Bi-directional growth of effortful control and respiratory sinus arrhythmia and their relation to adjustment in preschool age children

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Abstract

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This study sought to examine the co- development of effortful control and respiratory sinus arrhythmia (RSA), and their role in emerging adjustment problems and social competence during preschool, a period of marked plasticity (both neural and behavioral) and rapid central nervous system development. Effortful control and RSA are indicators of cognitive and emotion regulation, respectively. Despite solid evidence that these components of self-regulation are interrelated, there is almost no research examining the co-development of effortful control and RSA in preschool-age children. Examining how individual differences in the development of effortful control predict changes in RSA, and vice versa, might clarify how particular deficits of attention, behavioral and/or emotional regulation develop. In this study, 167 preschool children (Time 1 M age = 36 mos) completed neuropsychological measures of effortful control, a delay task, and a baseline RSA task, across 3 times points, spaced 9 months apart. An autoregressive latent trajectory model (ALT) was examined to capture two forms of growth. Results indicated that a latent growth curve model best represented the linear changes in effortful control and RSA, whereas there was no support for bidirectional or

time specific effects, as tested by an autoregressive latent trajectory model (ALT). In tests of bi-directional effects, children with the lowest levels of initial executive control had the highest rates of growth in RSA, which was contradictory to study hypotheses. This finding was likely the result of the relation between initial levels of effortful control and RSA, as children lower in effortful control also had lower initial RSA with more potential for growth in RSA over time. In addition, there were significant associations of delay ability and RSA with externalizing and anxiety problems, pointing to the need to study how self-regulation is associated with adjustment problems in community samples during the preschool period. Overall, this study depicts a complex picture of the development of self-regulation, in which different components of self-regulation relate to the development of the other.

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I would also like to thank all of the families who participated in this research.

Dedication

To my parents, Fran and Maggie, and my siblings, Tom, Molly, and Anna.

Introduction

Self-regulation is a multi-faceted construct that includes both cognitive and emotional components that can be measured at many levels of analysis, including physiological, neuropsychological, and behavioral levels (Calkins & Fox, 2002). Elucidating self-regulatory processes may be among the most critical goals for understanding the development of psychopathology (Posner & Rothbart, 2000). This is because deficits in cognitive or emotional aspects of self-regulation characterize almost all forms of psychopathology (Cole, Martin, & Dennis, 2004; Olson et al., 2005; Beauchaine, 2007). Neuropsychological and psychophysiological measures serve as increasingly important tools in the examination of how cognition and emotion regulation influence one another to predict childhood psychopathology (Lewis & Todd, 2007), extending examination past traditionally used report or interview measures (Pollak, 2005). Although the development of self-regulation spans infancy to early adulthood (Posner & Rothbart, 2000), during the period from 3-6 years of age, children show dramatic increases in their self-regulation abilities, largely due to the maturation of underlying neurological and physiological structures (Pollak, 2005; Blair, 2003).

A cognitive component of self-regulation, effortful control, represents the voluntary control of a child's attention and behavior and is associated with activity in the medial cortex, specifically the anterior cingulate cortex (ACC; Rothbart & Bates, 2006). Effortful control can be measured using neuropsychological and delay ability assessments. Emotion regulation represents the ability to modulate emotional reactivity (Cole, Martin & Dennis, 2004) and can be measured physiologically using respiratory sinus arrhythmia (RSA), which is the autonomic regulation of the heart by the vagal nerve. Mirroring functional interrelation of the ACC and vagus nerve (Thayer & Lane, 2007), attention, behavior, and emotion regulation are distinct but related features of self-regulation which might impact each other through development (Feldman, 2009). Despite solid evidence that these components of self-regulation are interrelated, there is almost no research examining the co-development of effortful control and RSA in young children, even though the preschool years are a period of particularly rapid development of self-regulation. For instance, lower effortful control may predict less growth in RSA, which in turn, may predict less growth in effortful control, thereby exacerbating deficiencies in the development of self-regulation. Examining how individual differences in the development of effortful control predict changes in RSA, and vice versa, might clarify how particular deficits of attention, behavioral and/or emotion regulation develop. From this, it is evident why several studies have demonstrated that both low effortful control and RSA have been linked to adjustment problems including anxiety, depression, and externalizing problems as well as social competence (Blair & Razza, 2007; Eisenberg, et al., 2001; NICHD Early Child Care Research Network, 2003). Examining how these constructs predict concurrent and later adjustment problems and social competence in young children may identify key mechanisms in the development of psychopathology and point to potential targets of intervention, such that interventions used to promote the growth of effortful control in young children, would be able to affect a broader system of self-regulatory components, including RSA (Urasche, Blair, & Raver, 2012).

The experience of adverse environmental conditions or events during the preschool years can play a major role in shaping individual differences in self-regulation and psychopathology (Pollack, 2005; Kochanska, Coy, & Murray, 2001). In particular, low income and poverty and their associated strains are related to lower self-regulation in children. In turn, early deficits in self-regulation may confer risk for psychopathology that extends far beyond the preschool period into later development (Sroufe, 1997). This study seeks to improve our understanding of self-regulation and its role in emerging adjustment problems by utilizing effortful control, delay ability, and physiological (RSA) measures of self-regulation and examining their co-development during a period of marked plasticity (both neural and behavioral) and rapid CNS development. The roles of effortful control and RSA in the emergence of adjustment problems and social competence will be examined in a sample of preschool children with elevated risk for problems by virtue of large numbers of the children living in low-income households.

Components of Self-Regulation

Self-regulation involves regulation of behaviors, physiology, executive functions, and emotions (Posner & Rothbart, 2000). Mechanisms of self-regulation also tap multiple components, including physiological and executive mechanisms. The two components of self-regulation targeted in the current study are executive (effortful control) and autonomic regulation (RSA).

Effortful control. The term effortful control refers to the attentional and inhibitory mechanisms that facilitate suppression of a prepotent response in favor of a correct non-dominant response (Rothbart et al., 2000). In other words, effortful control is a child's voluntary regulation of his/her behavior in the service of distal goals and rewards (Rothbart et al., 2000). Via mechanisms of effortful control, children monitor and control their thoughts and actions. Effortful control therefore comprises flexibility, response inhibition, and resistance to interference (Kochanska et al., 1996, Rothbart et al., 2000), and is thought to be similar to executive functioning (Kochanska et al., 2000, Zhou, Chen, & Main, 2012). Effortful control is thought to combine two different constructs, executive control, which includes attention and inhibitory components, and delay abilities. Executive control and delay ability stem from different brain regions (e.g., Bush, Luu & Posner, 2000). Specifically, executive control stems from activity in the prefrontal cortex and requires more from working memory (Carlson, 2005), whereas delay ability includes additional activity in the mesolimbic system (Dixon, 2010). In addition, there is evidence to suggest that executive control and delay abilities differ in their developmental course, predictors and relations with social, emotional and academic outcomes (Brock**,** Rimm-Kaufman, Nathanson, & Grimm, 2009; Carlson, 2005; Li-Grining, 2007). As reviewed below, executive control and delay have been shown to relate to RSA differently. Therefore, in this study, executive and delay components of effortful control will be examined separately.

Development of effortful control. Brain imaging studies and neuropsychological assessments reveal that the preschool period is a critical time to examine the growth of effortful control. Brain imaging studies reveal that the anterior cingulate cortex (ACC) and lateral prefrontal cortex are active in effortful control tasks that assess selective attention and inhibitory control (Rothbart & Rueda, 2005). These studies indicated differences in regional brain activity during effortful control tasks in children versus adults and that children show less differentiated cortical activation (Davis, Bruce, Snyder, & Nelson, 2003; Durston, et al., 2002). This developmental increase in effortful control is rapid between the ages of 3 and 6, and continues into middle childhood (Diamond & Taylor, 1996; Kochanska et al., 1996).

Although all children develop effortful control abilities between ages 3 and 6, there are vast individual differences in growth rates and levels (Posner & Rothbart, 2000), as indicated by neuropsychological assessment batteries and other laboratory tasks (Korkman, Kirk, & Kemp, 1998; Murray & Kochanska, 2002; Gerstadt, Hong & Diamond, 1994; Kochanska, et al., 1996).

Environmental risk factors are shown to interfere with the development of executive control and delay abilities. In a rare study examining effortful control in the context of risk, it was demonstrated that children with greater exposure to residential stressors and sociodemographic risk variables demonstrated smaller increases in executive control over two time points during the preschool period. However, these same risk factors did not predict changes in delay of gratification. In fact, delay of gratification demonstrated more stability over time than the executive control measures, providing additional evidence to examine these processes separately (Li-Grining, 2007). Interestingly, a similar pattern was found in the larger study from which the sample for the current study was drawn, such that lower income predicted lower level of executive control but not delay (Lengua et al., under review).

These studies demonstrate that underlying brain structures that support effortful control develop rapidly starting in the preschool period. Although all children develop in effortful control, there is significant variability in individual changes. These differences may result from environmental context or other factors. One such factor that may predict differences in growth of effortful control is a physiological component of self-regulation, RSA.

RSA

RSA is a measure of parasympathetic nervous system influence on cardiac activity. High RSA has been linked consistently with emotional stability, whereas low RSA has been linked consistently with emotional lability and dysregulation (see e.g., Beauchaine, 2007; Porges, Doussard-Roosevelt, Maiti, 1994). Although RSA is often referred to as vagal tone in the child development literature, this obscures important distinctions between tonic measures of RSA collected at baseline, and reactivity measures of RSA collected during challenge tasks (see Beauchaine, 2001).

Polyvagal theory describes the phylogenic origins of medullary brain structures that contribute to the regulation of autonomic states, which in turn facilitate adaptive behaviors—both social and survival-oriented (Porges, 1995, 2001, 2007). Polyvagal theory distinguishes between an evolutionarily primitive vagus originating in the dorsal motor nucleus, and a newer, distinctly mammalian vagus originating in the nucleus ambiguus. Efferent fibers travel from these brainstem structures to the heart through the vagus, or 10^{th} cranial nerve, terminating on the sinoatrial node (Porges, 1995, 2007). Efferent traffic through the vagus inhibits heart rate through cholinergic mechanisms, resulting in reduced RSA. Because vagal influence in heart rate is inhibitory, it is sometimes referred to as the 'vagal brake'.

One tenet of polyvagal theory is that the autonomic nervous system (ANS) response strategy to challenge follows a reverse phylogenetic hierarchy, starting with the newest (mammalian) structures, and reverting to older neural structures when mammalian responding fails (Porges, 2001). However, although functional in the short term, long-term use of more primitive structures may be damaging to the mammalian stress response system and elicit canalized responses from these older systems, resulting in habitual fight/flight behaviors or even more primitive behaviors such as freezing. Children who live in chronically stressful environments may be more likely to use these more primitive responses (Porges, 2003, Porges, 1995).

RSA increases into adolescence as vagal fibers become myelinated. The heritability of RSA is between 25% and 31% at rest, and approaches 50% when measured during stressful tasks (Snieder, Boomsma, VanDoornen, & DeGeus, 1997). Thus, both heritability and environment shape RSA. In addition, RSA demonstrates reasonable test-retest stability from 2 months to 5 years of age, $r = .30$ (Bornstein & Seuss, 2000; Fracasso, 1994). Additionally, baseline RSA demonstrated short-term stability across three time points (2-week intervals) in kindergarten children, r = .59 between time 1 and 2, r = .67 between time 2 and 3 (Doussard-Roosevelt, Montegomery, & Porges, 2003). It should be noted that this magnitude of stability is not seen across reactivity tasks.

These studies demonstrate that although there is some stability in RSA across several years, it is evident that environment or other factors also shape changes in RSA. It is possible that effortful control may predict changes in RSA. The following section describes brain based and behavioral evidence that effortful control and RSA reciprocally influence each other.

Reciprocal relations of effortful control and RSA. Brain based and behavioral studies vary not only in their level of analysis but also in the temporal relation being studied. Brain based studies are able to tap shorter time frames of influence, in which neural firings are communicating between regions of the brain that support effortful control and RSA. In contrast, behavioral studies typically reflect either cross-sectional examination or longitudinal time frames, in which the behavioral manifestations of these constructs are able to shape one another. Although only behavioral measures are being assessed in the current study, it is important to consider brain based studies as they reflect more moment-to-moment reciprocal relations that could eventually be detected with bi-directional growth patterns, which is the level of analysis utilized in the current study. In the proceeding section, brain based and behavioral studies examining the relations of executive control with RSA will be examined first, followed by an overview of the relations of delay ability with RSA.

Executive control with RSA. Brain-based studies suggest that underlying brain structures supporting effortful control and RSA are connected. Specifically, the ACC is interconnected to the vagus nerve (Bennarroch, 1997; Thayer & Lane, 2007) and the prefrontal cortex. Several other midbrain structures mediate these pathways, and the interconnections are reciprocal such that there are neural connections maintaining influence from the prefrontal cortex to the vagus nerve, a process generally referred to as top-down processing. In addition, there are also connections maintained from the vagus nerve to the prefrontal cortex, a process generally referred to as bottom-up processing. Within the ACC that connects the prefrontal cortex and vagus nerve are the dorsal cognitive subdivision (ACcd) and the rostral-ventral affective subdivision (ACad) as depicted in Figure 1.

