three samples.

As expected, the percent of children predicted to follow a given trajectory varied across samples, yet results still demonstrated clear consistency. Descriptively, in the Michigan longitudinal sample, 20% of children were classified as early developers who demonstrated higher initial levels of self-regulation and earlier gains, 45% as intermediate developers who had low initial self-regulation, followed by rapid gains, and 35% as later developers, who started with lower levels and gained more slowly compared to other groups. A similar pattern occurred within the MLSELD preschool sample with 29% of children classified as early developers, 45% of children as intermediate developers, and 26% as later developers.

Likewise in the Oregon sample: 50% of children were early developers, 32% were intermediate developers, and 18% were later developers.

Broad patterns that were replicated across samples indicated that more than half of the children assessed within a given sample (including both early and intermediate developers) demonstrated rapid growth across preschool. On average, these children accurately responded (correct or self-correct) 75% of the time or more by age five (58–60 months). Yet, about 20% of children (later developers) consistently demonstrated relatively few early gains, responding at less than 35% accuracy on the behavioral self-regulation task throughout preschool. This pattern persisted into kindergarten in both samples that spanned into early elementary school with gains for later developers lagging same sample peers; in the Oregon sample gains do not pick up until 70–72 months of age (i.e., nearly 6 years of age). In short, children classified as later developers were, on average, six months to a year behind their intermediate developing peers and *at least* a year and a half behind early developers.

Descriptively there were also several other similarities across samples, see Table 4 for means across samples. In all three samples boys made up the majority of the later developers group whereas the majority of early developers were girls. Likewise, across all three samples, early developers had the highest mean levels of language and, on average, their mother's obtained the highest education levels. Children in the later developers group demonstrated the lowest levels of language and had mothers with comparatively lower levels of education compared to the other two groups.

Predictors of self-regulation growth trajectories—In this section we investigated whether child attributes and mother education levels were indicative of which children are more likely to follow which trajectory. Given that a subset of children in each sample demonstrated a 'later developer' behavioral self-regulation trajectory, we first tested whether these children differed from children who globally demonstrated rapid gains in preschool, classified as 'preschool developers' in behavioral self-regulation (i.e., 'intermediate' and 'early developers' considered together). We followed this analysis up with a second analysis comparing intermediate to early developers. In all analyses, gender, language, and maternal education levels were included as predictors, controlling for children's age at the first measurement time point, race/ethnicity, and whether English was a indicated as a child's primary language.

We used the Benjamini-Hochberg procedure to account for multiple predictors (Benjamini & Hochberg, 1995). This procedure controls for the false discovery rate (i.e., Type I errors) associated with conducting multiple comparisons by ranking post-hoc the individual p-value associated with each predictor from smallest p-value to largest. Each individual p-value is then compared to its Benjamini-Hochberg critical value. The predictor with the largest p-value that is less than the Benjamini-Hochberg critical value, and all predictors ranked before it are considered significant. In the current study, we used a false discovery rate of .05, thus all predictors with a Benjamini-Hochberg critical value below .05, regardless of raw p-values, were considered significant. See Table 5 for all results including raw p-values and calculated Benjamini-Hochberg critical values.

Gender: Child gender was linked to what trajectory a child was likely to follow in both the Michigan longitudinal sample and the Oregon sample. Girls included in the Michigan longitudinal sample were 1.79 times more likely to be classified as preschool developers (following either an intermediate or early developers' trajectory) versus later developers. Further, in the Oregon sample, girls were 2.34 times more likely to be classified as early developers versus intermediate developers. No other comparisons were significant.

Language: Children's language skills also predicted within sample trajectory differences. For a 1 SD increase in expressive vocabulary, children in the MLSELD preschool sample were 1.40 times more likely to be classified as a preschool developer versus a later developer. Furthermore, for a 1 SD increase in vocabulary children were 1.68 times more likely to be identified as early developers versus intermediate developers. For the Oregon sample, children were 1.23 times more likely to be classified as demonstrating a preschool developer trajectory compared to later developer trajectory, and 1.63 times as likely to be identified as early developers versus intermediate developers per a 1 SD increase in expressive vocabulary. No other comparisons were significant.

