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Pathways to School Readiness: Executive Functioning Predicts Academic and Social-Emotional Aspects of School Readiness

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Abstract

The current study specified the extent to which hot and cool aspects of executive functioning predicted academic and social-emotional indicators of school readiness. It was unique in focusing on positive aspects of social-emotional readiness, rather than problem behaviors. One hundred four 3- to 5-year-old children completed tasks measuring executive functioning, social-emotional readiness, academic readiness, and vocabulary. As expected, age predicted executive functioning components and social-emotional readiness. Moreover, working memory and inhibitory control directly predicted academic readiness, whereas delay of gratification predicted social-emotional readiness. Working memory and inhibitory control predicted delay of gratification, consistent with the notion that simpler executive functions may set the stage for more complex executive functions. Interestingly, social-emotional readiness predicted academic readiness. These findings confirm that hot and cool aspects of executive functioning are related to social-emotional and academic school readiness.

Keywords: school readiness, hot and cool executive functioning, working memory, attention, inhibitory control, delay of gratification

Pathways to School Readiness: Executive Functioning Predicts Academic and Social-Emotional Aspects of School Readiness

Early childhood is characterized by impressive gains in children's cognitive and social development that set the stage for school readiness and success. The importance of this time period for later success has received increasing attention from educators, researchers, and policy makers in recent years. Early school success provides a firm foundation for later school success. Therefore, it is imperative to identify key aspects of early childhood development that promote school readiness. Research suggests that executive functioning is the single best predictor of school readiness (Blair, 2002; Blair & Razza, 2007). In particular, links between cools aspects of executive functioning and academic indicators of readiness are strong and pervasive (e.g., Brock et al., 2009; Kim et al., 2013; Willoughby et al., 2011). Recent studies have reported links between hot executive functioning and behavior problems (Kim et al., 2013; Willoughby et al., 2011), but only one study has focused on positive aspects of social-emotional readiness (Allan & Lonigan, 2011). As such, questions remain regarding which aspects of executive functioning are most important for positive aspects of academic and social-emotional readiness. The goal of this study was to specify how hot and cool aspects of executive functioning contribute to academic and social-emotional indicators of school readiness. This work was unique in focusing on positive aspects of social-emotional readiness, rather than behavior problems.

Executive functioning is a set of neurocognitive skills involved in goal-directed problem solving, especially in novel or challenging contexts (Carlson, Zelazo, & Faja, 2013; Müller & Kerns, 2015; Zelazo et al., 2005). To date, the vast majority of developmental research has focused on executive functioning during early childhood, documenting profound developmental increases between 3 and 5 years (Carlson, 2005; Garon, Bryson, & Smith, 2008). Although there is controversy regarding how best to characterize the components of executive functioning during early childhood, recent work has highlighted the distinction between hot and cool aspects (e.g., Zelazo & Carlson, 2013). Cool executive functioning refers to cognitive aspects of problem solving in decontextualized situations, usually involving relatively abstract, symbolic tasks. It is strongly associated with activation in lateral and anterior dorsolateral prefrontal cortex and anterior cingulate cortex. Descriptions of cool executive functioning emerged from cognitive neuropsychology and often include working memory, attention shifting or flexibility, and inhibition. We know that cool executive functioning is related to growth in literacy, mathematics, and writing during preschool and kindergarten (Blair & Razza, 2007; Fuhs et al., 2014; McClelland et al., 2007), as well as school readiness and academic achievement (Duncan et al., 2007). In contrast, hot executive functioning refers to problem solving in contexts with immediate motivational relevance, heightened emotional arousal, and/or appetitive demands, such as delay of gratification (i.e., suppressing the selection of an immediate reward in favor of a larger reward in the future). It is strongly associated with activation in the ventromedial and orbitofrontal prefrontal cortex and posterior cingulate cortex. Descriptions of hot executive functioning emerged from personality and temperament research (Beck et al., 2011; Bush et al., 2000; Hongwanishkul et al., 2005; Krain et al., 2006; Welsh & Peterson, 2014; Zelazo & Müller, 2002; Zelazo & Carlson, 2013). Delay of gratification—one aspect of hot executive functioning—is related to social aspects of school readiness (Razza & Raymond, 2013) and school achievement and social success during adolescence and beyond (Mischel et al., 1989).

Traditionally, early academic skills such as recognition of letters and numbers have been used as important indicators of school readiness. Recently, the conceptualization of school readiness has been expanded to include social and emotional aspects. Many researchers and practitioners believe that school readiness must be understood in terms of developing social-emotional and academic competence (Blair, 2002; Denham, 2006). Children high in social and emotional competence are better able to develop and maintain peer relationships and to understand and manage emotions (Denham, 2006). These skills have been linked to more positive attitudes towards school and higher achievement (Ladd, Birch, & Buhs, 1999; see Razza & Raymond, 2015 for a review).