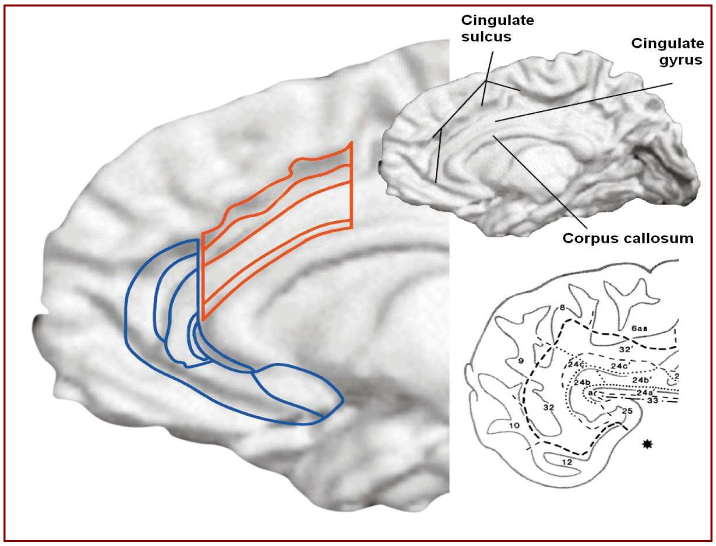

Figure 1. Adapted from Bush, Luu, & Posner (2000). Graphic of the anterior cingulate cortex that depicts neural connections to the prefrontal cortex and vagus nerve. The red region is the "cognitive" division with connections to the prefrontal cortex and the blue region is the "affective" region with connects to the vagus nerve.

The cognitive subdivision has neural connections to the lateral prefrontal cortex. Prefrontal regions of the brain are responsible largely for attention, response selection, and error detection (Posner & DiGirolamo, 1998). The affective subdivision is connected to the amygdala and has outflow to the vagus nerve. These areas are responsible primarily for emotional responses and regulating emotional responses (Drevets & Raichle, 1998).

As one function of the ACC is to control attention and inhibition, there is evidence that emotional reactivity results not only in limbic activation but also in simultaneous deactivation of frontal areas involved in cognitive inhibitory control. These reciprocal relations are supported by brain-mapping studies that have also shown that there is reciprocal suppression of the affective subdivision during cognitive tasks and suppression of the cognitive subdivision during affective tasks as shown through a counting or cognitive stroop and an emotional stroop (Drevets & Raichle, 1998). During development, the affective and cognitive divisions are continually engaging the other, such that in young children, there is a constant negotiation between use of affective and cognitive processes.

Two behavioral studies have also examined the relation of RSA and executive function, a construct similar to effortful control. In the first study, higher executive functioning was associated with higher baseline RSA (Mezzecappa, 1998). In the second study of 220- 3.5 year old children, higher baseline RSA was associated with higher executive function scores (Marcovitch et al., 2010). However, in both of these studies, all measures were collected contemporaneously so direction of effect cannot be determined (Mezzecappa, 1998).

Reciprocal relations of delay ability and RSA. There are only a few studies to examine the relations of RSA or heart rate reactivity measures with delay ability measures, thus evidence for these reciprocal relations are being drawn exclusively from behavioral measures. In one study, lower vagal recovery from an emotionally challenging task was associated with more negative wait strategies during a delay of gratification task in 4-7 year old children (Santucci et al., 2008). In a sample of pre-adolescent children, heart rate was assessed during a delay of gratification task. Heart rate reactivity was related to better attention regulation, although heart rate reactivity did not correspond with behavioral observation of greater delay performance.

However, in this same study, a person-oriented approach demonstrated that children who waited for the entire wait period did show some heart rate reactivity, possibly indicating they were bringing effortful processes to aid them in distraction (Wilson, et al., 2009). These studies describe the mechanisms through which effortful control and RSA influence each other. A longitudinal examination of bi-directional changes of the different components of effortful control and RSA can provide needed clarity of direction of effects.

Bidirectional growth of EC and RSA: Current Study. Studying self-regulation during key developmental periods in the context of stressful environments can reveal how deficits in one component of self-regulation might increase deficits in another component of self-regulation. These patterns are measurable during periods of rapid maturation as structures between subcortical and cortical regions are highly plastic and are particularly sensitive to environment. New synapses are formed, and others are pruned or discarded. Over time, these synapses strengthen and lead to long-term changes in neural organization (Lewis & Todd, 2007).

Children who experience environments of stress are at risk for problems in self-regulation abilities (Cicchetti & Manly, 2001). Such stressful environments are likely to elicit reactive responses (particularly fearful or frustration reactivity) that inhibit the expression of higher-order cognitive control processes, and over time, these patterns (at a behavioral level and possibly neural level) are strengthened (Blair, 2002). Therefore, in stressful environments, experience-dependent growth may lead to neural circuitry associated with a behavioral system that is predominantly reactive and is less well developed in cognitive or emotion regulation abilities (Derryberry & Reed, 1996; Posner & Rothbart, 2000). The current study oversamples children in stressful environments in order to be able to observe how components of effortful control and RSA shape each other. By examining effortful control and RSA within this sample, there will be greater variability of children's self-regulation development, increasing the ability to find evidence of bi-directional growth.

Given this theoretical model for how components of self-regulation may shape each other, we can hypothesize about the process of how effortful control and RSA each might impact the other and identify the cognitive and emotional mechanism by which this process may unfold. It is hypothesized that higher levels of effortful control and delay ability will likely promote more growth in RSA over time. It is possible that with greater effortful control, children may be able to employ cognitive strategies that modulate emotional reactivity, setting a pattern of higher-order regulation of emotions. Studies that have examined emotion regulation in observation or self-report measures have also found that greater effortful control promotes emotion regulation (Dennis et al., 2010, & Zalewski et al., 2011). Conversely, higher levels of RSA will likely promote more growth in effortful control and delay ability over time (Blair & Dennis, 2010). Children who have the physiological capacity to regulate their emotions will be better able to utilize higher order regulatory capacities, thus strengthening and promoting the use and growth in higher order regulation (Blair, 2002).

Self- Regulation, adjustment problems, and social competence

Effortful control, adjustment problems and social competence. Lower effortful control has been linked with internalizing and externalizing problems and higher effortful control has been linked with social competence across different developmental periods. Specifically, children with low levels of effortful control display more externalizing behavior problems than their peers (Lengua, 2002, 2006; Olson, Shilling, & Bates, 1999; Eisenberg et al., 2004). Boys ages 4-6 with higher levels of effortful control demonstrated fewer aggressive behaviors by using non-hostile verbal methods of negotiation with their peers (Eisenberg, Fabes, Nyman, Bernzweig, & Pinulas, 1994). These more advanced communication skills are facilitated in part by effortful control-mediated inhibition of emotional reactivity.

In addition, aspects of effortful control, particularly attention regulation, appear to be important in modulating internal emotional states (e.g., Eisenberg, Fabes et al., 2000), with relevance for internalizing problems (Eisenberg, Cumberland et al., 2001). This emotional pathway was empirically tested in a sample with pre-adolescent children, demonstrating that two different types of undercontrolled emotion regulation profiles mediated the relation of lower effortful control with later externalizing problems and depressive symptoms (Zalewski et al., 2011). Studies examining the relation between effortful control and internalizing problems during the preschool period are just emerging in the literature. In a study with sixty-five 3-5 year old children, a model was supported in which there as indirect path between lower effortful control to higher internalizing problems through family functioning (Crawford, Schrock, & Woodruff-Borden, 2011).

Although less research has linked effortful control with symptoms of depression and anxiety among preschoolers, studies point to effortful control as a predictor of internalizing problems in middle childhood (Eisenberg, Cumberland et al., 2001; Lengua, 2003). Effortful control may predict lower internalizing problems through the modulation of both fearfulness and sadness, and through inhibition of impulses to withdraw from social situations.

Higher levels of effortful control were related to greater social competence in preschool children when tested 6 months later (Lengua, Honorado, & Bush, 2007). Another study delineated an association of higher effortful control with greater social competence as mediated by children’s ability to modulate their behavioral and emotional gestures in a disappointment task (Liew, Eisenberg, & Reiser, 2004).

RSA, adjustment problems and social competence. According to polyvagal theory, deficiencies in the vagus nerve place individuals at risk for emotional lability, which characterizes almost all forms of psychopathology. Numerous studies demonstrate low baseline RSA in individuals with diagnosable psychopathology—both on the internalizing and externalizing spectra (Beauchaine 2001; Beauchaine, 2007; Katz, 2007). For example, children with combined internalizing/externalizing disorders compared to low problem behavior 5-year-olds exhibit larger reductions in RSA during behavioral challenge tasks, with similar findings among 6-7-year-olds (Calkins, 2007; Boyce et al., 2001). Lower baseline RSA and greater RSA reactivity to challenge tasks are also observed in children and adolescents with ADHD/ODD Mead et al., 2004) and self injury (Crowell et al., 2006) compared with normal controls. Not all studies have found that baseline RSA was related to internalizing or externalizing problems. In one study with 94 preschool children, zero-order correlations between RSA and internalizing and externalizing problems were non-significant. However, reactivity scores were significantly related to problems in that children who had greater change scores from baseline to a stressor had fewer problems (Hastings, et al., 2008).

In younger children, several studies have examined the relation of RSA with social competence, although few utilize a longitudinal design. In a study with kindergarten children, higher baseline RSA was associated with greater social competence (Doussard-Roosevelt, Montgomery, & Porges, 2003). Similar findings were demonstrated with children from a Head Start classroom in that higher baseline levels were related to higher teacher reports of social competence (Blair & Peters, 2003).

In sum, effortful control and RSA are related to each other and to adjustment, but few studies have examined these relations longitudinally. As executive control and RSA are physiologically connected, it is possible they might shape each other over time. Therefore, the main aim of this study is to understand how effortful control and RSA are related to each other over time and whether they impact the development of each other. To do this, an autoregressive latent trajectory (ALT) model will be employed.

Autoregressive latent trajectory (ALT) model

To examine the co-development of executive control with RSA and delay ability with RSA, an autoregressive latent trajectory model will be tested (Bollen & Curran, 2004). The ALT model is the combination of two models that are commonly used in the literature, the autoregressive (simplex) model and a latent trajectory model. The ALT model permits for the empirical test of two different types of development. The following sections introduce each model component, which will ultimately build toward the ALT model. Variables of the current study are used in the models below to begin to depict how the specific study aims will be empirically tested.

Latent Curve Model. The latent trajectory model, of which the linear model is most often used, allows each case to have a distinct intercept and slope to describe the trajectory of a variable over time (Figure 2). The latent trajectory, in comparison to the autoregressive model, focuses on individual trajectories over time.

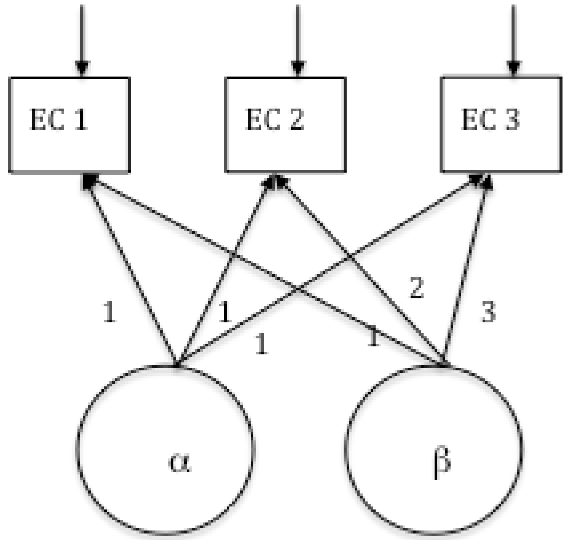

Figure 2. Latent trajectory model for single repeated measure. This will be repeated for delay ability and RSA.

The bivariate, or parallel process, model for a latent curve model includes two variables (Figure 3). This model permits the prediction of slope of one variable from the intercept of the other. Therefore, this is an ideal method to test the relation of executive control with RSA and delay ability with RSA.

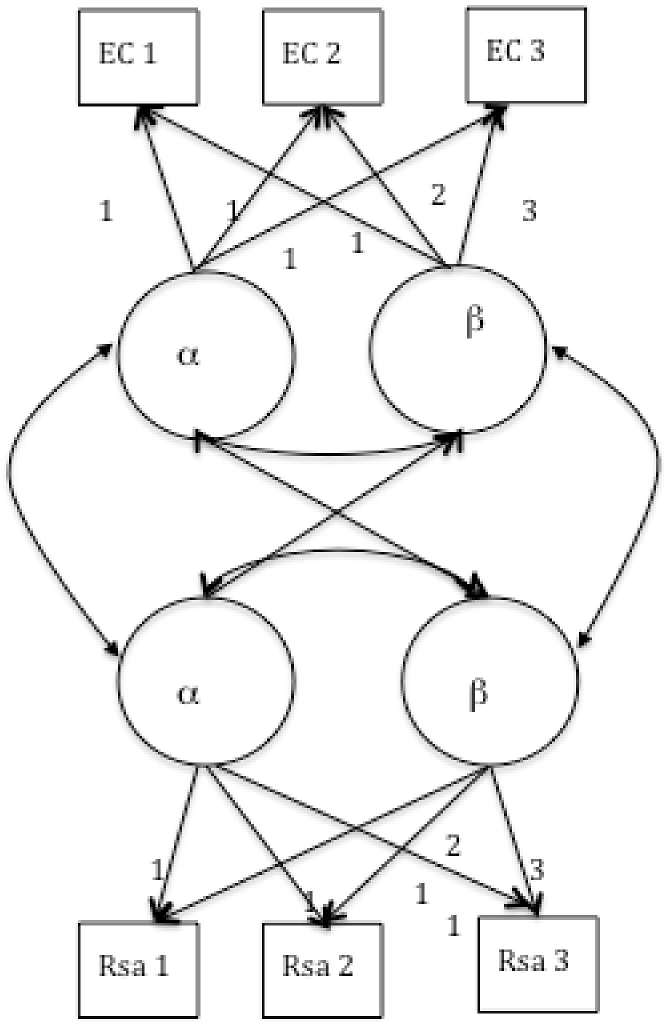

Figure 3. Bivariate latent growth curve model. This will be repeated for delay ability with RSA.