Mother education: Mother education predicted trajectory differences in the MLSELD preschool sample and the Oregon sample. In the MLSELD preschool sample, children whose mothers completed one additional level of education (e.g., moving from associate to bachelors) were 1.30 times more likely to be classified as a preschool developer than a later developer. Likewise, of the children who demonstrated growth across preschool, there were significant differences between intermediate developers and early developers such that for a 1 unit difference in mother education, children were 1.26 times more likely to be classified as early developers. Within the Oregon sample, for every 1 unit increase in reported maternal education, children were 1.23 times more likely to be classified as demonstrating a preschool developer trajectory versus a later developer trajectory. No other comparisons were significant.

Discussion

The development of effective self-regulation is widely recognized as an early marker for later life successes (Blair & Raver, 2015; Calkins, 2007; Diamond, 2002; Gross & Thompson, 2007; Moffitt et al., 2011). The primary goal of the current paper was to evaluate the trajectory of behavioral self-regulation across early childhood in three distinct samples across two states in order to determine if there was consistent heterogeneity in this trajectory/ies across children. In addition, we evaluated whether several predictors that are often associated with self-regulation could be used to indicate the type of trajectory a child was likely to follow, with an ultimate goal of validating trajectory differences as meaningful and consistent with previous findings, while further increasing our understanding of developmental differences in early childhood behavioral self-regulation across children. Overall, our findings indicate that self-regulation rapidly increases across early childhood, with children in all samples following three distinct trajectories that were distinguishable based on several important factors.

The Development of Behavioral Self-regulation

The general growth trajectory of behavioral self-regulation across early childhood was best represented by an exponential function. This was the case across all three samples, although there were differences across samples in whether growth was accelerating or decelerating, likely related to sample specific differences in relation to what ages were captured. This result is consistent with previous findings suggesting that behavioral self-regulation (and the executive function skills that support behavioral self-regulation) develop(s) in a nonlinear fashion with early, rapid gains during the preschool (e.g., Cameron-Ponitz et al., 2008; Diamond, 2002; Wiebe et al., 2012).

Heterogeneity in Behavioral Self-regulation Development

The growth mixture modeling results indicated heterogeneity across children in the developmental trajectories. Despite differences in sample locations, background characteristics, and study windows, in all three samples children could be characterized as either early developers, intermediate developers or later developers relative to their within sample peers. Likewise, an identifiable overall pattern emerged such that for the majority of (but not all) children in all samples there was a period of rapid development of behavioral self-regulation in preschool with individual differences in when rapid growth occurred, how rapidly it occurred, and what level of behavioral self-regulation children demonstrated at the beginning of preschool.

Yet, overall, approximately 20% of children appear to make few gains in preschool. This was especially the case in the MLSELD preschool and Oregon sample, with a subset of children in both samples showing little to no growth until 60 months (i.e., 5 years) of age. Children classified as later developers in the Michigan longitudinal sample did show gains before age five, but these gains still lagged behind their sample peers (e.g., it takes children classified as later developers an additional nearly three years, with children ~80 months old or age 6.75, to obtain relatively identical mean levels of self-regulation their early developing peers demonstrated at four years of age).

In general, we conclude that many children are still developing behavioral self-regulation skills as they leave preschool and enter kindergarten, and that they may need behavioral supports in kindergarten with a subset of children just beginning to develop advanced behavioral self-regulation. The current study’s findings mirror teacher observations, with nearly half of teachers indicating that they feel many children enter kindergarten without the self-regulation skills necessary to be ready to learn in formal education setting (Rimm-Kaufman et al., 2000). These finding are also fairly consistent with previous growth trajectory findings within a smaller, Taiwanese sample (Wanless et al., 2016). Interestingly, this previous study reports that both a two and three trajectory solution fit the data, but the three class solution produced an extremely small class (p. 109; Wanless et al., 2016). It is plausible that three classes were consistently found in the current study due to inclusion of larger, more heterogeneous samples.

The overarching similar patterns observable across samples and in the literature at large, indicate that once children start to utilize executive function skills to carry out complex directions, it is a relatively short developmental time before they are able to accurately and consistently follow multiple abstract rules such as those utilized in the Head-Toes-Knees-Shoulders self-regulation task. Importantly, what is clear from the current study that was less clear in previous work is that: 1) it generally takes just about 2–3 years to go from little ability to self-regulate in the face of complex instructions to task mastery in this context and 2) All children will master the basic skills needed to participate in self-regulatory tasks, however the age at which they do so varies across children and is related to child characteristics and contextual factors Thus, the important relations between children's *levels* of behavioral self-regulation and later development outcomes documented in previous work (e.g., McClelland et al., 2006) may be better described as reflecting differences in the *timing* of the development of behavioral self-regulation.