Recent research has documented important links between executive functioning and school readiness (see Razza & Raymond, 2015 for a review). For example, Brock et al. (2009) tested kindergartners using a variety of executive functioning and school readiness measures. Their findings indicated that a two-factor model of executive functioning fit better than a single factor model, supporting the distinction between hot and cool executive functioning during early childhood. Cool executive functioning (Balance Beam and Pencil Tap) predicted math achievement (Applied Problems and Letter-Word Identification subscales from the *Woodcock Johnson Test of Achievement, Third Edition [WJ-III]*). In contrast, hot executive functioning (Toy Sort and Gift Wrap) did not predict achievement when concurrent with cool executive functioning. These findings suggest that cool executive functioning predicts academic aspects of school readiness.

In a similar study, Willoughby et al. (2011) invited 3- to 5-year-old children to complete a battery of self-regulation tasks. The researchers also obtained details regarding achievement and problem behaviors. Their results were best described by two latent factors representing hot and cool self-regulation. When considered together, structural equation modeling indicated that cool regulation (Balance Beam and Pencil Tap) was associated with achievement (Applied Problems, Letter-Word Identification, and Sound Awareness subscales from the *WJ-III*), whereas hot regulation (Snack Delay and Tongue Task) was associated with inattentive-overactive behaviors (IOWA Conners Rating Scale and Types of Aggression Rating Scale). These findings support a strong link between cool self-regulation and academic achievement. They also demonstrate a link between hot self-regulation and problem behaviors.

Recently, Kim et al. (2013) investigated relations among hot and cool executive functioning and academic performance and behavior problems. One hundred children completed executive functioning tasks at 38 and 52 months. Mothers, father, and teachers rated behavior problems and academic performance at 67, 80, and 100 months. Children completed interviews about their behavior at 100 months. Structural equation modeling revealed that scores on cool executive functioning tasks (Walk a Line Slowly, Turtle and Rabbit, Drawing, Tower, Green Signs Red Signs, Snow Grass, Day Night) predicted academic performance (MacArthur Health Behavior Questionnaire) but not behavior problems (Child Symptom Inventory-4, Dominic-R interview), whereas scores on hot executive functioning tasks (Snack Delay, Gift Wrap, Gift Bow, Gift in Bag) predicted behavior problems but not academic performance. These findings add to a growing body of literature demonstrating tight links between cool executive functioning and academic readiness, as well as hot executive functioning and behavior problems.

In contrast, Allan and Lonigan (2011) found that one single executive functioning construct representing hot and cool executive functioning (Box Search, Delay of Gratification, Less is More, Gift Delay, Grass Snow, Head to Toes, KRISP, and Walk a Line Slowly) best described their data. Moreover, this single executive functioning construct was strongly related to academic performance (Test of Preschool Early Literacy) and less strongly related to socioemotional development (Social Competence and Behavior Evaluation Short Form). These findings are important in addressing positive aspects of socioemotional development; however, they leave unanswered questions about differential links between cool executive functioning and academic readiness and hot executive functioning and social-emotional readiness.

The goal of the present study was to test the extent to which hot and cool aspects of executive functioning contribute to academic and social-emotional indicators of school readiness across early childhood. We focused on social and emotional understanding rather than behavior problems to provide a comprehensive account of relations between executive functioning and school readiness domains. That is, we wanted to ensure that the field focuses not only on preventing behavior problems but also on promoting healthy social-emotional development for all students (Razza & Raymond, 2015). We measured hot and cool aspects of executive functioning though a variety of tasks designed for preschool-aged children. Cool executive function included working memory, sustained attention, and inhibitory control; hot executive function included delay of gratification. Academic readiness was measured using preliteracy and mathematics tests, and social-emotional readiness was measured using scenarios related to social and emotional understanding. Based on this previous literature, we expected strong developmental gains in executive functioning and school readiness. We also predicted strong links between cool executive function and academic readiness. Our predictions for hot executive function and social-emotional readiness were less precise given we extrapolated from emerging findings linking hot executive function and behavior problems relevant for school contexts. Nonetheless, we expected moderate links between hot executive function and social-emotional readiness. Thus, combining these predicted effects suggested investigating a model in which cool and hot executive functioning fully (or partially) mediate the effects of age on academic and social-emotional readiness for school. Further, given that the literature does not lead to precise predictions about the relations between hot executive function and social-emotional readiness, an exploration and refinement of a full mediational model (see Figure 1) is warranted.