Autoregressive model. A key feature of an autoregressive model is that it is the regression of a variable on its earlier value (Figure 4). Variables can be observed or latent.

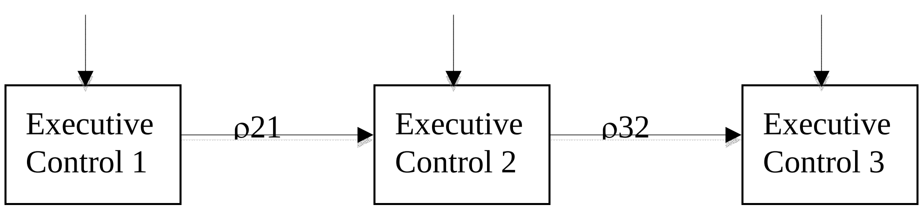

Figure 4. Univariate autoregressive (simplex) model, using executive control as the measurement variable, with three time points.

A bivariate autoregressive model includes cross-lagged paths, which permits testing across different repeated measure variables (Figure 5). These cross-lagged paths represent the longitudinal prediction of one variable from the other above and beyond the autoregressive prediction of that variable from itself.

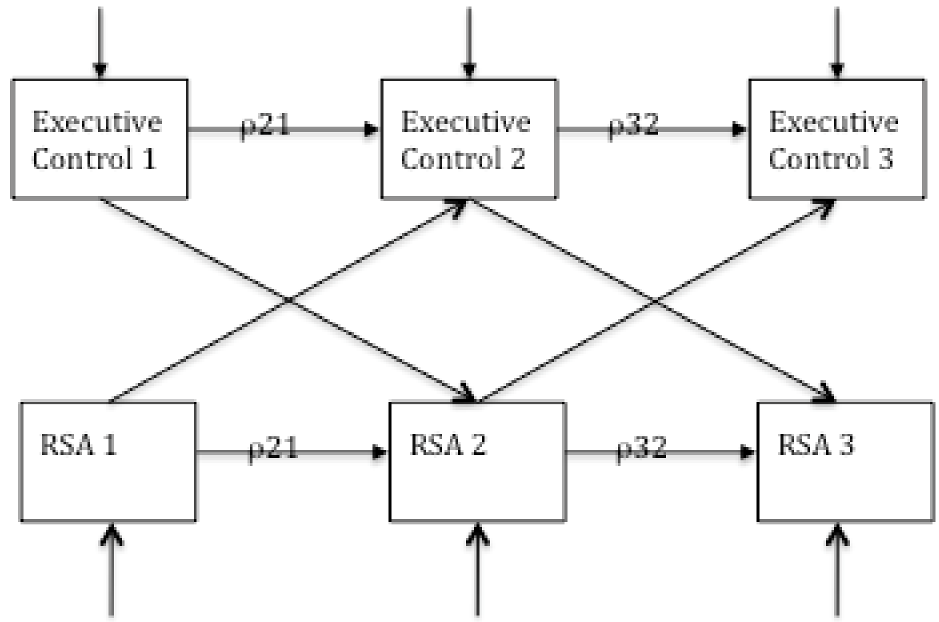

Figure 5. Bivariate (or multivariate) autoregressive model using executive control and RSA across three time points. Will be repeated for delay ability and RSA.

Autoregressive Latent Trajectory. The autoregressive latent trajectory model integrates the autoregressive and latent growth curve models of change (Figure 6).

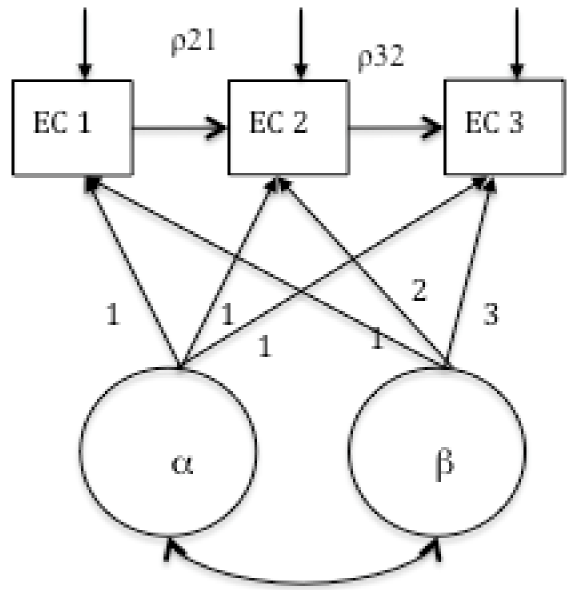

Figure 6. Univariate autoregressive latent trajectory model. The multivariate autoregressive model includes all components, including the cross-lagged paths.

The bivariate or multivariate ALT model will test all components of a latent growth curve model and an autoregressive model (Figure 7).

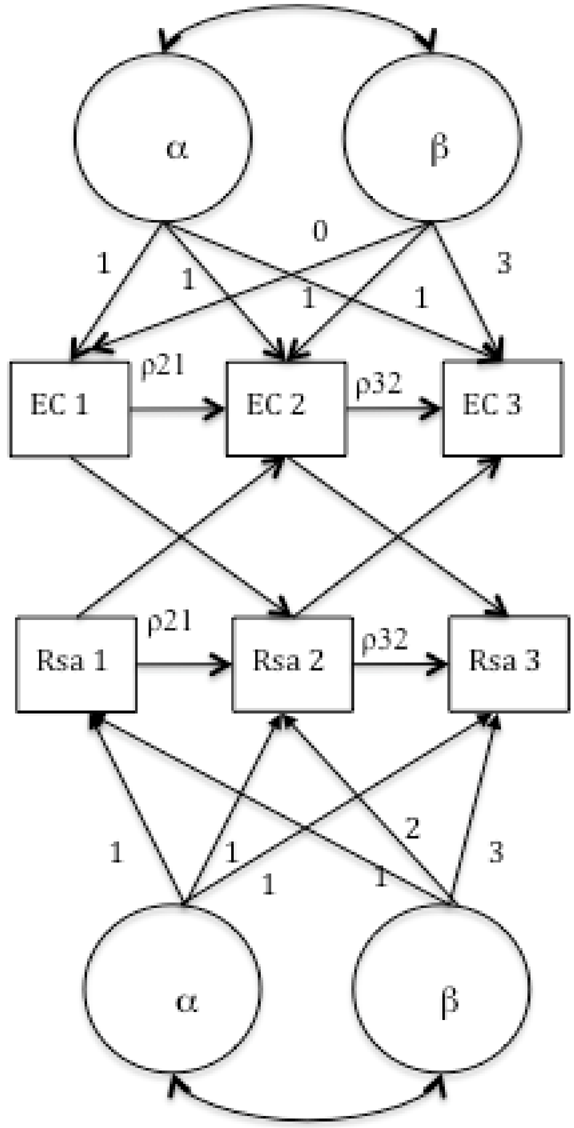

Figure 7. Bivariate autoregressive latent trajectory model

Finally, in order to test how growth (slopes will be tested) in effortful control and RSA relate to adjustment problems and social competence, each outcome variable of interest (depression, anxiety, externalizing behaviors, and social competence) will be examined (Figure 8). The corresponding Time 1 adjustment variable will be controlled for (i.e. Time 1 depression for testing Time 3 depression outcomes).

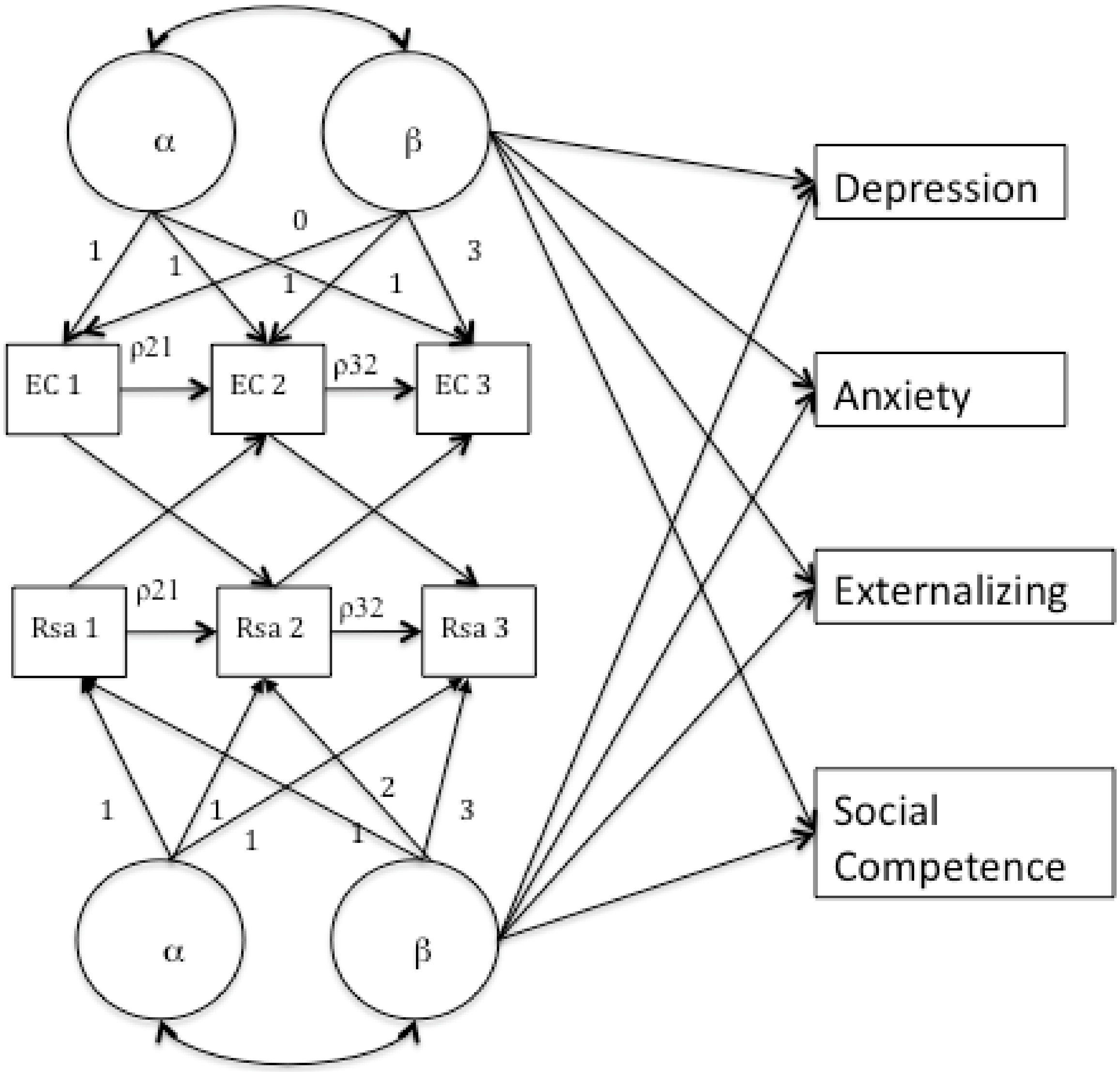

Figure 8. ALT model testing the stable and time-varying effects of RSA on effortful control with adjustment outcomes (covariances among growth factors across constructs are not depicted but will be modeled). Two statistical aspects of this model are not depicted in the figure. 1. The intercept of effortful control and RSA will also be modeled with adjustment outcomes. 2. Time 1 adjustment will be controlled for each model tested.

From this, the four study hypotheses are:

1. Low baseline RSA is expected to predict lower levels of effortful control and lower rates of growth across this developmental period. Higher baseline RSA is expected to predict higher levels of effortful control and higher rates of growth. A LGC model will be specified in which the intercept and slope of effortful control are conditioned on the intercept of RSA,

controlling for children's age and cognitive ability. Additional potential covariates, including child gender, family income, maternal education, single parent status, and maternal self-control, will be examined. If they are significantly related to effortful control and RSA growth factors, they will be included in all subsequent models.

2. Effortful control is expected to relate to growth trajectories of RSA. Higher effortful control is expected to predict higher baseline RSA and higher rates of growth across this developmental period. Lower initial levels of effortful control are expected to predict lower baseline RSA and less growth of baseline RSA over time. A LGC model will be specified in which the intercept and slope of RSA are conditioned on the intercept of effortful control, controlling for children's age and cognitive ability.

3. The third hypothesis is exploratory. Although we expect that lower baseline RSA will predict lower effortful control and that these effects will exacerbate over time, no other studies have tested such a specific model that would suggest if one variable will exert a more pronounced effect on the other. ALT analyses will explore the aim of understanding whether effortful control exhibits a stronger effect on RSA or vice versa.

4. We hypothesize that initial levels and slope of effortful control will be positively related to increases in social competence, whereas they will be negatively related to changes in depression, anxiety, and externalizing problems. It is expected that initial levels and slope of baseline RSA will be positively related to changes in social competence, whereas they will be negatively related to changes in anxiety, depression, and externalizing problems.

METHODS

Participants

This research is part of a larger study (N = 306) examining developmental trajectories of effortful control in a sample of preschool children at elevated risk for problems with self-regulation and adjustment problems (PI: Lengua). In the current study, a community sample of 167 3-year-old children was assessed across three waves, permitting the examination of developmental changes and the reciprocal relations between effortful control and RSA. The participants in the present study were a subset of the larger sample. This particular subset was chosen through stratified random sampling. Specially, after 95% of families had visited for their T3 visit (the remaining 5% of families took several more months to recruit and were mainly families from poverty background), I categorized families into poverty, 1.5 x poverty, low income, middle income, and upper income categories used in this study. After determining which families were successfully videotaped, I randomly selected 33 to 34 families from each income bracket, in order to achieve the minimal sample size needed to run an ALT model. Besides requiring that families had been videotaped, no other criteria were used to select the subsample (i.e. only maintaining children who were compliant with the RSA collection) because the goal was to keep the subsample as similar to the entire sample as possible.