Indicators associated with self-regulation growth trajectories—Our findings indicate that early childhood behavioral self-regulation trajectories are distinguishable based on associations with other variables. Consistent with past findings (e.g., Matthews et al., 2009) the identification of a child as a girl was associated with earlier development trajectories. In all samples, there were more boys in the later developers group, with results reaching statistical significance in the Michigan longitudinal sample. Interestingly in the Oregon sample there was also a statistically significant difference in the number of boys in the intermediate trajectory compared to the early developer's trajectory. These findings are generally consistent with previous findings (e.g., Matthews et al., 2009) and suggest that boys may need additional supports at the beginning or during preschool to ensure they develop the self-regulation skills necessary for entry into kindergarten. Notably, gender differences were observed in the two samples that spanned into the formal years of education (kindergarten and beyond), possibly providing support to previous evidence suggesting that gender differences appear more substantially over time (Entwistle et al., 2007; Matthews et al., 2009; 2014). More work is necessary to determine why gender differences are linked to different pattern of self-regulation development. Likewise systematic investigations of how these associations change across time are also warranted. One possibility beyond the scope of the current study is that boys can be more sensitive to environmental experiences including chaos (Cameron Ponitz, Rimm-Kaufman, Brock, & Nathanson, 2009; Wachs, 1992; Wachs et al., 2004), as well as parent and teacher expectations of school success (Entwistle, et al., 2007; Wanless et al., 2011). It is possible that overtime, continued chaos or continued high or low expectations from parents and teachers may have cumulative effects on skill development.

Likewise, language was also predictive of what behavioral self-regulation trajectory a child was likely to follow. Within the MSELD preschool and Oregon sample, higher levels of expressive language at the start of preschool was associated with earlier development, similar to other field findings (Bohlmann et al., 2015; Vallotton & Ayoub; 2011). There is long standing theoretical support for the role of language as an organizational tool used to aid self-regulation development (Cole et al., 2010; Vygotsky 1934/1986), and the current study provides some evidence that early language skills may affect the timing and rate of development of early self-regulation growth across early childhood. Higher levels of language may give children the ability to organize and better understand incoming information such as complex behavioral rules, contributing to the use of more complex self-regulation that relies on attending to and keeping track of information (i.e., working memory), while inhibiting a well learned dominant response pattern. Future studies are necessary to better understand the ongoing relations between language and self-regulation development (Bohlman et al., 2015). Specifically, more studies evaluating the potential mechanisms regarding language's role (e.g., see Winsler et al., 2009) and the specifics of what other aspects of language lead to the rapid develop of self-regulation.

Mothers' education levels also affected what trajectory a child was likely to follow. Early developers generally lived in homes where mothers reported the highest education levels, with children in Oregon and the MLSELD significantly more likely to be classified as an intermediate or early developer based on maternal education. Mother education serves as a proxy for aspects of the environment, including available household resources. These resources include physical resources such as toys, games, learning materials, and books that can support self-regulation development (Brooks-Gunn & Duncan, 1997), but also abstract resources such as a less stressful home environment (see Blair & Raver, 2012). Additionally, more highly educated mothers often hold different beliefs compared to their lower educated counterparts that affect their parenting behavior towards their children (see Bradley & Corwyn, 2002 for review), that could in turn affect developing self-regulation. Maternal education may also help to explain why children within the Oregon sample developed self-regulation slightly later relative to both Michigan samples. There was a higher preponderance of mothers with lower education levels and families were more likely to be living at or below the poverty line, perhaps indicating that children had fewer familial supports to help them to develop their self-regulation. Furthermore, although beyond the purview of the current study, it is also important to note that poverty consistently predicts the complexity of children's developing language (Fernald, Marchman, & Weisleder, 2013; Hart & Risley, 1995), and is often related to gender differences in children's performance (Entwistle et al., 2007). A greater investigation across multiple indicators of a child's environment is a necessary next step in fully understanding what attributes affect children's self-regulation development in context.