Method

Participants

One hundred four children (51 boys, 53 girls) ages 3.0 to 6.0 years (*M* = 4 years, 6.22 months, *SD* = 9.83 months) participated. A few children did not complete all tasks due to failure to understand instructions or refusal to complete the needed details, so 93 children had complete data for all measures (see Table 1). They represented a community sample from a small, Midwestern city and surrounding areas. Following approval from the university Institutional Review Board, children were recruited from local preschools, childcare agencies, birth announcements from the local newspaper, and a research participant database at a large public university. Most children were White (88.5%), though a smaller number were Asian (4.8%), Hispanic (1.9%), Black (1%), or Other (3.8%). Children with identified special needs and children for whom English was not their primary language were not recruited. Children received small prizes at the conclusion of their laboratory visit.

Executive Functioning Measures

Hot and cool aspects of executive functioning were assessed using a battery of age-appropriate tasks completed at our laboratory in one session that lasted 60 to 90 minutes. We recognize that this was a long session for children, so breaks were included to help keep the work manageable. Tasks were completed in one of five counterbalanced orders. The delay of gratification task always followed the others to minimize disruptions from the treats, and the vocabulary measure always was administered last given it was intended for descriptive purposes only. It is possible that fatigue led to attrition for the vocabulary task, which was always completed last. Importantly, fatigue did not lead to substantial attrition for the delay of gratification task, which was always the second to last task in our session (see Table 1).

Working Memory. Forward digit span (FDS; Carlson, 2005) was used to measure working memory, a cool aspect of executive functioning. Children were given two practice trials of two digits. If children passed the trials, then the researcher continued. If children failed both attempts, the task was ended. There were twenty test trials including lists ranging from 2 to 5 digits (i.e., 5 lists of each length). If children missed three or more in a set of five, the task was discontinued. FDS was scored live by the researcher using the total number of correct digit sequences completed (from 0 to 20). Inter-rater reliability was established by having another research assistant independently code 20 participants' responses (20% of sample) from DVD. The intraclass correlation was 1.00, indicating excellent inter-rater reliability. Forward digit span was used rather than backward digit span given precedence in the literature focusing on executive functioning during early childhood (e.g., Carlson, 2005).

Sustained Attention. The Picture Deletion Task for Preschoolers – Revised (PDTP – R), a visual search cancellation task, was used to assess sustained attention (Byrne et al., 1998). We chose to investigate sustained attention rather than attentional flexibility (which is commonly included in definitions of executive functioning) given strong links to academic domains (Reck & Hund, 2011). The PDTP- R is an eight-page booklet that presents target and distracter stimuli to measure sustained attention. Children were asked to mark the target stimuli in an array of pictures as fast as possible with a self-inking bingo marker. A pretest consisting of geometric shapes was presented on two pages. The target (triangle) and distracters (circle, square, diamond, and octagon) were presented in a randomized 10 x 6 array. There was a 5-min time limit on the pretest. Next, the test of cat postures was presented. The cat posture test contained a total of 480 cats (120 targets, 360 distracters) presented on 8 pages. Each pages had a 10 x 6 array with one cat posture as the target presented in a green box at the top of the page (i.e., side view of cat standing with tail in the air) and four cat postures (i.e., cat lying down, cat sitting, cat pouncing with tail in the air, cat facing forward with straight front legs) as the distracters for a total of 15 targets and 45 distracters per page. The stimuli were presented in a predetermined random order. Children were asked to mark each target picture with a bingo marker as quickly as possible. The test phase had a 25-min time limit. A research assistant scored the number of omission and commission errors offline using a template overlaid on each page of the booklet. Previous research suggests that errors of omission are more predictive of sustained attention, whereas errors of commission are related to impulsivity (Byrne et al., 1998); thus, errors of omission (from 0 to 120) were used as the attention variable for data analysis. Given our use of an error score, lower scores were indicative of better performance. Inter-rater reliability was assessed by having another research assistant independently code 20 participants response booklets offline. Intraclass correlation coefficients for omission and commission errors were 1.00, indicating excellent inter-rater reliability.

Inhibitory control. Day/Night Stroop was used to measure inhibitory control (Carlson & Moses, 2001). Children were instructed to say "day" to a black card with a picture of the moon and stars and "night" to a white card with a picture of the sun. Two practice trials were administered to ensure children understood the task followed by praise for correct answers and feedback for incorrect answers. Children then received 16 test trials without feedback in a fixed random order. Correct verbal responses were scored as a 1, whereas incorrect responses received a 0. The researcher scored Day/Night live and summed the responses at the end of the session (from 0 to 16). Inter-rater reliability was assessed by having another research assistant independently code response accuracy for 20 participants from DVD. The intraclass correlation coefficient was .99, indicating excellent inter-rater reliability.