Recruitment

Children and their mothers were recruited from various sources including, community centers, Craig's List, daycare/schools, the newspaper, referrals from other participants and a subject pool from women who had given birth 3 years previously at the University of Washington and agreed at that time to be contacted for potential research opportunities. Families at these sites received information forms about the study and could indicate their interest in participating in the study on the information forms returned through their organization or mailed directly to the research project in postage paid envelopes. Recruitment sites received an honorarium of $100.00 when 90% or more of their families returned the forms, regardless of the number of families indicating interest in participating. If a site returned 75% or 50% of the forms, the site received $75.00 or $50.00, respectively. When forms were returned, families were called and asked if they were interested in learning more about the study. A trained staff member explained the study at this time and determined if the assessment timing would match with the child's third birthday, if the family was still interested, and whether they were eligible based on exclusionary criteria. In total, over 1400 families were contacted, 318 were deemed eligible and 306 showed up for their first assessment. Families were either not reachable at the listed phone number and of the families who were not eligible, the most common reason was that we were[1] done recruiting from that specific income category.

In total, families were recruited from a variety of agencies. In addition, the percentage of families from poverty backgrounds recruited from the various sources are reported here. Out of 306 families, 12 families were recruited from Community Centers (50% of these families were poverty); 3 from Craig's list (0% poverty); 48 from Daycare/School (15% of these families were poverty); 5 from newspaper (0% poverty); 28 from referrals (21% of these families were poverty); and 210 families were recruited from the subject pool (15% of these families were poverty). [1]

[1] The following numbers reflect the entire study (N =306).

Families were excluded from the study if 1) they were non-English speaking; 2) the child had a developmental delay or disability; 3) if the child was on an anticonvulsant or taking high blood pressure medication.

Participants and retention. Family income was sampled to reflect the whole range of income (12.7% earning < $17,600; 10.2% earning between $17,600-$28,400; 14.4% earning between $28,400 – $35,600; 13.3% earning between $35,600-$48,200, and about 50% of the sample earned over $48,2000). The highest degree of education obtained by mothers ranged from having an eighth grade education to having an advanced graduate degree. Thirty-eight percent of mothers had received some college education or less, 8.5% of mothers had a professional degree and 53.6 % of mothers had a college degree or higher. In regards to family income and maternal education, the subsample matched closely with the full sample, although the mean family income and maternal education status were slightly higher for the full sample. Twenty-two percent of female primary caregivers were single parents. Of the 167 preschoolers studied, 51.8 % were female. Mothers reported on their child's racial background. Fifty-nine percent of the children in the study were European American or White; 27.6% more than one racial background; 5% African American; 3% Latino or Hispanic; and less than 1% mothers endorsed 'other'. From the current subsample of the larger study, 11 families did not come in for their Time 2 visit and 10 families for their Time 3 visit. Six of these families did not complete either their Time 2 or Time 3 visit. Families missing any data at Time 2 or and 3 were compared to those missing no data on Time 1 family income, child executive control, delay ability and RSA, or adjustment variables. On these variables, there were no significant differences between families who missed their Time 2 or Time 3 visit.

Procedures

The target child and primary female caregiver came to the University of Washington's laboratory for three assessments separated by nine months (spanning 18 months total). The University of Washington Institutional Review Board approved the larger study and informed consent was obtained. First, families were contacted a day or two prior to their actual visit to remind parents of the visit. Transportation logistics were reviewed with each family to determine if there were any changes to the family needing a town car service to pick them up or to remind them of where to park when they arrived. Given the low-income nature of this sample, families were provided free parking right outside the building, in an attempt to make a University campus more comfortable for women who had not been on one before. The family was greeted by two trained undergraduate or post-baccalaureate students who proceeded to work with the family for their session. Mothers and children were shown the rooms they would be working in so children could see their mother would be nearby. Immediately upon entering the child room, mothers and children were consented and assented. Most children were able to separate from their mothers but extra warm up time was allotted for children who had difficulties. Once separated, children completed neuropsychological measures of effortful control, delay ability, and completed a baseline assessment of RSA. While children completed the measures with a trained child experimenter, the female primary caregiver participated in a structured interview assessing demographic information and child adjustment outcomes. The female primary caregiver also completed many other measures to assess children's temperament, family conflict and mother's own levels of self-control. The parent experimenter read the questions aloud to all mothers as to minimize any bias due to reading abilities. In addition, the experimenters were instructed on specific protocols regarding potential child abuse or high maternal depression. Specifically, experimenters were not to confront the parent about the issue but to report any concerning details to the primary investigator (or project director when the PI was out of town) immediately following the session who then followed up with the parent within 48 hours. Mothers and children also completed parent-child interaction tasks for about ½ hour that were part of the larger study but not included in the present study. Finally, mothers were instructed on how to sample their child's saliva to collect cortisol, a measure that is also not included in the current study.

Families were paid $70, $90 and $110 for their Time 1, Time 2, and Time 3 assessments, respectively. Various strategies were used to retain families due to the high-risk status of many participating families (Capaldi & Patterson, 1987; Capaldi et al., 1997; Streissguth & Giunta, 1992). This included sending 'Go123' newsletters to families homes in order to increase their connection with the study and to alert us as soon as possible to any problems with addresses so efforts could be made to locate the family. In addition, emergency contacts were collected for each family at the end of their first visit and were used when participants were unreachable over time. Finally, as part of the efforts to maintain families across all time points, home visits were offered to families who otherwise would miss a time point. At Time 2, 4 families were assessed at their home and at Time 3, 7 families were assessed at their home.

Families were scheduled for their 2nd and 3rd visits within 2 weeks of a 9-month interval from their prior visit. On average for the entire sample, the interval between Time 1 and Time 2 was 9.40 (SD = .64) months and the average interval between Time 2 and Time 3 was 9.04 (SD = .91) months.

Measures

Effortful Control. Effortful control was assessed at all time points with identical measures of attention regulation, cognitive and behavioral inhibitory control, and delay ability.

Measures were selected to be of varying difficulty for children across the preschool period so that identical measures could be used over time. Measures included a combination of executive function subscales of the NEPSY, a developmental neuropsychological assessment battery (Korkman, Kirk, & Kemp, 1998), and other well-known effortful control tasks from Murray & Kochanska (2002). Given emerging evidence that delay ability might operate differently than the executive attention and inhibitory control aspects of effortful control, two separate effortful control variables were created: executive control and delay ability (Fisher, Tininenko, & Pears, 2007; Li Grinig, 2007).

Executive control. Executive Control was assessed using 6 tasks: NEPSY Inhibition, NESPY Auditory Attention, Bear-Dragon, Day-Night, Dimensional Card Sort, and Head Toes Knees Shoulders. All tasks were coded by intensively trained undergraduate or post-baccalaureate students. Each task is described below. Means, standard deviations and ranges for each of the component executive control tasks is provided for each task. Time 1 intraclass correlation coefficients (ICCs) are also reported for Inter-rater reliability. The ICCs were examined for both the subsample and the full sample. However, reliability for Inhibition was not completed due to challenges in scoring this variable that resulted from having so many items being administered in rapid succession. However, the overall reliability for the executive control composite was adequate (described below) so inclusion of Inhibition without its own reliability score calculated is deemed acceptable. Except for the NEPSY Auditory Attention subtest, the ICCs were similar and therefore, the full sample ICCs are reported. However, both ICCs will be reported for Auditory Attention because of discrepancies between the subsample and full sample. Approximately 17% of the tapes were coded for reliability.

The Inhibition and Auditory Attention subscales of the NEPSY were designed for use with children 5 and older. However, the scales were administered to the children in this study to allow use of identical measures of executive control longitudinally. Thus, these tasks were understandably difficult for children in this sample. Total scores for both scales were calculated as the proportion correct responses across the task.

The *Inhibition* subtest assesses a child's ability to inhibit a dominant response in order to enact a novel response. Children were presented with a page with four circles (black, blue, yellow and red). Children were instructed to touch the red circle only when they heard the word red. A series of words are said aloud including many color words. If children passed the teaching example, a CD consisting of 45 words was played for children to follow. Children earned 1 point for either correctly touching when they heard the word red or by not touching when another word was read aloud. At Time 1, the average Inhibition score was, *M* = .18 (*SD* = .31, *Range* = 0-1); Time 2, *M* = .48 (*SD* = .40, *Range*, 0-1); Time 3, *M* = .74 (*SD* = .32, *Range* = 0-1).

The *Auditory Attention* subtest is a continuous performance test that assesses the ability to be vigilant and to maintain and shift selective auditory set. At Time 1, the average Auditory Attention score was *M* = 0.09 (*SD* = .24, *Range* = 0 – 0.87; Time 2, *M* = .27 (*SD*= .27, *Range*= 0-.98), Time 3, *M* = .49 (*SD* = .35, *Range* = 0-1). The ICC for the entire sample was .72. However, the ICC for the subsample used in the current analyses was much lower, .37, revealing this particular subtest may not have been reliable.

Behavioral inhibitory control was assessed using the Bear-Dragon task (Kochanska, et al., 1996), which required the child to perform actions when a directive is given by a bear puppet, but not when given by a dragon puppet. In this study, the bear puppet was replaced with a monkey puppet. Specifically, to begin, the experimenter asked children to imitate 10 self-directed actions (e.g. "Touch your ears"). The experimenter then introduced two puppets- a "nice monkey" and a "naughty dragon"- and instructed children to do what the monkey says but not do what the dragon says. In the practice trials, the experimenter moved the monkey's mouth and says (in a high-pitched voice), "Touch your nose," and then moved the dragon's mouth and said (in a low gruff voice), "Touch your tummy." To pass the practice trials, children were instructed to follow the monkey's commands but ignore the dragon's commands. Following this, experimenters conducted a verbal rule check and provide feedback as necessary. Finally, this is followed by 10 test trials (5 monkey trials and 5 dragon trials in alternating order) in which children were provided no feedback or assistance. After the fifth command, children were reminded of the rules, regardless of performance. Children received scores ranging from 0 to 3 on each dragon trials (0 = a full commanded movement, 1 = a partial commanded movement, 2 = a wrong movement, 3 = no movement). For monkey trials, the codes were reversed, (0 = no movement, 1 = a wrong movement, 2 = a partial commanded movement, 3 = a full commanded movement). Total scores were the proportion of the score across both monkey and dragon items to the total possible score. The average score at Time 1 was *M* = 0.61 (*SD* = 0.20, *Range* = 0.33 – 1.00); Time 2, *M* = .86 (*SD* = .21, *Range* = .33 – 1.00); Time 3, *M* = .96 (*SD*= .11, *Range* = .50-1.0). The ICC was .98 (full sample).

Cognitive inhibitory control was assessed using the Day-Night task (Gerstadt, Hong, & Diamond, 1994), which required the child to say "day" when shown a picture of moon and stars and "night" when shown a picture of the sun. Children's actions were scored 1 for correctly providing the non-dominant response or 0 for providing the dominant response. Total scores were the proportion of correct responses. The average total score at Time 1 was *M* = 0.41 (*SD* = 0.32, *Range* = 0.00 – 1.00); Time 2 *M* = 0.58 (I = .31, Range = 0-1); Time 3, *M* = 0.70 (*SD* = .29, *Range* = 0-1). The ICC was .97 (full sample).

The Dimensional Change Card Sort (Zelazo, Muller, Frye, & Marcovitch, 2003) assessed cognitive inhibitory control, attention focusing and set shifting. In this task, children were introduced to two black recipe boxes with slots cut in the top. Target cards were attached to the front of each box. The target cards consisted of a silhouetted figure on a colored background (star on blue background and truck on red background). Children were instructed to sort cards according to either the shape or color properties on the target cards, first according to shape (6 trials), then according to color (6 trials). The experimenter stated the sorting rule before each trial, and presented a card and labeled it according to the current dimension (e.g., on a shape trial, "Here's a truck. Where does it go?"). If children correctly sorted $\geq$50% of cards, they advanced to the next level in which the target cards integrated the sorting properties. Target cards consisted of a colored figure on a white background (blue star and red truck), and children were again instructed to sort according to shape (6 trials) and then color (6 trials). If they correctly sorted $\geq$50% of the cards, children advanced to the next level in which they were instructed to sort by one dimension (color) if the card had a border on it and by the other dimension (shape) if the card lacked the border (12 trials). The score was the proportion of correct trials out of the total possible of 36 trials. The average total score at Time 1 was, *M* = 0.41 (*SD* = 0.17, *Range* = 0.00 – 0.83), Time 2, *M* = .61 (*SD* = .26, *Range*= 0-.97); Time 3, *M* = .78 (*SD* = .16, *Range* = .25-1). The ICC was .99 (full sample).

The Head, Toes, Knees, Shoulders (HTKS) task also integrated attention and inhibitory control (Ponitz et al., 2008). Children are asked to follow the instructions of the experimenter, but to enact the opposite of what the experimenter directed (e.g. touch toes when asked to touch head). Behaviors were coded as 0 points if the child touched the directed body part, 1 point if the child self-corrected his/her behavior, and 2 points if the child only touched the opposite body part. Total scores were the proportion of the score across items to the total possible score. The average score for Time 1 was, *M* = 0.01 (*SD* = 0.07, *Range* = 0.00 – 0.65); Time 2, *M* = .16 (*SD* = .24, *Range* = 0-.85); Time 3, *M* = .41 (*SD* = .32; *Range* = 0 -.93). The ICC was .97 (full sample).

Consistent with previous research, an overall executive control score was computed as the mean of the proportion scores of the individual tasks for each time point. Means and standard deviations are reported in Table 1. Executive control scores were considered missing if $\geq$ 50% of the component scores were missing. Internal consistency of the composite executive control measure was 0.67, and the inter-rater reliability for the sub-sample was .80, whereas it was .90 for the entire sample.