Practical Implications

These findings have several implications. First, given that majority of children appear to demonstrate rapid gains in behavioral self-regulation between the ages of three and seven (but particularly during the preschool years), this research supports previous work emphasizing this time period as a potential critical period (Blair, 2002; 2010; Diamond, et al., 2007; McClelland & Cameron, 2012). Utilizing preschool curricula such as Tools of the Mind (Bodrova & Leong, 2007) that center on scaffolding children's early self-regulation skills or targeted games and activities focusing on promoting self-regulation (e.g., Schmitt, McClelland, Tominey & Acock, 2015) may provide children the support they need to develop behavioral self-regulation skills early. On the other hand, programs and curricula that focus on self-regulation *and* consider/target multiple aspects of the developing child may ultimately prove even more impactful for preparing all children for formal education (see Dickinson, McCabe & Essex, 2006; Lonigan et al., 2015). Future investigations evaluating school contexts and their associations with different self-regulation developmental trajectories are necessary to provide further support to these assertions.

In addition to offering insights into the developmental trajectories of behavioral self-regulation, this work also offers tentative evidence indicating which trajectory a child is likely to follow may be predictable based on background characteristics. Specifically, it may be possible to screen for children who are at risk of entering kindergarten without the self-regulation skills teachers feel are necessary to succeed (Rimm-Kaufman et al., 2000). For example, our study indicates that boys from families with lower education levels who score lower on early vocabulary tests compared to peers may be at risk of starting kindergarten behind in self-regulation. Although a more thorough investigation of predictive traits is warranted, even these few consistent predictors, in conjunction with delays in preschool self-regulation progress, may be enough to indicate a need for support, particular given research indicating that later behavioral self-regulation development can impact school readiness and future academic skills and success for years to come (see McClelland et al., 2006; Wanless et al., 2016).

This type of developmental work also could enhance progress monitoring by early childhood professionals. Recent research has advocated that early education environments should include a three-tiered system of service delivery that includes increasing instructional intensity to the level of student needs (e.g., Fox, Dunlap, & Cushing, 2002). A better understanding of how self-regulation development progresses, and what constitutes normal versus delayed development (i.e., benchmarks related to student needs) gives teachers the tools they need to customize level of instruction appropriately, including information for when to seek outside support for children who may need intervention. Past research indicates that early interventions targeted at increasing behavioral self-regulation skills can result in significant behavioral self-regulatory gains as well as some academic gains, particularly for individuals who are have lower initial levels of behavioral self-regulation compared to peers (Schmitt, et al., 2015; Tominey & McClelland, 2011).

As preschool and kindergarten have evolved in focus across the last few decades (and continue to evolve) from social-emotional skills to more academic skills (Kagan, Kauerz, & Tarrant, 2007; Stipek, 2011), it is critical for researchers and policymakers alike to remember that social-emotional development such as self-regulation development can have long lasting impacts on children's school readiness and success, including academic success. Past research indicates that children who begin kindergarten with lower levels of self-regulation skills also lag in math and literacy skills through sixth grade, with the gaps in achievement widening through second grade between children with higher kindergarten self-regulation and children with comparatively lower levels of self-regulation (McClelland et al., 2006). Although future research linking academic achievement to different self-regulation trajectory classifications is needed, we speculate that children classified in the current study as 'later developing' may struggle with academic achievement given that these children did not demonstrate the rapid gains their peers demonstrated in preschool with some not showing those types of gains until nearly the end of kindergarten. It is possible that a lagged trajectory in early childhood may have cascading effects on children's future development as many of the skills that rely in part on self-regulation skills may also be delayed until self-regulation skills are more adequately acquired. Regardless, the fact that all ‘later developers’ across samples in the current study demonstrated markedly less developmental progress compared to peers should be addressed as early as possible given that self-regulation in its own right is an important developmental milestone (Bronson, 2000).

Limitations and Future Studies

The current study utilized one measure of self-regulation, which, although reliable and valid, does not fully capture the multi-dimensional nature of self-regulation. The inclusion of other measures of self-regulation that each focus on a different aspect of self-regulation would certainly be informative in future studies for better understanding how these multiple aspects come together to support behavioral self-regulation. Additional measurement work is also needed, as it is not clear how these aspects integrate, or develop in relation to each other across time (Allan & Lonigan, 2014; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Willoughby et al., 2011; Zelazo & Carlson, 2008). Studying the development of multiple aspects of self-regulation could provide a greater specificity of information, particularly related to the subset of children who demonstrated later development.