Delay of gratification. Mischel's Delay of Gratification paradigm was used to measure hot executive functioning (Mischel, Shoda, & Rodriquez, 1989). Children were given a choice to wait an unspecified period of time for a larger reward or choose a smaller reward immediately. Children sat at a table while the researcher placed a place mat, a bell, and two cups with 2 or 5 small treats in front of them. The researcher explained that she must leave the room and said, "If you wait for me to come back then you can have this one (pointing to the preferred, larger number of treats). If you don't want to wait you can ring the bell (demonstrated ringing the bell) and bring me back anytime you want me to come back. But, if you ring the bell you can't have this one (pointed to preferred number) but you can have that one (pointed to nonpreferred, smaller number)." The researcher tested the child's comprehension of the task and left the testing room and went to the adjacent observation room to view close-circuit video of the child. The researcher returned to the room when the child rang the bell (n = 52), after ten minutes had elapsed (n = 51), or if the child appeared distressed (n = 1). The researcher recorded the elapsed time in seconds before the child rang the bell or the task ended (from 0 to 600 seconds). Inter-rater reliability was assessed by having another research assistant independently view 20 sessions from DVD to measure delay time. The intraclass correlation coefficient was 1.00, indicating excellent inter-rater reliability.

School Readiness Measures

Academic readiness. Academic readiness was measured using two subscales of the *Woodcock – Johnson III Tests of Achievement* (*WJ III*; Woodcock et al., 2001). The letter-word identification subtest assesses the ability to identify letters and words, and the applied problems subtest assesses the ability to solve practical math problems. The researcher scored *WJ III* live and totaled the responses. Composite scores were created by transforming raw scores for each subtest to W scores—a scale that accounts for item difficulty and ability regardless of age—and creating a mean score based on the subtests. Composite W scores were used in data analysis. Inter-rater reliability was assessed by having another research assistant independently view 20 sessions from DVD. The intraclass correlation coefficient for items on which children provided a verbal answer was .99, indicating excellent inter-rater reliability.

Social-emotional readiness. Children's social-emotional readiness was measured using social and emotional scenarios selected from a set designed for children ages 3 to 5 years (Mulstay-Muratore, 2006). Ten scenarios were used in this study, including 5 scenarios addressing "what if" and 5 scenarios "describing feelings." The first emotion scenario included these instructions: "Now we're going to look at some pictures. For the first pictures I want you to tell me how the boy or girl feels. Mary got a present. How does she feel?" The first what if scenario included the following instructions: "I'm going to show you a picture and ask you what you would do if something happened. Let's try one. What do you do when somebody drops something?" Children viewed each picture as the researcher asked the corresponding question. Children's verbal responses were coded live by the researcher. They received 1 point if they gave the correct answer. The total number of correct responses (0-10) was used in data analysis. Inter-rater reliability was assessed by having another research assistant independently score 20 children's responses from DVD. The intraclass correlation coefficient was .99, indicating excellent inter-rater reliability. Cronbach's alpha for the 10 items was .62, demonstrating acceptable internal consistency given the small number of items included.

Receptive Vocabulary Measure

The *Peabody Picture Vocabulary Test, Fourth Edition* (*PPVT-IV*; Dunn & Dunn, 2007) was used to measure receptive language. Form A includes 228 items. It was administered and scored according to standard procedures. Raw scores were used for descriptive purposes (see Table 1). Vocabulary was not included in data analyses given its strong correlation with age.

Results and Discussion

The goal of this study was to test the extent to which hot and cool aspects of executive functioning contribute to academic and social-emotional indicators of school readiness across early childhood, while accounting for strong developmental gains in these domains. Descriptive statistics and bivariate correlations for all variables can be seen in Table 1. The hypothesized path analysis model included age, the four executive functioning components as mediators, and academic and social-emotional readiness (see Figure 1). We included paths from age to all four executive functioning components based on previous demonstrations of strong developmental gains in executive functioning during early childhood (Carlson et al., 2013). We included paths from all four executive functioning components to both academic readiness and social-emotional readiness to fully test the extent to which hot and cool aspects of executive functioning predicted social-emotional and cognitive indicators of school readiness, though we expected strong links from cool executive functions to academic readiness and moderate links from hot executive functioning to social-emotional readiness. A variety of indicators suggested that this model was a poor fit for our data: The likelihood ratio χ^2 test statistic was substantial, χ^2 (8, n = 93) = 23.40, $p \approx .003$. Further, the Root-Mean-Square-Error-of-Approximation (RMSEA) was 0.19; the Comparative Fit Index (CFI) was 0.66; and finally the Non-Normed Fit Index (NNFI) was 0.12, all of which suggest a poor fit between the model and data.