Delay ability. Children's delay ability was assessed using a gift delay task (Kochanska et al., 1996). In this task, the child was told that s/he would receive a present, but that the experimenter wanted to wrap it. The child was instructed to sit facing the opposite direction and to not peek while the experimenter noisily wrapped the gift. Children's peeking behavior (frequency, degree, latency to peek, latency to turn around) and difficulty with the delay (fidgeting, tensing, getting out of seat, grimacing, talking) were rated. Means and standard deviations for each time point are provided in Table 1. Latencies and behavior scores were converted to proportions of total possible times/scores and averaged. ICC was .72 for the subsample and .63 for the entire sample.

RSA. Heart rate and RSA were collected using a 2-lead electrocardiograph (ECG) and respiratory band from *Biopac PRO Lab* 3.7.1 (Goleta, CA). Electrodes were placed on the child's right clavicle and lower left abdomen. The ground electrode was placed on the upper left chest. The respiratory band was fit approximately under the child's ribcage.

RSA was computed using the methods of Porges (1985). First, ECG R-waves were detected and time-stamped using AcqKnowledge software (Goleta, CA) and then exported, along with original ECG recordings. Custom-purpose Matlab software was used to overlay inter-beat interval (IBI) time series on top of ECG waveforms to inspect accuracy and correct misses and false alarms of AcqKnowledge's beat detection algorithm. Epochs contaminated by large mechanical artifacts or other electrical interference that obscured or distorted the heartbeat waveforms were excluded from subsequent analysis. Artifact-free segments of corrected IBI sequence from relevant epochs of recording were re-sampled at 2.8 Hz. Each re-sampled segment was filtered with a 21-point 3rd-order polynomial derived from Fig. 3A of Litvack et al. (1995) and subtracted from the unfiltered segment to obtain a high-pass filtered segment. This segment was then converted to a sequence of fourier coefficients via fast-fourier transformation. RSA, defined as the log of the average power of these fourier coefficients falling in the frequency range between 0.24 and 1.04Hz, was reported in units of ln(ms^2). The age-specific frequency pass-band used for RSA was intended to match developmentally normal respiration rates as reported elsewhere (Hastings et al., 2008).

Specifically to collect baseline ECG, after the electrodes and respiratory band are securely and comfortably placed on the child, the experimenter read a 3.5-minute neutral story to collect RSA baseline. Experimenters were trained to read in a neutral tone of voice and were instructed not to elicit speech from the child, as this is known to influence RSA measurement. While collection was underway, a trained technical experimenter flagged both the start and stop times for the ECG data in order to ensure proper collection.

After data collection was proceeding, very quickly we realized that many of the preschoolers did not want to put the ECG leads on their body. Therefore, two systems for dealing with this were quickly developed. First, to make children more comfortable with having ECG leads and a respiration band on their body, we first demonstrated putting sample leads on either their choice of Dora the Explorer or Spiderman. Children were encouraged to help so they could become comfortable. Children were then invited to look like the character, and were invited to put leads on. The second modification for handling missing ECG data was to create our own behavioral scoring system to rate child compliance. This was done to help describe missing data. Zero was scored for non-compliant and 1 was scored for compliant and children were then rated as to whether they verbally refused (i.e. stated "No", "I don't want to do this"), passively refused (i.e. did not lift hands, refused to lift shirt, stated "where's my mom?"), or demonstrated noncompliance in other ways (i.e. running around the room, hiding under the table). At Time 1, 37 children were scored as non-compliant. To note, there were a few children who received a non-compliant score who nonetheless have a RSA score. This could occur if the child only allowed a portion of the baseline to be collected before indicating he/she wanted the leads off. Or, a non-compliant score accompanied with a RSA score could occur if a child only wanted the respiratory belt to removed. Conversely, there was a small portion of children who did not receive a RSA score but who were compliant through baseline collection. This could occur if a there was a technical problem. Therefore, the non-compliant data and missing physiological data do not correspond perfectly. However, non-compliance or refusal accounts for the majority of missing data for RSA. Several t-tests were performed to examine if children who were non-compliant differed across family income, Time 1 executive control, Time 1 delay ability, and the Time 1 adjustment problems and social competence. Children who were non-compliant for the RSA task had lower Time 1 executive control, t (160) = -2.65, p =.02, (Non-compliant M = .23, Compliant M = .29) and delay of gratification, t (143)= -3.34, p =.001 (Non-compliant M = .47, Compliant *M* = .64). At Time 2, only 8 children were non-compliant. There were no significant differences for non-compliant children versus compliant children on executive control, delay ability or income (Time 2 adjustment outcomes and social competence were not tested as they are not part of the analyses). Finally, at Time 3, 5 children were non-compliant. There were no significant differences between non-compliant and compliant children. Overall, the missing data from children's non-compliance suggests that at Time 1, some bias was introduced in missing RSA data as a result of child noncompliance.

Adjustment Problems. At each time point, child depression, anxiety, externalizing problems and social competence were measured using parent report. Only Time 1 and Time 3 measures were used for analyses in this study. In order to predict changes in symptoms, Time 1 levels were entered as control variables and Time 3 was the outcome measure. Descriptive statistics are presented for these time points. Parents completed the Child Behavior Checklist (CBCL, 4-18 years version; Achenbach, 1991). The scale was augmented with problem behavior items from the preschool version (ages 2-3) that do not overlap with items on the 4-18 version (34 items) to allow for administration of identical measures across all time points. This is critical for growth curve analyses. The CBCL has a long history and has been shown to be both a valid and reliable measure of children's behavior problems (see Achenbach, 1991). Depression and anxiety were scored using an alternate method allowing them to be scored separately (Lengua, West, Sandler, 1998), and externalizing was measured using the aggression and delinquent behavior subscales. Average scores for mother's report on child depression at Time 1 were 2.09 (*SD* = 1.86, α = .49) and at Time 3 were 2.16. *SD* = 2.20, α = .60. For child anxiety at Time 1, average scores were 2.7 (SD = 2.28, α = .62) and at Time 3 were 2.71 *SD* = 2.48, α = .72.

Finally, mothers reported on child externalizing at Time 1 in which the average scores were 5.87 (SD = 3.49, α = .74) and at Time 3 were 5.61, (SD = 3.90, α = .79).

Social Competence. Social competence was assessed with parent report on the 34-item preschool version of the Social Skills Rating Scale (SSRS, Gresham & Elliot, 1990). The SSRS assesses cooperation, assertion, responsibility, and self-control. This measure was standardized on a large, national sample and provides norms. Internal consistency reliability of .90 has been reported, and validity has been established based on negative correlations with CBCL measures of problem behavior and associations with academic competence (Gresham & Elliot, 1990). At Time 1, mothers' mean reported child social competence was 45.83, (*SD* = 8.42, α =.83) and at Time 3 it was 49.79, *SD* = 6.44, α = .78.

Covariates. Non-demographic covariates included child cognitive ability and maternal self-control. Maternal self-control was measured by the 'Self-Control Scale, Short form' which is a 13-item self-report measure derived from the original 36 item measure (Tangney, Baumeister, & Boone, 2004). Items include "I am good at resisting temptation" and "I wish I had more self-discipline" (reverse scored). The reliability of this measure was α = .71.

Cognitive ability combined measures of verbal and nonverbal abilities. Verbal ability was assessed using Comprehension of Instructions, a subtest of the NEPSY. Nonverbal ability was assessed using the block construction subtest of the NEPSY, which requires the integration of visuospatial skills with motor activity and it is primarily a measure of visual-construction abilities. Cognitive ability was also made into a proportion score.

Analytic Plan. Data were analyzed using Latent Growth Curve (LGC), and auto-regressive latent trajectory (ALT) analyses. Full information maximum likelihood estimation (FIMLE) was used in all analyses. FIMLE requires estimation of means and intercepts as well as covariances and path coefficients, and uses all the data available simultaneously to calculate parameter estimates (Kline, 1998). FIMLE has been found to be less biased and more efficient than other techniques used to handle missing data such as pairwise and listwise deletion (Arbuckle, 1996). Mplus version 4.2 (Muthén & Muthén, 2004) was used. LGC and ALT analyses were used to test the relations among developing effortful control, RSA and adjustment problems and social competence. An ALT model combines LGC with a cross-lagged path model to examine longitudinal relations. This is an ideal data analytic method to test the hypothesized relations because it examines two kinds of longitudinal relations, growth patterns and time-varying effects (Curran & Bollen, 2001). First, growth was modeled using latent factors that provided estimates of both average levels (stability) and systematic change in effortful control and RSA. Second, cross-sectional and time-lagged causal paths were added to the growth model as indicated in Figure 4, and nested model tests were used to determine if these paths improved the fit of the model. If supported by the data, these causal paths suggest time-varying effects between constructs. Thus, ALT analysis will allow us to analyze mean change (covariances among the latent factors), rank-order change (cross-lagged causal paths), and time-varying effects across constructs.

Power

LGC modeling in structural equations modeling (SEM) will be used to test the study aims. LGC models are more powerful than traditional fixed effects repeated measures ANOVAs for detecting change and correlates of change (Curran & Muthèn, 1999). In SEM, tests of the hypotheses include not only the magnitude and significance of each proposed relation, but also tests of the overall fit of the proposed model to the data. MacCallum et al. (1996) have proposed an approach in which the null hypothesis is that the proposed model is a “close fit” to the relations in the population, and the alternative hypothesis is that the proposed model represents an inadequate fit. Thus, power in this case refers to the ability to detect when the alternative hypothesis about model fit is false. This approach uses the root-mean-square error of approximation (RMSEA; Steiger & Lind, 1980) as an estimate of fit, which takes into account the degrees of freedom or number of parameter estimates in a model. Thus, given two models with equal fit to the data, the model with fewer parameter estimates (more parsimonious) will have a lower RMSEA. RMSEA between .00 and .05 are thought to indicate a good-fitting model and RMSEA >.08 indicates an inadequate model fit. Therefore, power is a function of degrees of freedom in the model, sample size, level of significance (traditionally $\leq$.05), and the RMSEA of the null ($\leq$ .05) and alternative (>.08) models. Using this approach, MacCallum et al. (1996) have provided a system (and SAS program) for determining the minimum sample size needed at a specified level of power. For the proposed project, the traditionally accepted level of power of .8 was used. Structural models that include latent growth factors are powerful models because many of the factor loadings are constrained to specify the pattern of growth. Thus, LGC models tend to have greater degrees of freedom than other structural models. Degrees of freedom in these models ranged from 62 to 125. The minimum sample size needed to detect a false alternative hypothesis (i.e., the hypothesis that the proposed models have inadequate fit to the data) ranges from 113 to 183. The target sample size for analyses will be 167 and thus, power to detect significant effects will be adequate for a majority of analyses in the proposed study.

Model Estimation

Models were estimated with Mplus 6.1 (Muthén & Muthén, 2010) using the Full Information Maximum Likelihood Estimator. Missing data on dependent variables was handled through the use of the expectation maximization algorithm. Model fit was evaluated using the χ^2

likelihood ratio test, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). For CFI and TLI, wec used the conventional cutoff $\geq$.90 for acceptable fit and $\geq$.95 for good fit. RMSEA values <.08 represent acceptable fit, while values <.05 indicate good fit. SRMR values <.10 support acceptable fit, while values <.08 support good fit (Hu & Bentler, 1999; McDonald & Ho, 2002). Nested models were compared using the χ^2 difference test ($\Delta\chi^2$; Bollen, 1989).

Bollen and Curran's (2004, 2006) data analytic recommendations for building and testing Autoregressive Latent Trajectory (ALT) models were followed together with the technical report provided by Morin and colleagues (2011). First, univariate Latent Growth Curve (LCMs) Models were tested for executive control, delay ability and RSA. Second, autoregressive (AR) models were tested with each of these three variables, testing the time-varying effects. Third, ALT models were estimated for each of these three variables, which is simultaneously testing latent growth curve and autoregressive models. Finally, the bivariate models for latent growth curve models, autoregressive models, and ALT models were tested.

RESULTS

AIM I

To examine the relations of executive control, delay ability, and RSA across time points, the relations among each other, and the relations with potential covariates are reported in Table 1. Higher family income, maternal education, and child cognitive ability at Time 1 were significantly related to higher levels of executive control at each time point. Measures of executive control from each time point were moderately correlated with each other. There was a similar pattern for RSA and delay ability in that Time 1-3 RSA and Time 1-3 delay ability were modestly correlated. Next, the relation between the two effortful control measures, executive control and delay ability, were examined in order to confirm that examining them separately in relation to RSA is warranted. Executive control and delay ability were only moderately correlated with each other at each time point, suggesting that these are not redundant measures. Therefore, a different pattern of relations of executive control and delay ability with RSA was possible. Finally, prior to considering the cross lagged paths between executive control and RSA and delay ability and RSA, these correlations were examined. There were no significant relations of executive control at any time point with RSA at any time point. There was only one significant correlation between Time 1 delay ability with Time 3 RSA, but this was small in magnitude, r = .19, p =.03. Because there were essentially no significant correlations between these measures, it is unlikely that including cross lagged paths would be significant improve the fit of the models such that cross-lagged association are supported. (i.e. bivariate autoregressive models: executive control Time 1 predicting RSA Time 2, RSA at Time 2 predicting executive control at time 3, etc), although it is possible that they predict each other when examined with growth curve models (i.e. ALT model).