In addition, caution must be taken regarding whether the functional form found within the current study is specific to the measure used, or is indicative of the latent construct of behavioral self-regulation. Past evidence and theory (e.g., Diamond, 2002; Vallotton & Ayoub, 2011) support the current finding that the development of behavioral self-regulation is non-linear across early childhood, yet more research with multiple measures is needed to adequately confirm that this is the case and that the functional form of development is not an artifact of the particular assessment(s) used. Likewise, additional research focused on functional form differences across the trajectories is necessary. Consistent with typical GMM practices, the current work used a common functional form (exponential), while allowing rate of change to vary across trajectories. Our findings suggested that some children may demonstrate a different functional form indicative of a more steady progression of skill development. There is little past work or theory specifying trajectory form differences or how mechanisms of development relate to those differences. In short, it is still not clear whether children may acquire skills differently across trajectories with some children ‘leaping’ in skills indicating a possible rapid integration of multiple skills into a behavior, while others slowly build the skills that support self-regulation.

In the current study we focused on a core set of predictors to validate trajectory differences; more comprehensive work is necessary to determine underlying mechanisms of regulatory differences. As anticipated, the set of chosen indicators we focused on supported that the individual differences captured by the three trajectories found per sample are meaningful, yet a host of other indicators will likely provide more information regarding trajectory differences, as well as indicating what child skills and environments are important to help children optimize their regulatory development. For example, direct evaluation of the early contexts provided to children by aspects of parental warmth and responsiveness and their predictive association with developmental differences in self-regulation is a promising next step (Grolnick & Farkas, 2002; Landry et al., 2002).

Likewise there is a need to evaluate genetic and neurological predictors of trajectory differences, particularly given recent findings suggesting that self-regulation and many of the processes, including neural processes, that underlie it may be genetic in nature (e.g., see Friedman, et al., 2008; Friedman, Miyake, Robinson & Hewitt, 2011) although still open to environmental influences via probabilistic epigenesis (see Blair & Raver, 2012; Deater-Deckard, 2014). This must be considered given the remarkable regularity of patterns across three diverse samples in the current study.

Conclusions

The present study is an important contribution to our understanding of how self-regulation develops during early childhood. Specifically, findings indicate that the development of behavioral self-regulation is exponential in nature. Likewise, there are differences in this trajectory such that majority of children demonstrate rapid gains across the preschool time period, while a subset of children demonstrated low levels of initial behavioral self-regulation and later self-regulation development. Differences in what trajectory a child was likely to follow were linked to different child attributes and background characteristics. Based on these findings researchers and educators alike should consider carefully how best to support children's development of behavioral self-regulation during early childhood, particularly for children who may be at-risk of making few gains during preschool as early self-regulation development seemingly places children on a trajectory for later school, economic, and health successes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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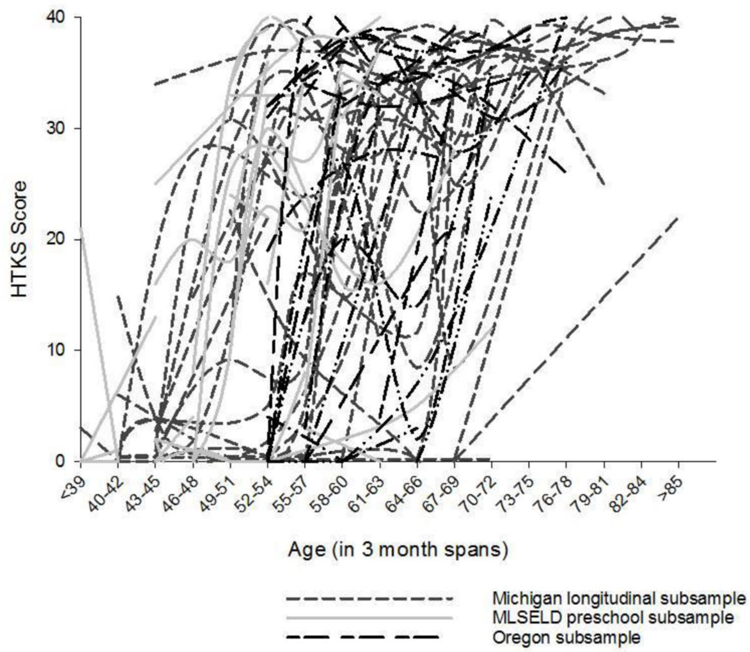

Figure 1.
Random subset of 25 children per sample's (75 total) smoothed behavioral self-regulation trajectories