Our next step was to consider whether alternative models provided a better fit. Our original model did not include paths between executive function components; however, it is quite plausible that the components are related in meaningful ways. For instance, basic executive function processes may set the stage for more complex executive functions (Dawson & Guare, 2010; Gnaedinger, Hund, & Hesson-McInnis, in press; Meltzer, 2007, 2010). With this conceptualization in mind, we allowed working memory to predict delay of gratification, which improved the model fit. Our original model also did not include direct paths from age to the school readiness outcome measures. We know there are strong developmental gains in readiness, so direct paths may be warranted. The next model included a path from age to social-emotional readiness, which again improved fit. We hypothesized that the links from cool executive functions to academic readiness would be strong and that the links from hot executive functioning to social-emotional readiness would be moderate. The next model removed paths from inhibitory control (an aspect of cool executive functioning) to social-emotional readiness and from delay of gratification (an aspect of hot executive functioning) to academic readiness, consistent with our specific predictions about hot and cool executive functions. It also removed the direct path from age to delay of gratification. These changes resulted in improved fit. Our original model did not include paths between the two aspects of readiness, despite evidence suggesting tight links among readiness domains (Bierman et al., 2008; Denham, 2006; Webster-Stratton & Reid, 2004; Welsh, Parke, Widaman, & O'Neil, 2001). The next model included a path from social-emotional readiness to academic readiness, resulting in marked improvement to fit. The next two models omitted paths from sustained attention and working memory (i.e., cool executive functions) to social-emotional readiness, consistent with our hypotheses about hot and cool executive functions, again resulting in improved fit. In the final model, we added a path from inhibitory control to delay of gratification, consistent with simple executive functions setting the stage for complex executive functions. These models were theoretically feasible. They also met empirically-based inclusion and exclusion criteria (e.g., new paths had modification indices greater than 5 and omitted paths had standardized coefficients less than .10). The final model is depicted in Figure 2. This model fits quite well according to a multitude of criteria. The likelihood ratio χ^2 test statistic was small, χ^2 (10, n = 93) = 8.94, $p \approx .54$. It is important to note that this approximate *p*-value is based on an asymptotic χ^2 distribution (see Bollen, 1989, p. 415). Despite the approximation of this probability estimate, it seems unlikely that the true *p*-value is, in fact, less than 0.05. Without relying on asymptotic distributions or tenuous assumptions, however, the ratio of the χ^2 statistic to its degrees of freedom is quite favorable at 0.894 (Jöreskog, 1993). We also considered the RMSEA to test approximate fit, (Browne & Cudeck, 1993). Our model produced an RMSEA of 0.02, providing further evidence for the fit. Additionally, the CFI value of 1.00 was very high (Hu & Bentler, 1999). Finally, the NNFI supports our conclusion of a good fit, with a value of 1.05 (Hu & Bentler, 1999). Overall, this model explained 40% of variance in social-emotional readiness and 51% of variance in academic readiness for kindergarten, adding further evidence that developmental gains and individual differences in hot and cool executive functioning are important for academic and social-emotional aspects of school readiness (Blair, 2002; Blair & Razza, 2007).

We calculated the t-value as the ratio of each parameter to its estimated standard error to provide a descriptive framework for assessing the relative size of each parameter estimate, noting the absolute value of these t-ratios with asterisks in the path diagram (see Figure 2). We expected that cool cognitive aspects of executive functioning would evince strong links with academic readiness. As expected, working memory and, to a lesser extent, inhibitory control predicted academic readiness. These findings are consistent with past results indicating that working memory is related to the development of language, spelling, writing, reading comprehension, counting, and mathematics (Bull & Scerif, 2001; Espy et al., 2004). For example, memory abilities during the preschool years predict math achievement at age 7 years (McClelland et al., 2007). Moreover, working memory and attention during the preschool years predict growth in math and reading in kindergarten (Welsh et al., 2010). Higher working memory capacities allow children to remember directions and instructions and follow-through in pursuit of goal-directed activities (Gathercole & Pickering, 2000). Moreover, higher working memory capacities help children succeed on tasks that require holding information in mind, such as building early literacy and numeracy skills (Bull, Espy, & Wiebe, 2008; Welsh et al., 2010). The findings involving inhibitory control are consistent with past research showing that inhibition measured during the preschool years predicted mathematics and letter knowledge in kindergarten (Blair & Razza, 2007). Being able to inhibit a prepotent response provides children with opportunities to engage in adaptive classroom behaviors that are necessary for academic success (Razza & Raymond, 2015).