Table 1. Correlations among executive control, delay of gratification, RSA and covariates.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Executive control 1	--	--	--	--	--	--	--	--	--					
2. Executive control 2	.50*	--	--	--	--	--	--	--	--					
3. Executive control 3	.51*	.55*	--	--	--	--	--	--	--					
4. Delay 1	.28*	.36*	.30*	--	--	--	--	--	--					
5. Delay 2	.26*	.24*	.34*	.50*	--	--	--	--	--					
6. Delay 3	.10	.22*	.16*	.42*	.44*	--	--	--	--					
7. RSA 1	.17	.10	.05	-.01	-.10	-.05	--	--	--					
8. RSA 2	-.11	.03	-.04	-.07	-.08	-.10	.36*	--	--					
9. RSA 3	-.12	-.11	-.10	-.19*	-.13	-.09	.33*	.47*	--					
10. Child Sex	.04	-.01	-.06	-.10	-.05	-.22	-.12	.05	-.03	--				
11. Child Cognitive Ability	.50*	.51*	.55*	.34*	.28*	.18	.10	.02	-.12	-.02	--			

12. Family income	.23*	.21*	.19*	.26*	.21*	.05	-.13	-.06	-.15	.02	.23	--		
13. Maternal Education	.17	.22*	.25*	.25*	.19*	-.02	-.19	-.06	-.08	.01	.21	.49*	--	
14. Maternal Self control	.02	-.02	-.13	-.10	-.16	-.13	-.09	.04	.14	-.02	-.05	-.01	-.01	--
Mean	.27	.48	.69	.61	.77	.79	4.80	4.97	5.05	--	.23	8.09	6.49	3.72
SD	.14	.20	.17	.25	.23	.20	.44	.52	.54	.50	.08	4.00	1.75	.47

Abbreviations = RSA = RSA
*p < .05, ** p < .01

Univariate models

Unconditional Models

Prior to examining the bivariate growth of executive control with RSA and delay ability with RSA, univariate models for each variable were examined. First, univariate LGC models were tested prior to the inclusion of covariates to examine the linear growth trajectory of executive control, delay ability, and RSA. Figures 9 through 11 graphically depict growth for each individual on the three variables as well as the mean trajectory. From visual inspection, executive control and RSA demonstrate linear growth. However, inspection of delay ability does not reveal linear growth but rather demonstrates many patterns of change. Although the mean line increases over the three time points, there appear to be several different patterns of change.

Statistically, latent growth curve models were used to examine the trajectories of growth for executive control, RSA, and delay ability. The unconditioned growth models were specified so that the intercept was set to represent initial status at age 3 and the slope was set to represent change over three equally spaced time points (slope factor loadings of 0, 1, 2). Results are reported in Table 2. For executive control, chi-square and CFI reveal that linear growth models fit. The intercept and slope was significantly different from zero. The variance around the slope was significant. For delay ability, the model fit poorly. An intercept only model was tested instead, thereby modeling whether the intercept differed significantly from zero and if there was significant variability around the intercept. The slope of delay ability was not modeled because the variability around the slope was not significant, despite the mean level increase over time. Rather, there are several patterns of change. Chi-square and CFI demonstrate acceptable fit for a delay ability intercept only model. The variance around the intercept was significantly different from zero. This is also reported in Table 2. Finally, a linear growth curve model fit adequately for RSA. However, the variance around the slope was not significant meaning children's RSA is increasing uniformly across participants. Taken together, the growth and variability suggests that development of executive control and RSA may be shaped by other factors.

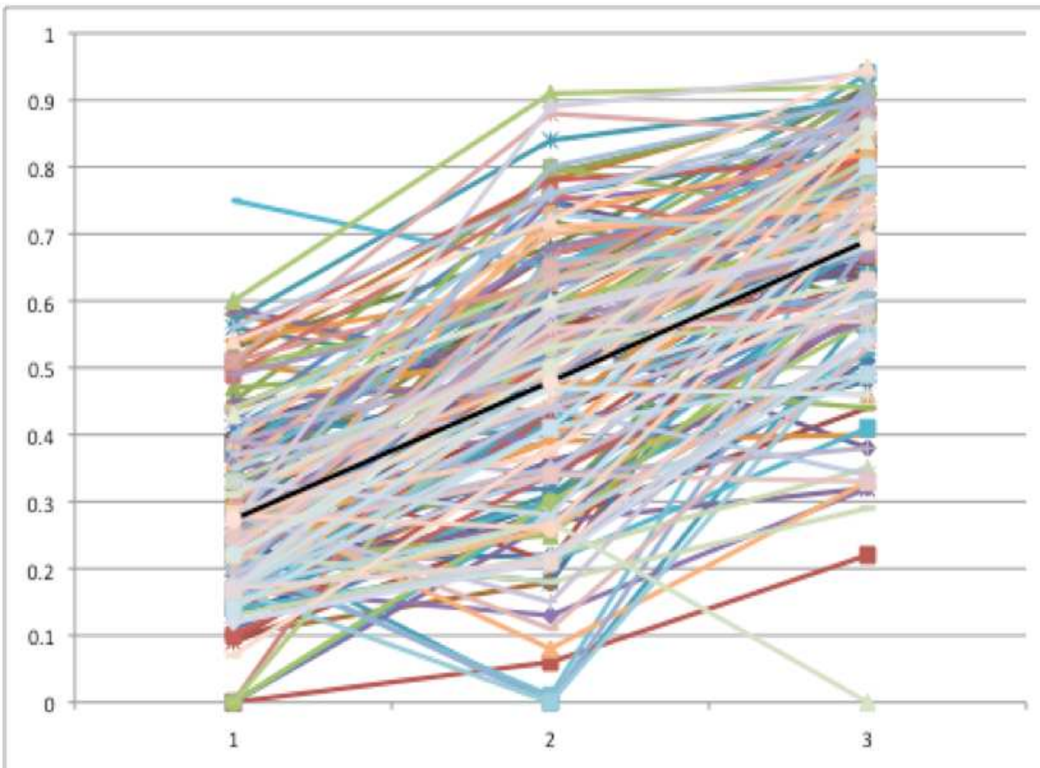

Figure 9. Executive Control across Time 1 – 3. Black line represents mean.

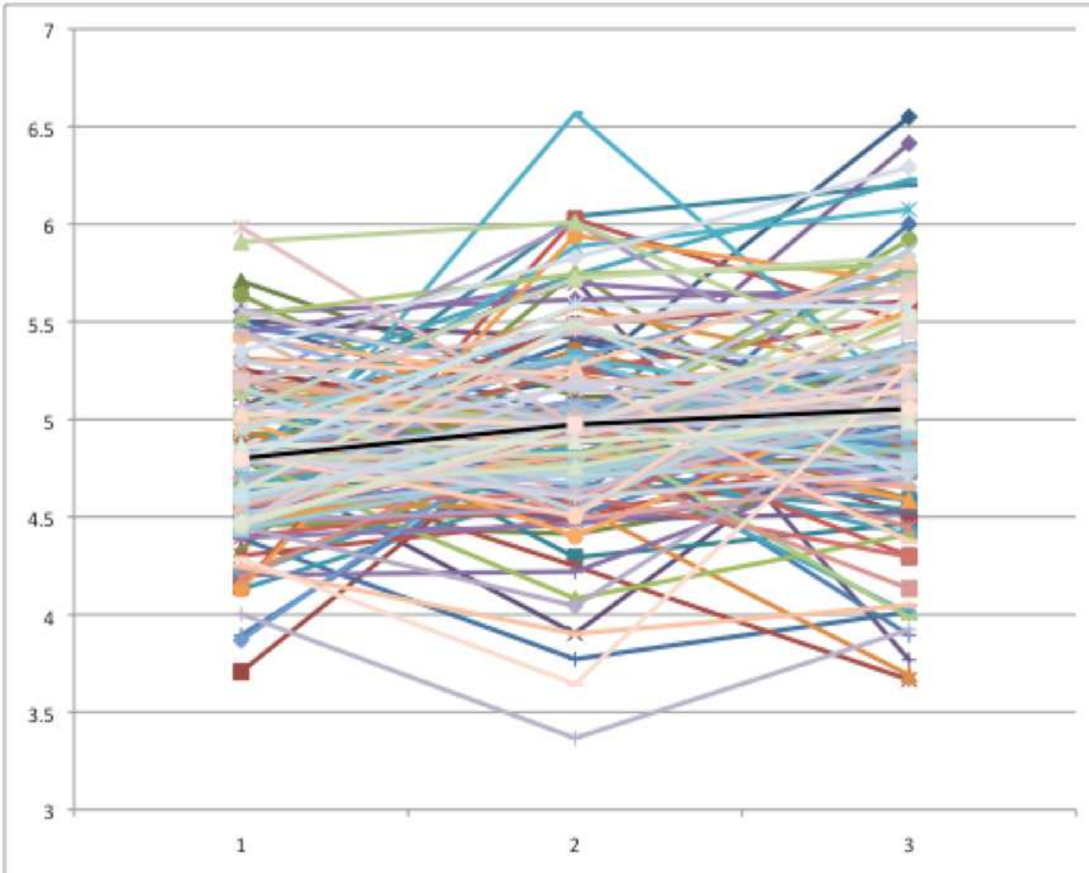

Figure 10. RSA across Time 1-3. Black line represents mean.

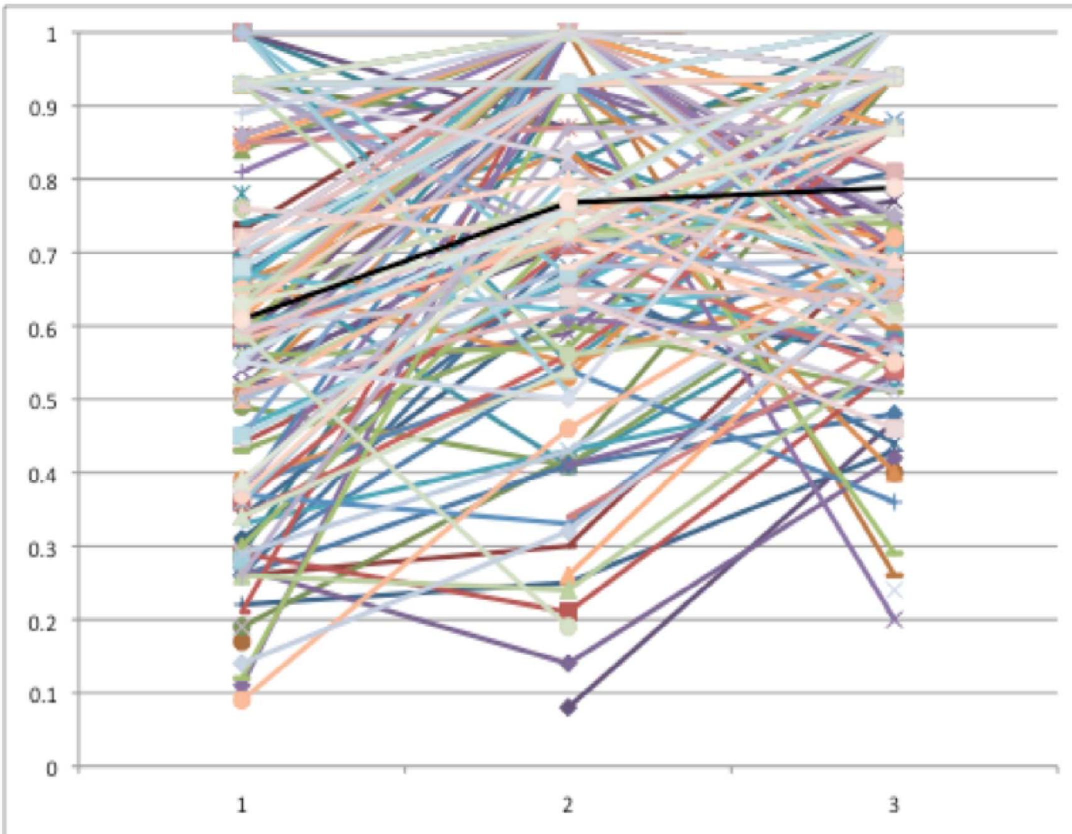

Figure 11. Delay ability across Time 1-3. Black line represents mean.

Table 2. Unconditioned Latent Growth in Executive Control, RSA, and Delay Ability

	Model Fit		**Intercept Factor**		**Slope Factor**	
	χ^2 (1)	CFI	M (SE)	Variance (SE)	M (SE)	Variance (SE)
Executive Control	.21	1.00	.27*** (.01)	.02*** (.00)	.21*** (.01)	.01** (.00)
RSA	1.57	.99	4.82*** (.04)	.09** (.04)	.13*** (.03)	.03 (.02)
Delay Ability	17.69*	.77	.63*** (.02)	.04*** (.01)	.09*** (.01)	.00 (.00)
Delay Ability-Intercept only Model	3.24	.97	.63*** (.02)	.02 (.04)*	--	--

Reported means and variances are unstandardized values.

*p < .05, **p < .01, ***p < .001

Conditional Univariate Growth Models. Next, covariates were examined for possible inclusion for subsequent models. The LGC models for executive control, delay ability and RSA were each tested with growth factors conditioned on the following covariates: child sex, family income, maternal education, child cognitive ability, and maternal self-control. Covariates with significant associations with growth factors were retained for subsequent analyses. Cognitive ability predicted the executive control intercept ($\beta = .59$, $p < .01$), RSA intercept ($\beta = .29$, $p < .05$) and slope ($\beta = -.39$, $p < .05$), and delay ability intercept (intercept only model; $\beta = .30$, $p < .05$). Lower maternal self-control predicted the delay ability intercept ($\beta = -.21$, $p < .05$). Although income was not significantly related to any of the growth factors, it was retained given the focus on income in the larger study. In addition, when examined individually, income was in fact related to the executive control intercept ($\beta = .27$, $p < .05$), but was not significant when cognitive ability was also included in the model.