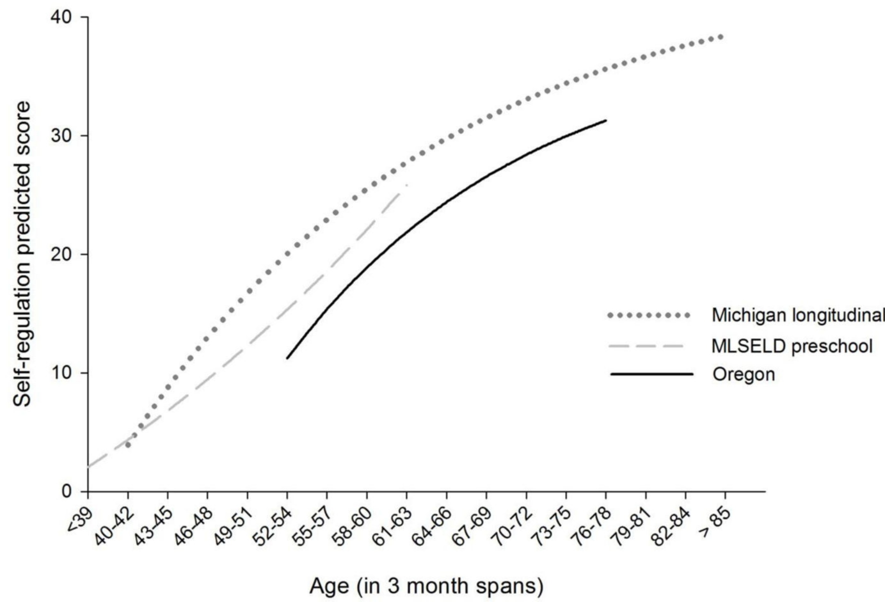

Figure 2.
Latent growth curve model of the developmental trajectory of behavioral self-regulation by sample.

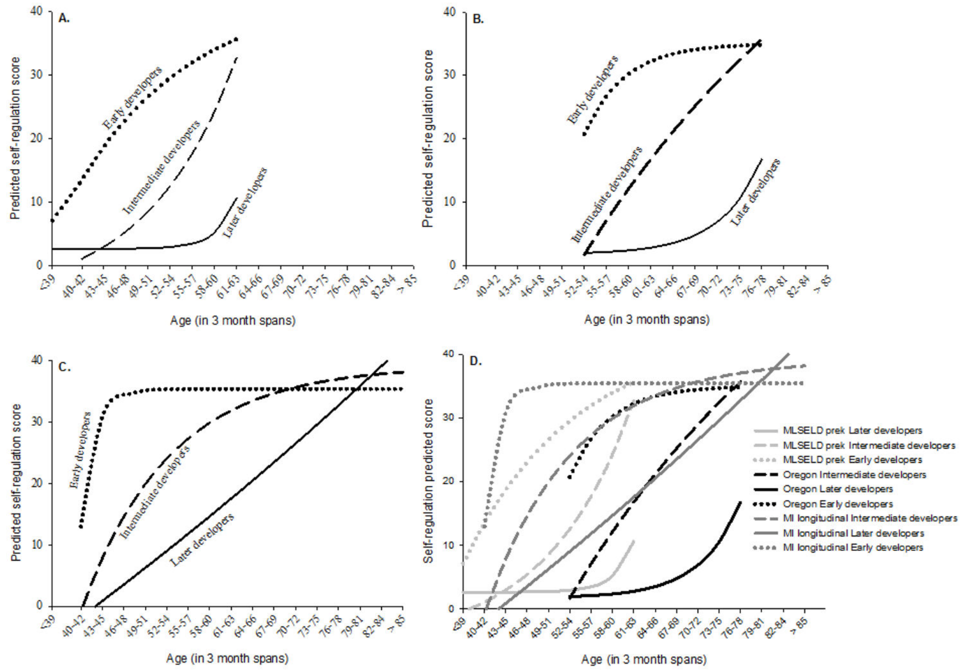

Figure 3.

Predicted developmental trajectories for behavioral self-regulation by sample. A. MLSELD preschool sample, B. Oregon sample, C. Michigan longitudinal sample, D. all samples picture together; MI = Michigan.