Contrary to predictions, sustained attention was not strongly associated with academic readiness in this study. Previous research identifies attention as one of the strongest predictors of academic achievement; however, the results were based on parent ratings of attention and not observational measures (Duncan et al., 2007). Perhaps the lack of strong linkage is related to the type of attention measured in our observational task—sustained attention (i.e., omission errors in a cancellation task). Attention is a complex construct, and observational measurement in early development is difficult (Isquith, Crawford, Espy, & Gioia, 2005). Future research should continue to explore assessment of attention during the preschool years, including sustained attention and attentional flexibility. It is important to note that flexibility often is included in conceptualizations of executive function, so additional work is needed to clarify its contribution to school readiness.

As expected, delay of gratification—a hot aspect of executive functioning—predicted social-emotional readiness. Consistent with past research, children who delayed for longer periods of time had higher levels of social skills (Mischel et al., 1989; Razza & Raymond, 2013). The delay of gratification task requires high levels of self-regulation. To wait effectively for the preferred treats, children must be able to manage their emotional reactions. Past research suggests that emotion regulation predicts social skills during the preschool years (Denham et al., 2003). Thus, it is not surprising that hot executive functioning was related to social-emotional readiness (Razza & Raymond, 2013, 2015). Nonetheless, our findings represent an important contribution to the literature by showing that hot executive function is related to positive aspects of social-emotional development, which encompasses more than an absence of problem behaviors. Our findings focused specifically on young children's understanding of emotions and social interactions, which are key aspects of social success.

Interestingly, the final model included paths from working memory and inhibitory control to delay of gratification, suggesting intriguing relations among cool and hot aspects of executive functioning. Previous findings have shown that complex executive functions depend on simpler aspects, which is consistent with our findings (Dawson & Guare, 2010; Gnaedinger et al., in press; Meltzer, 2007, 2010). Age did not predict delay of gratification directly, as it did the cool executive functions. The ability to delay gratification had an indirect effect on academic readiness via social-emotional readiness. This path from social-emotional readiness to academic readiness is consistent with claims that multiple domains of readiness are important. Moreover, it confirms the importance of adaptive classroom behaviors for academic success (Razza & Raymond, 2015; Turner et al., 2013). These paths in the final model are important in that they establish indirect effects of working memory and inhibitory control on academic readiness as mediated by their effects on delay of gratification, which in turn effects social-emotional readiness, which then in turn predicts academic readiness. Future research is needed to further explicate the nature of executive functioning and its component(s) during childhood—including interrelations among components—and their relation to domains of readiness.

Overall, our findings are consistent with recent claims that executive functioning includes an assorted set of higher-order cognitive processes that support goal-directed problem solving (Marcovitch & Zelazo, 2009). In particular, our findings add to a growing body of empirical support for theoretical accounts that identify hot and cool executive functioning as separate yet complementary systems (Hongwanishkul et al., 2005; Zelazo et al., 2005; Zelazo & Carlson, 2013; Zelazo & Müller, 2002). Our results further suggest that cool aspects of executive functioning are linked directly with academic readiness, whereas hot executive functioning is linked directly with social-emotional readiness and with academic readiness by way of social-emotional readiness. Clearly, additional theoretical, empirical, and practical work is needed to understand executive functioning and its development during childhood, as well as specific links with school readiness domains. Our work suggests that probing the pathways by which executive functioning may mediate age-related gains in school readiness deserves further consideration.

Promoting School Readiness

Our findings underscore the importance of embracing academic and social-emotional aspects of school readiness. Social-emotional skills are implicated in the successful regulation of thinking and behavior necessary for school success (Blair, 2002). These skills go beyond the absence of problem behaviors. For example, cooperation, prosocial behavior, following directions, and listening are social-emotional factors important for school readiness (Rimm-Kaufmann et al., 2000). Children who enter kindergarten with greater social skills often develop more positive attitudes towards school and experience greater success adjusting to school, in addition to better grades and higher achievement (Ladd et al., 1999). In addition, research suggests that children with higher social skills are more accepted by their peers and teachers, have an easier time making and keeping friends and initiating positive relationships with teachers, and feel more positive about school (Denham, 2006; Ladd et al., 1999). Moreover, Welsh et al. (2001) found a reciprocal relationship between social and academic competence. For example, first grade academic competence predicted second grade social competence. Importantly, academic competence and social competence predicted one another from second to third grade. Together, these findings underscore the interrelated nature of socioemotional skills and academic achievement.