Univariate Autoregressive Models

Prior to testing the bivariate autoregressive models (i.e. cross lagged paths), univariate autoregressive models were tested, which examines whether relative changes from Time 1 to Time 2 predict relative changes from Time 2 to Time 3. Neither the executive control, RSA, nor delay ability autoregressive models demonstrated adequate fit to the data. The data was explored further to understand why the autoregressive model—or a simplex model did not fit the data for executive control, delay ability and RSA. A simplex model assumes that the connection between the initial and later measurements weakens over times, thus predicting a gradual decline in inter-measure correlations for later measurements and for measurements farther apart (i.e. Time 1 and Time 3; Hayduk, 1994; Raykov, 2010). When examining the correlations within the executive control, delay ability, and RSA matrix, this is not the pattern. To explain this example, the correlation matrix for executive control will be explored.

Table 3. Correlations among executive control to illustrate modeling problems with autoregressive modeling

	1	2	3
1. Executive control 1	--	--	--
2. Executive control 2	.50*	--	--
3. Executive control 3	.51*	.55*	--

Here, it can be seen that the relation of Time 1-3 executive control does not degrade over time. In fact, for this model to adequately fit (i.e., the observed model being compared to the expected model) would be that $\rho 21 * \rho 23 = \rho 31$. Mathematically from above, to have been achieved an adequately fitting model, we would have expected that .50 * .55 = .275. The relationship between executive control at Time 3 with Time 1 is much higher in magnitude than .275. This discrepancy between the expected versus the observed led to poor fitting models. An autoregressive---or simplex model—does not explain the developmental process of the three self-regulation variables. Despite the autoregressive models not working, a bivariate autoregressive model (i.e. Time 1 executive control predicting Time 2 RSA) was nonetheless attempted. This model did not converge.

Univariate Autoregressive Latent Trajectory Models

In order to examine an integrated model of growth—the overall growth trajectories of effortful control and RSA as well as the time specific variations, an ALT model was tested. Models did not converge for either executive control or RSA. This suggests that an ALT model does not accurately describe the overall pattern of growth for this data. This is likely a result of the autoregressive paths fitting poorly. The lack of convergence could have also resulted from a lack of power.

Table 4. Results from the Univariate Latent Curve Models (LCM), Autoregressive Models and Autoregressive Latent Trajectory (ALT) Models. ++

	X2(df)	**CFI**	**TLI**	**RMSEA**	**SRMR**
Executive Control					
LCM	4.08(4)	1.00	.99	.01	.04
Autoregressive	60.12(7)*	.74	.55	.21	.12
ALT+					
RSA					
LCM	2.99(4)	1.0	1.1	.00	.03
Autoregressive	4.95(1)*	.92	.06	.15	.04
ALT+					
Delay Ability-intercept only model					
LCM	7.8(5)	.97	.95	.06	.07
Autoregressive	12.25(5)*	.92	.86	.09	.06
ALT					

*$p < .05$, ** $p < .0$

+ model did not converge; ++

note: the values for the LCMs reported in Table 4 differ from the values presented in Table 2 because covariates were added to the Table 4.

Multivariate Models

Multivariate/bivariate models assessed the co-development of executive control with RSA and delay ability with RSA. Only the latent growth curve bivariate model (also known as a parallel process model) will be tested because the univariate autoregressive and ALT models either fit poorly (i.e. autoregressive) or did not converge (i.e. ALT). The bivariate models specifically examine the aims of the proposed study, which aims to uncover how components of self-regulation shape each other over time.

Aim I: Test bidirectional associations between growth in effortful control and RSA during the preschool years.

The bivariate growth models were specified so that the intercept for both executive control and RSA were set to represent initial status at age 3 and the slope was set to represent change over three equally spaced time points (slope factor loadings of 0, 1, 2). Covariates that were significant in the univariate models were retained for the bivariate models. Entered within the same model, executive control slope was regressed on RSA intercept and RSA slope was regressed on executive control intercept. Again, chi-square and CFI reveal that linear growth models fit. The results from the two sets of multivariate models (executive control with RSA and delay ability with RSA) are reported in Table 5. The bivariate latent curve model demonstrated adequate fit. In contrast to the hypotheses, higher executive control intercept was negatively associated with RSA slope ($\beta = -.54$, $p < .05$). The intercept of RSA did not predict the slope of executive control ($\beta = -.22$, n.s.). The slope of RSA with the slope of executive control was not significant ($\beta = .22$, n.s.). In order to understand the negative relation between the intercept of executive control with the slope of RSA, the data was further explored. The data was plotted to demonstrate the mean slope level of children who had low, mean level, and high levels of executive control. Children with lower levels of executive control had lower starting mean levels of RSA but had the greatest growth. In contrast, children with high levels of executive control had the highest starting RSA levels and had the least growth in RSA.

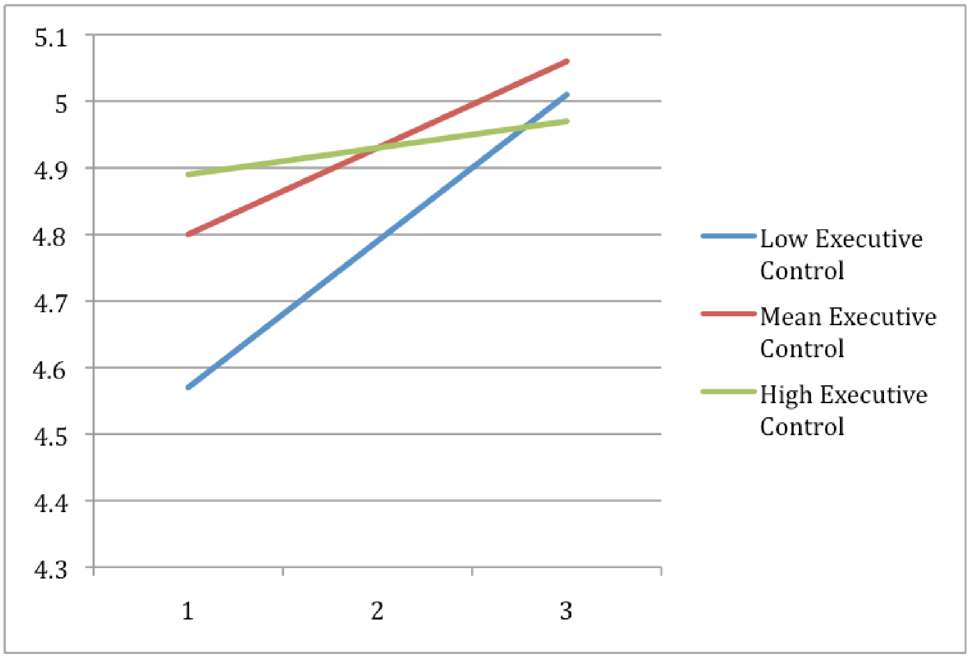

Figure 12. Plot of high, mean, and low executive control with the slope of RSA. Y-axis is RSA.

Next, the co-development of delay ability with RSA was tested. Covariates were retained as identified in the univariate latent growth curve models. Recall that the univariate growth model for delay ability indicated that there was not systematic linear growth in delay, but rather a model that included only an intercept (mean level at the initial time point) provided a better fit to the model. Therefore, the co-development between delay ability and RSA was tested in a model specified such that initial levels of delay ability were tested as predictors of growth in RSA, but not vice versa. Therefore, this model was unable to test whether the intercept of RSA predicted the slope of delay ability. This model demonstrated adequate fit, although the intercept of delay ability did not predict the slope of RSA.

Table 5. Multivariate latent growth curve models for executive control with RSA and delay ability with RSA

	X2 (df)	CFI	TLI	RMSEA	SRMR
Executive Control with RSA	17.62 (15)	.99	.98	.03	.06
Delay of Gratification with RSA	19.20	.98	.96	.04	.07

AIM II

In the second aim of this study I examined whether the growth factors of effortful control and RSA predicted adjustment. Prior to testing these relations, correlations of effortful control and RSA with the Time 1 and Time 3 outcome variables were examined (Table 6). From the correlations, only delay ability at Time 2 was related to lower externalizing problems at Time 3 and greater social competence at Time 1. Time 1 mother report of child anxiety was related to lower levels of RSA. There were no other significant relations.

Table 6. Correlations of effortful control variables and RSA with outcome measures at Time 1 and Time 3.

	DEP1	**DEP3**	**ANX1**	**ANX3**	**EXT1**	**EXT3**	**SOC1**	**SOC3**
EC1	-.02	-.01	.04	.05	-.12	-.04	.11	.00
EC2	-.04	.00	.02	.07	-.06	-.05	.12	-.07
EC3	-.05	-.08	-.04	.00	-.16	-.08	.11	.06
Delay 1	.01	.07	.08	.03	-.05	-.09	.09	-.12
Delay 2	-.12	-.03	-.00	.09	-.14	-.21*	.17*	.02
Delay 3	-.03	.05	.01	.12	.01	-.10	.06	-.01
RSA1	-.06	.03	.15	.08	-.03	.08	.05	.03
RSA2	-.11	-.04	-.01	-.03	.12	-.07	-.08	.04
RSA3	-.10	.03	-.20*	-.02	.02	-.03	-.02	.06

*p < .05, ** p < .0

Abbreviations: DEP =Depression score; ANX = Anxiety; EXT = Externalizing; SOC = Social Competence; RSA = RSA

Despite the lack of significant relations, growth models were tested as predictors of adjustment outcomes as it was possible the growth of executive control and RSA predicted adjustment outcomes. To do this, I examined the whether the univariate growth models predicted changes in adjustment problems (depression, anxiety, and externalizing) and social competence, controlling for the Time 1 corresponding adjustment measure (reported below; Table 7).

For instance, the covariates, Time 3 depression was regressed on Time 1 depression and the executive control intercept and slope. Executive control intercept and slope did not significantly predict changes in from Time 1 to Time 3 depression scores. These steps were repeated for anxiety, externalizing, and social competence. Next, these steps were repeated for delay ability (intercept only model) and RSA with each adjustment outcome.

Table 7. Model fit statistics and standardized parameter estimates for conditional univariate latent growth curve models with adjustment outcomes and social competence

	$\chi 2$ (df)	**CFI**	**TLI**	**RMSEA**	**SRMR**	**β Intercept***	**β Slope***
Executive Control							
Depression	3.72(4)	1.00	1.00	.00	.04	.02	-.11
Anxiety	3.79(4)	1.00	1.03	.00	.04	.01	-.04
Externalizing	3.93(4)	1.00	1.00	.00	.04	.05	-.02
Social Competence	5.59(4)	.99	.98	.05	.04	.00	.11
Delay Ability^{+}							
Depression	9.93(7)	.98	.96	.05	.06	.08	--
Anxiety	11.84(7)	.96	.93	.07	.06	.09	--
Externalizing	10.35(7)	.97	.95	.05	.07	-.17	--
Social Competence	9.34(7)	.98	.97	.06	.06	-.11	--
RSA							
Depression	2.35(4)	1.00	1.06	.00	.02	.05	.06
Anxiety	4.83(4)	.99	.97	.04	.03	-.08	.21
Externalizing	7.00(4)	.97	.89	.07	.03	.08	-.25
Social Competence	4.15(4)	.99	.99	.02	.02	.09	.04

+ An intercept only model was tested ; * Standardized β are provided. All were n.s.

The bivariate models were tested next (Table 8). Specifically, Time 3 depression was regressed on the covariates, Time 1 depression and the intercept of executive control and RSA and the slope of executive control and RSA. The effects of the intercept and slopes of executive control and RSA on Time 3 depression were not significant. The effects of the intercept and slopes of executive control and RSA on Time 3 anxiety was also not significant. For externalizing problems, the model did not converge unless Time 1 externalizing behavior problems were removed from the model. After Time 1 externalizing was removed from the model, the effects of the intercept and slope of executive control and RSA on Time 3 externalizing were not significant. The model for social competence did not converge.

A bivariate model was conducted testing the effects of the intercept of delay ability (intercept only model) and the intercept and slope of RSA on Time 3 outcomes (Table 9). Although all models fit adequately, there were no significant predictors of Time 3 adjustment outcomes.

Table 8. Model fit statistics and standardized parameter estimates for conditional bivariate executive control and RSA latent growth curve models with adjustment outcomes and social competence

	X2 (df)	**CFI**	**TLI**	**RMSEA**	**SRMR**	**β EC Intercept***	**β RSA Intercept***	**β EC Slope***	**β RSA Slope***
DEP	12.09(15)	1.00	1.03	.00	.04	.16	-.04	-.18	.18
ANX	14.71(15)	1.00	1.00	.00	.04	.24	-.18	-.15	.33
EXT[a]	11.68(13)	1.00	1.02	.00	.04	-.13	.02	-.06	-.14
SOC COM[b]									

DEP = Depression; ANX = Anxiety; EXT = Externalizing; SOC COM = Social Competence; a = Time 1 externalizing not included in the model; b = model did not converge; * Standardized β are provided. All were n.s.

Table 9. Model fit statistics and standardized parameter estimates for conditional bivariate delay ability and RSA latent growth curve models with adjustment outcomes and social competence

	X2 (df)	**CFI**	**TLI**	**RMSEA**	**SRMR**	**β Delay Intercept***	**β RSA Intercept***	**β RSA Intercept***
DEP	20.32(21)	1.00	1.01	.00	.05	.13	.06	.07
ANX	22.87(21)	.99	.98	.02	.06	.12	-.09	.22
EXT	26.15(21)	.97	.95	.04	.06	-.17	.01	-.24
SOC COM	22.27(21)	.99	.99	.02	.05	-.09	.08	.04

DEP = Depression; ANX = Anxiety; EXT = Externalizing; SOC COM = Social Competence

* Standardized β are provided. All were n.s.