Table 1

Descriptive Statistics for Self-regulation by Sample and Age

Variable	Michigan longitudinal			MLSELD preschool			Oregon		
Self-regulation	**N**	**M**	**SD**	**N**	**M**	**SD**	**N**	**M**	**SD**
-HTKS age 39 mos. or less	-	-	-	103	3.66	7.70	-	-	-
-HTKS age 40 – 42 mos.	98	4.98	8.92	128	5.50	9.95	-	-	-
-HTKS age 43 – 45 mos.	101	8.92	12.26	144	7.25	11.38	-	-	-
-HTKS age 46 – 48 mos.	111	12.95	14.81	185	9.15	11.32	-	-	-
-HTKS age 49 – 51 mos.	111	18.21	15.16	241	11.95	13.49	-	-	-
-HTKS age 52 – 54 mos.	153	20.48	15.22	276	16.73	14.27	157	12.44	13.11
-HTKS age 55 – 57 mos.	151	21.67	14.58	293	17.63	14.86	161	16.53	13.32
-HTKS age 58 – 60 mos.	152	25.19	13.46	217	22.78	14.28	201	18.74	14.20
-HTKS age 61 – 63 mos.	128	28.29	10.61	165	25.28	14.01	186	21.78	14.40
-HTKS age 64 – 66 mos.	140	29.51	10.78	-	-	-	174	23.15	13.54
-HTKS age 67 – 69 mos.	154	31.20	8.90	-	-	-	140	26.61	13.01
-HTKS age 70 – 72 mos.	110	33.49	6.97	-	-	-	162	28.85	10.47
-HTKS age 73 – 75 mos.	108	35.58	4.85	-	-	-	97	30.32	11.84
-HTKS age 76 – 78 mos.	118	35.37	5.31	-	-	-	95	30.47	10.61
-HTKS age 79 – 81 mos.	113	37.05	3.08	-	-	-	-	-	-
-HTKS age 82 – 84 mos.	80	36.60	4.56	-	-	-	-	-	-
-HTKS age 85 mos. or more	61	37.55	3.30	-	-	-	-	-	-

Note. HTKS refers to the Head-Toes-Knees-Shoulders task. Mos. refers to months. Dashes represent ages that data were not collected by sample.

Table 2

Summary of Latent Growth Model Fit Statistics

Models	-2 Log Likelihood	Free parameters	AIC	aBIC
Michigan longitudinal sample				
- Linear	7071.40	6	14154.81	14158.94
- Quadratic	6961.99	10	13943.97	13950.86
- Modified logistic	7024.69	8	14065.38	14070.88
- Latent basis	7184.79	19	14407.57	14420.65
- Exponential	6934.36	10	**13888.71**	**13895.59**
MLSELD preschool sample				
- Linear	6688.04	6	13588.08	13595.82
- Quadratic	6760.81	10	13541.63	13554.52
- Modified Logistic	6783.97	8	13583.95	13594.26
- Latent Basis	6779.69	13	13585.38	13602.14
- Exponential	6760.21	10	**13540.42**	**13553.32**
Oregon sample				
- Linear	5216.08	6	10444.16	10448.97
- Quadratic	5192.96	10	10405.91	10413.92
- Modified logistic	5208.42	8	10432.85	10439.25
- Latent basis	5202.44	13	10430.88	10441.29
- Exponential	5189.12	10	**10398.23**	**10406.24**

Note. AIC refers to the Akaike information criterion, aBIC refers to the adjusted Bayesian information criterion. Bolded values indicate best fit.

Table 3

Summary of Growth Mixture Model Fit Statistics

Models	Michigan longitudinal				MLSELD preschool				Oregon			
	AIC	aBIC	Ent.	BLRT	AIC	aBIC	Ent.	BLRT	AIC	aBIC	Ent.	BLRT
2 Trajectory												
- Means only	13897	13902	.81	<.01	13558	13567	.68	<.01	10445	10451	.83[a]	<.01
- Means + shape	13948	13954	.79	<.01	13521	13531	.70	<.01	10218	10229	.83[a]	<.01
3 Trajectory												
- Means only	14032	14039	.65	.99	13428	13441	.63	<.01	10260	10270	.80	0.99
- Means + shape	**13832**	**13840**	**.74**	<.01	**13378**	**13393**	**.62**	<.01	**10212**	**10221**	**.82**	<.01
- Within level free	13833	13842	.74	<.01	13380	13396	.61	<.01[b]	10218	10230	.68	<.01
- Within level + slope free	-	-	-	-	13613	13640	1.00[a]	1.00	10455	10469	1.00[a]	1.00[b]
- All within free	13905	13917	.99[a]	<.01	-	-	-	-	-	-	-	-
4 Trajectory												
- Means only	13994	14003	.67	.38	13430	13444	.71[a]	<.01	-	-	-	-

Note. Dashes (-) denote that the model did not converge, an indicator of poor fit. Means only model: only level and growth means were allowed to vary between trajectories; means + shape: basis coefficients were allowed to vary (i.e., shape of curve) between trajectories. The “3 trajectory” models also included extra models to test whether relaxing within trajectory constraints resulted in better model fit. AIC refers to the Akaike information criterion, aBIC refers to the adjusted Bayesian information criterion. Bolded values indicate best fit. Ent. refers to entropy values, and BLRT indicates the p-value from the bootstrapped likelihood ratio tests.