In addition to highlighting the importance of social skills, it is critical to acknowledge the vital role of emergent literacy and numeracy in academic success. Duncan et al. (2007) found that early math skills, followed by reading and attention, were the best predictors of academic achievement, whereas social skills was not a predictor of later academic achievement. Social skills may set the stage for school success, but we must not lose our focus on early literacy and numeracy skills. Instead, our findings support the notion that school readiness should focus on *both* academic and social skills (Blair, 2002). In fact, our findings indicate that (a) school readiness assessment should consider academic and social skills, as well as executive functioning components, (b) interventions should consider academic and social-emotional learning guidelines, and (c) classrooms should provide multiple modalities of learning that address the needs of children with differing levels of executive function, such as visual supports to remember rules and schedules, play facilitation to foster inhibitory control and social interactions, and frequent feedback to support children's attention (Daily et al., 2010). It is possible that executive functioning assessments could compliment other school readiness assessments meant to identify children needing additional support. Additionally, classroom activities could support developing executive function through storytelling, games like "Freeze Dance" that require children to inhibit actions, and songs that build on each other through repetition to enhance memory (Center on the Developing Child, 2014; Diamond & Lee, 2011).

We chose not to employ data imputation procedures to estimate missing data because it was not clear that the gain in power resulting from a larger sample size would offset potential questions about the process. Nonetheless, to assess the extent to which our modeling was limited by relying on full cases, we used Full Information Maximum Likelihood to estimate the 2.28% of data that were missing, bringing the number of cases from 93 to 104. Then, we tested the fit of the final model described above. The overall pattern of results was very similar. Interestingly, the parameter estimates and squared multiple correlations were slightly stronger, representing slightly better component fit. The overall model fit was similar, though the RMSEA was larger, perhaps indicating a slight reduction in overall fit. Our overall conclusion was that model fit was reasonable regardless of decisions regarding how best to handle missing data, lending further support for our interpretations and conclusions.

Despite revealing important details about links between executive functioning and school readiness, the present study was limited in scope and methodological approach. First, the sample size was modest, and the demographic characteristics of the sample were quite homogeneous, perhaps limiting the generalizability of results. Although many path analysis studies use much larger samples, our sample of 93 participants (with complete data) represents a reasonable ratio of participants to estimated parameters with roughly nine times as many participants as parameters, which is well within recognized guidelines for a ratio of at least five but preferably eight to ten participants per parameter (Bentler & Chou, 1988). Replicating the pattern of findings with a larger, more diverse sample would be beneficial. Another limitation resulted from the small set of measures included. Although much progress has been made with regard to measuring executive functioning during the preschool years, it remains difficult for young children to complete task batteries as lengthy as those used with adult participants. Future research should include larger, more diverse samples, additional measures that would support structural equation modeling, and longitudinal designs to understand mechanisms of change. Nonetheless, our findings expand existing early childhood research by specifying the relations among hot and cool aspects of executive functioning and school readiness domains, particularly with respect to positive aspects of social-emotional readiness. As such, these findings support the notion that executive functioning is important for school readiness and provide compelling details about the pathways to school success.

References

Allan, N. P., & Lonigan, C. J. (2011). Examining the dimensionality of effortful control in preschool children and its relation to academic and socioemotional indicators. *Developmental Psychology, 47,* 905-915.

Beck, D. M., Schaefer, C., Pang, K., & Carlson, S. M. (2011). Executive function in preschool children: Test-retest reliability. *Journal of Cognition and Development, 12,* 169-193.

Bentler, P.M., & Chou, C. (1988). Practical issues in structural modeling. In J.S. Long (Ed.), *Common Problems/Proper Solutions: Avoiding Error in Quantitative Research* (pp.161-192). Newbury Park, CA: Sage.

Bierman, K. L., Domitrovich, C. E., Nix, R. L., Gest, S. D., Welsh, J. A., Greenberg, M. T., Blair, C., Nelson, K. E., & Gill, S. (2008). Promoting academic and social-emotional school readiness: The Head Start REDI program. *Child Development*, *79*, 1802-1817.

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist, 57,* 111-127.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy abilities in kindergarten. *Child Development, 78,* 647-663.

Bollen, K. A., (1989). *Structural equations with latent variables.* New York, NY: Wiley.

Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., & Grimm, K. J. (2009). The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly, 24,* 337-349.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K.A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 136-162). Newbury Park, CA: Sage.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33,* 205-228.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibitory control, switching, and working memory. *Developmental Neuropsychology, 19,* 273-293.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4,* 215-222.

Byrne, J. M., Bawden, H. N., DeWolfe, N. A., & Beattie, T. L. (1998). Assessment of psychopharmacological treatment of preschoolers with ADHD. *Journal of Clinical and Experimental Neuropsychology, 20,* 613-627.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28,* 595-616.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development, 72,* 1032-1053.

Carlson, S. M., Zelazo, P. D., & Faja, S. (2013). Executive function. In P. D. Zelazo (Ed.), *Oxford Handbook of Developmental Psychology, Vol. 1* (pp. 1-47). Oxford, UK: Oxford University Press.