DISCUSSION

In this study, I examined the bidirectional growth of effortful control and RSA during the preschool period. In addition, growth of the components of effortful control and RSA were tested as predictors of adjustment problems and social competence. Results of latent growth curve models indicated significant linear growth in executive control and RSA over time, but not in delay ability. In addition, initial levels of executive control were negatively associated with growth in RSA. Adjustment outcomes were not significantly predicted by initial levels or growth of executive control, delay ability, or RSA. The results found in this study point to the complex relation between the growth of RSA and effortful control which reflect the autonomic and cognitive forms of regulation, respectively. These findings may provide partial support for polyvagal theory in that children with lower levels of executive control had to recruit from older autonomic forms of regulation, potentially setting a pattern of greater use and reliance on RSA. A developmental pattern in which older physiological mechanisms are strengthened may confer risk for their emotional development at a later time point not captured in the current study.

Growth in Components of Self-regulation

One major aim of this study was to determine whether growth in effortful control and RSA predicted growth in the other. Prior to examining how the growth in each was related to the other, I first examined their individual patterns of change across time. As expected, there was significant growth in executive control across the 18 months examined. Importantly, there was individual variability in the rate of growth (variability in the slope factor) that was unrelated to the intercept. This suggests that children varied in their patterns of growth independent of their level of executive control at the start of the study. Thus, other factors, including RSA and the covariates examined, might contribute to children's pattern of growth.

This finding both compliments and extends our understanding of the growth of effortful control at this point of development. First, it compliments what others have shown in that executive control demonstrates both *change* (Li-Grining, 2007), in that most children are increasing in this capacity, and *stability,* in that there were moderate correlations across the three time points (Eisenberg, et al., 2005). The significant rate of growth of executive control also supports that the 3-6 year age span is a critical development period for growth in executive control. The current study extends our knowledge about executive control in that it is the first to demonstrate growth, and not just changes in executive control occurring during the preschool period, as evidenced by employing a latent growth curve model.

Interestingly, delay ability did not follow the same growth patterns as executive control. The variance around the slope factor for delay ability was not significantly different than zero. Upon visual inspection, there were multiple patterns of change across the time points, with some children increasing, others decreasing, and others demonstrating little or no change. This finding is consistent with the few studies that have examined stability and change in delay ability. In a demographically diverse sample with the most similar methodological approach to the current study, Li-Grining (2007) found that for children ages 2-4 (and measured 16 months later), time 1 and 2 delay ability were correlated at $r = .40$ and that children grew about ½ standard deviation across the two time points. However, the change was more modest for 3 and 4 year old children and more robust for 2 year olds. This study points to the likelihood that the age range assessed in the current sample could have been past the optimal range for capturing linear growth. Even if this were true, future research could utilize growth mixture modeling to explore potential groups that exhibit various patterns of change.

As delay ability and executive control are both components of effortful control, it is interesting to note that in the current sample, the pattern of growth for each during the preschool period is quite different. It appears that from ages 3-4.5, executive control exhibits a rapid period of growth, which the current study was able to observe. Delay ability, on the other hand, exhibits many patterns of change across the 3-4.5 year age span. Although many children did exhibit an increase in delay ability, a significant proportion of other children exhibited other patterns of change. The differences between growth patterns in executive control and delay ability may stem from underlying brain structures that are associated with each. It is possible that brain maturation underlying delay ability occurs at an earlier point in development compared to executive control, which stems from higher cortical brain regions (Blair, 2002). It would have been ideal to have measured both components of effortful control starting at earlier points in development. Doing so may have permitted the ability to capture more linear growth in delay ability.

Methodological differences should be considered for explaining the different patterns of growth in delay ability compared to executive control. Compared to executive control which was assessed with 6 tasks, delay ability was derived from only one task (despite there being multiple components within the task factoring into the final score). Therefore, if the child did not perform well on the delay task, there were no other measures to stabilize the child's final score. In contrast, if a child performed poorly on a single executive control task, there were several other tasks that went into the child's final score.

In regards to the other component of self-regulation, RSA also demonstrated significant linear growth. To my knowledge, there is only one other study that examined RSA with a latent growth curve model. This recent study (Hinnant, Elmore-Staton, & El-Sheikh, 2011) examined growth in RSA in 8-10 year olds, finding a non-significant slope. However, they also found marginal variability in the slope, with conditional models demonstrating that demographic factors such as race and sex influenced differences in intercept and slope. The authors suggest that changes in RSA may occur earlier in development. The significant slope found in the current data seems to suggest that we identified at least a portion of an important development period for the growth of RSA. The current data is consistent with other studies demonstrating that the preschool period is an ideal time to observe growth in RSA and that there was test-retest reliability across the 9-month assessment periods (Mezzacappa, 1998). Despite modest stability over the three time points, there was also potential for other factors to shape its growth.

In contrast to the growth models, the univariate autoregressive models were tested to determine intra-individual stability of effortful control and RSA. Specifically, these analyses tested whether changes in Time 1 to Time 2 predicted changes from Time 2 to Time 3. These univariate analyses were conducted in order to build toward testing bivariate associations, a main study aim, such as whether Time 1 effortful control predicted Time 2 RSA (cross lagged paths). However, these models did not converge, likely for two reasons. First, the correlations for each construct measured over time suggested moderate stability that was sustained over time, rather than degraded over time as implied by a simplex model. In addition, the correlations between effortful control variables with RSA were largely non-significantly, making it unlikely that these bi-directional effects would emerge as significant.

Bi-directional growth

It was surprising to find that neither of the effortful control variables was correlated with baseline RSA. Very few studies have examined the relation between effortful control and RSA.

However, the present findings are inconsistent with what is typically found as higher effortful control is related to higher levels of baseline RSA (Marcovitch et al., 2010; Mezzacappa, 1998). Although the samples in previous studies did not explicitly aim to represent the full range of income, they were demographically diverse in other regards. For instance, in the Marcovitch study (2010) with a sample size of 220, over 30% of the preschool children were African American. In the Mezzacappa study (1998), 20 children were recruited from therapeutic schools because of emotional and behavioral problems (22 children from public schools). Given the overall similarity between the samples used in past research with the current study, the inconsistency of relations between effortful control with RSA raises questions about current theoretical understanding of the interrelation of components of self-regulation (Calkins & Fox, 2002). The zero-order correlations appear to hint that the components of self-regulation are developing independently although the correlation was nearing significance. However, concluding that these components of self-regulation are developing independently would be premature. The bi-directional associations between components of self-regulation revealed a more complex picture of the interplay of development between the components of self-regulation examined in this study.

Whether executive control and RSA shape each was also examined by testing whether initial levels or growth in either factor predicted growth in the other (bivariate model). Higher initial executive control was negatively associated with the slope of RSA, which was on average increasing. The plotted data revealed that children who had lower initial executive control scores demonstrated the greatest growth in RSA. Conversely, children with the highest initial executive control scores had the least growth in RSA. Taken together, this hints at the likelihood that children who had higher initial levels of executive control also had higher starting levels of RSA

(Time 1 executive control and RSA were nearing significance) and therefore did not have room to grow. In contrast, this may also mean that children with lower executive control had to employ other methods of self-regulation, such as RSA. As polyvagal theory reviews, older physiological mechanisms for managing stress are used when more sophisticated regulatory capacities are not yet online. These associations may demonstrate that children whose executive control functions are not as developed have had to recruit overtime from the vagus nerve to regulate their stress physiology, thereby developing a pattern in which they rely on RSA as their main regulatory mechanism. Conceptualizing the findings this way suggests that executive control and RSA are interrelated, despite that within an individual child, they do not necessarily develop at the same rate.

Examining the other direction of effect, the intercept of RSA did not predict the slope of executive control. The lack of a significant finding was surprising given the posited neural connections between lower level biological processes influencing higher order executive processes (Blair, 2002). Again, polyvagal theory would have predicted that children with lower baseline RSA would have had less growth in executive control as development of more sophisticated regulatory mechanisms would have been interrupted.

Taken together, these bidirectional findings provide partial support for polyvagal theory in that children with lower executive control had to rely more on older forms of regulatory mechanisms, perhaps strengthening RSA at the expense of developing stronger executive control processes. These findings underscore the notion that developmental process can co-occur and influence each other, even when their rate of change is different. Overall, these findings run partially contrary to the hypotheses that executive control and RSA would develop at similar rates (as in children would retain their rank order). The findings from the current study again suggest that components of self-regulation are interrelated, but perhaps in a more complex manner than originally hypothesized.

Despite the negative association between the intercept of executive control and the slope of RSA, caution should be used when interpreting this result. Given that the overall mean increases for RSA were modest in this study, it is difficult to know whether the values of growth in RSA are meaningful. Despite the statistically significant finding, without more knowledge from the field as to what levels of RSA would be deemed problematic in this developmental period, it is difficult to know if these modest increases were meaningful.

Finally, a bivariate model was tested for an intercept only delay ability model with RSA. Although the model fit adequately, the intercept of delay did not significantly predict the slope of RSA (the only relation to be tested). From this finding, it appears that RSA is developing independently of delay ability.

Self-regulation, adjustment problems, and social competence

The second aim of this study was to assess how individual differences and growth in effortful control and RSA simultaneously predict depression, anxiety, and externalizing problems and social competence in young children. This aim was first addressed by examining the correlations between executive control, delay ability, and RSA with child outcomes at both Time 1 and 3. Specifically, higher delay ability at Time 2 was related to lower externalizing problems at Time 3 and higher social competence at Time 1. Time 1 mother report of child anxiety was related to lower levels of RSA at Time 3. These associations fall in line with the literature, demonstrating that higher self-regulatory capacities are associated with lower adjustment problems (Lengua, 2003, Zalewski et al., 2011; Eisenberg, et al., 2001). However, there were no other significant relations. In addition, although the latent growth curve models demonstrated adequate fit to the data, none of the intercepts or slopes of executive control, delay or RSA predicted adjustment when both effortful control and RSA were included in the models simultaneously. Taken together, the few significant associations or prediction of the self-regulation variables with adjustment outcomes and social competence is surprising. In regards to the findings with RSA, one possible reason that the current results differ from previous studies is that earlier research has used samples in which participants were specifically recruited for behavioral and emotional problems. The current participants, selected from the community, were not recruited based on any clinical measures. Therefore, the associations between RSA and adjustment outcomes may occur in clinical and not community samples. In contrast, although the relation between effortful control with adjustment outcomes has largely been studied in community samples, the developmental period studied in previous research has typically been with older children. It may be premature to see differences in adjustment outcomes, even if there are deficits in effortful control. Finally, it could hint that children lower in effortful control have utilized other mechanisms to manage their behavior and emotions.

It should be noted that when tested in the full dataset, Time 2 executive control was positively related to social competence at Time 2 (Lengua, et al., under review), however there were no other relations for executive control with a total problems score (which combined internalizing and externalizing problems). Using the full data set may yield additional significant associations.

Strengths and Limitations

A major strength of the study design was the measurement of different facets of self-regulation, namely executive control, delay ability, and RSA, across three equally distant time points, which has rarely been done to date. In addition, this study carefully tested these questions during a period known for rapid development (neural and behavioral). Using a sample recruited disproportionally for families from low income and poverty backgrounds increased the chances that we would observe different patterns of growth across time. In addition the use of an integrated model of change, a latent growth curve model and an autoregressive (simplex) model, permitted a sophisticated look at the developmental phenomena of several key self-regulatory processes.

However, as the latent growth curve and autoregressive models are complex and the minimum N was used to conduct these analyses, this may have led to some limitations in being able to detect significant findings. Although this sample was in theory adequately powered, attempting to test an ALT model with three time points and a sample of 167 is pushing statistical capacities. Given that the current analyses were attempted with a subsample of data, and that a fourth time point is currently being collected, these same analyses will be conducted again when that data become available.

Another potential limitation was only using mother report for child adjustment outcome. As developmental and clinical science seeks to use more multi-method or multi-reporter approaches, it will be important in future analyses to test these relations with teacher report and observational measures.

As mentioned before, one limitation is that delay ability was sampled from only one task. Although there were multiple components of delay that factored into the final composite score, the components were nonetheless derived from the same task. In contrast, executive control was sampled from a range of tasks that varied in difficulty, thereby potentially increasing the reliability of executive control. Delay was also one of the last tasks measured, so some children may have been fatigued by the end of entire assessment period. Using a single behavioral task to measure delay ability allows for more bias to be introduced from experimenter error, child fatigue or other sources of error may dilute our overall confidence in this construct.

Finally, results might be dependent on the subsample selected as there were some differences between the entire sample and subsample in regards to mean levels and reliability scores. Although efforts were taken to ensure that the subsample would be representative of the larger sample on income, other bias might have been introduced.

Future Directions

As stated above, a future study should include the full data set and use the fourth time point, as ALT models are ideally tested with at least 4 time points. Future work should also compare the baseline RSA measure with RSA collected during the NEPSY tasks, to be able to glean evidence if children were employing attention during the book reading. Finally, future research should look to characterize the change patterns of delay ability. Neither the latent growth curve model nor the autoregressive model did an adequate job of depicting how this variable changes over time. From visual inspection, the plotted data suggest that there may be several types or patterns of change occurring.

Implications and Conclusions

To our knowledge, this is the first study that examines the simultaneous growth of two core components of self-regulation, effortful control control and RSA, and tests their simultaneous prediction of emerging adjustment problems and social competence. As emotion and cognitive self-regulation deficits underlie most forms of psychopathology, further understanding of atypical development of self-regulation is critically needed (Posner & Rothbart, 2000). This study was poised to provide important knowledge about the development of self-regulation during a period of rapid development. Lower executive control was found to be related to lower initial levels of RSA but a higher rate of growth, whereas children who demonstrated higher initial levels of effortful control also had higher initial RSA but grew less. In addition, by examining both cognitive and emotional components of self-regulation, this study attempted to elucidate potential pathways to emerging adjustment problems and social competence, finding a few significant relations between lower self-regulation and later externalizing and anxiety problems. Overall, these findings suggest that effortful control and RSA may impact each other across development, however, the way in which they interrelate is complex. In addition, it may be too early to understand how early deficits in some forms of self-regulation lay the foundation for adjustment outcomes.

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