[a] Included non-positive definite warnings that affected model trustworthiness, class specification and related entropy values.

[b] Bootstrap LRT p value may not be trustworthy

Table 4

Summary of Behavioral Self-regulation Trajectory Descriptives

Variables	Gender		Language		Mother education	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
MLSELD preschool						
- Later	0.44 (.50)	0–1	41.72 (15.09)	1–67	5.74 (1.95)	2–10
- Intermediate	0.55 (.50)	0–1	44.04 (15.39)	1–69	6.63 (2.00)	2–11
- Early	0.51 (.50)	0–1	52.52 (10.20)	23–69	7.49 (2.00)	3–11
Oregon						
- Later	0.49 (.40)	0–1	455.42 (18.14)	384–495	3.23 (1.96)	1–11
- Intermediate	0.41 (.49)	0–1	465.54 (11.89)	425–498	5.13 (2.81)	1–11
- Early	0.57 (.50)	0–1	473.51 (9.39)	450–501	5.99 (2.91)	1–11
Michigan longitudinal						
- Later	0.42 (.50)	0–1	466.12 (15.94)	398–498	7.16 (1.74)	2–9
- Intermediate	0.57 (.50)	0–1	467.47 (13.13)	418–498	7.37 (1.51)	2–9
- Early	0.54 (.50)	0–1	471.12 (15.03)	418–513	7.43 (1.51)	2–9

Note. For gender, girls are coded 1, boys are coded 0. MLSELD preschool language scores are from TOPEL vocabulary subtest; Michigan longitudinal and Oregon language scores are from the Woodcock Johnson Picture Vocabulary Subtest (w-scores).

Table 5

Predictors of Behavioral Self-regulation Trajectories

	b (s.e.)	β	Raw P-value	B-H crit. value	Odds ratio
MLSELD preschool					
-Later vs. Preschool*					
• Gender	0.38 (0.21)	0.09	.06	.06	1.46
• Language	**0.05 (0.01)**	**0.34**	**<.01**	**<.01**	**1.40**
• Mother ed.	**0.26 (0.06)**	**0.26**	**<.01**	**<.01**	**1.30**
-Intermediate vs. Early					
• Gender	−0.29 (0.23)	0.07	.21	.21	0.75
• Language	**0.08 (0.02)**	**0.52**	**<.01**	**<.01**	**1.68**
• Mother ed.	**0.23 (0.07)**	**0.22**	**<.01**	**<.01**	**1.26**
Oregon					
-Later vs. Preschool*					
• Gender	−0.08 (0.31)	−0.02	.79	.79	0.92
• Language	**0.05 (0.02)**	**0.19**	**<.01**	**<.01**	**1.21**
• Mother ed.	**0.21 (0.08)**	**0.26**	**<.01**	**.01**	**1.23**
-Intermediate vs. Early					
• Gender	**0.85 (0.26)**	**0.19**	**<.01**	**<.01**	**2.34**
• Language	**0.08 (0.02)**	**0.49**	**<.01**	**<.01**	**1.63**
• Mother Ed.	0.00 (0.05)	0.001	.99	.99	1.00
Michigan longitudinal					
-Later vs. Preschool*					
• Gender	**0.58 (0.24)**	**0.15**	**.02**	**.04**	**1.79**
• Language	0.02 (0.01)	0.14	.05	.07	1.15
• Mother ed.	0.09 (0.08)	0.07	.30	.30	1.09
-Intermediate vs. Early					
• Gender	−0.20 (0.31)	−0.05	.50	.76	0.82
• Language	0.02 (0.01)	0.16	.13	.38	1.17
• Mother ed.	0.02 (0.11)	0.01	.89	.89	1.02

Note. B-H crit. Value refers the Benjamini-Hochberg critical value for a given predictor. Mother ed. refers to mother reported education level. Bolded values indicate significant findings.