Center on the Developing Child. (2014). *Activities Guide: Enhancing and Practicing Executive Function Skills with Children from Infancy and Adolescence.* Unpublished pamphlet, Harvard University.

Daily, S., Burkhauser, M., & Halle, T. (2010). A review of school readiness practices in the states: Early learning guidelines and assessments. *Child Trends: Early Childhood Highlights, 1,* 1-12.

Dawson, P., & Guare, R. (2010). *Executive skills in children and adolescents: A practical guide to assessment and intervention* (2nd ed.). New York, NY: Guilford.

Denham, S. A. (2006). Social-emotional competence as support for school readiness: What is it and how do we assess it? *Early Education and Development, 17,* 57-89.

Denham, S. A., Blair, K. A., De Mulder, E., Levitas, J., Sawyer, K. S., Auerbach-Major, S. T., et al. (2003). Preschool emotional competence: Pathway to social competence. *Child Development, 74,* 238-256.

Diamond, A., & Lee, R. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333,* 959-964.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology, 43,* 1428-1446.

Dunn, L. M., & Dunn, D. M. (2007). *Peabody Picture Vocabulary Test, Fourth Edition.* Boston, MA: Pearson.

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contributions of executive functions to emergent mathematical skills in preschool children. *Developmental Neuropsychology, 26,* 465-486.

Fuhs, M. W., Nesbitt, K. T., Farran, D. C., & Dong, N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology, 50,* 1698-1709.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134,* 31-60.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at seven years of age. *British Journal of Educational Psychology, 70,* 177-194.

Gnaedinger, E. K., Hund, A. M., & Hesson-McInnis, M. S. (in press). Reading-specific flexibility moderates the relation between reading strategy use and reading comprehension during the elementary years. *Mind, Brain and Education.*

Hongwanishkul, D., Happaney, K. R., Lee, W. S. C., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology, 28,* 617-644.

Hu, L., & Bentler, P. M. (1991). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling,* 6, 1-55.

Isquith, P. K., Crawford, J. S., Espy, K., & Gioia, G. C. (2005). Assessment of executive function in preschool aged children. *Mental Retardation and Developmental Disabilities Research Reviews, 11,* 209-215.

Jöreskog, K. G. (1993). Testing structural equation models. In K. A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 294-316). Newbury Park, CA: Sage.

Kim, S., Nordling, J. K., Yoon, J. E., Boldt, L. J., & Kochanska, G. (2013). Effortful control in "hot" and "cool" tasks differentially predicts children's behavior problems and academic performance. *Journal of Abnormal Child Psychology, 41,* 43-56.

Krain, A. L., Wilson, A. M., Arbuckle, R., Castellanos, F. X., & Milham, M. P. (2006). Distinct neural mechanisms of risk and ambiguity: A meta-analysis of decision-making. *NeuroImage, 32,* 477-484.

Ladd, G. W., Birch, S. H., & Buhs, E. S. (1999). Children's social and scholastic lives in kindergarten: Related spheres of influence? *Child Development, 70,* 1373-1400.

Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science, 12,* 1-25.

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology, 43,* 947-959.

Meltzer, L. (2007). *Executive function in education: From theory to practice.* New York, NY: Guilford.

Meltzer, L. (2010). *Promoting executive function in the classroom.* New York, NY: Guilford.

Mischel, W., Shoda, Y., & Rodriquez, M. L. (1989). Delay of gratification in children. *Science, 244,* 933-938.

Müller, U., & Kerns, K. (2015). The development of executive function. In R. M. Lerner (Editor-in-Chief), L. S. Liben, & U. Müller (Vol. Eds.), *Handbook of Child Psychology and*

Developmental Science (7th edition), Volume 2: Cognitive Processes (pp. 571-623). Hoboken, NJ: Wiley.

Mulstay-Muratore, L. (2006). *Autism & PDD: Answering questions* (Vol. 1). East Moline, IL: LinguiSystems, Inc.

Razza, R. A., & Raymond, K. (2013). Associations among maternal behavior, delay of gratification, and school readiness across the early childhood years. *Social Development*, *22*, 180-196.

Razza, R., & Raymond, K. (2015). Executive functions and school readiness: Identifying multiple pathways for school success. In S. Robson & S. F. Quinn (Eds.), Routledge International Handbook of Young Children's Thinking and Understanding. New York, NY: Routledge.

Reck, S. G., & Hund, A. M. (2011). Sustained attention and age predict inhibitory control during early childhood. *Journal of Experimental Child Psychology, 108,* 504-512.

Rimm-Kaufman, S. E., Pianta, R. C., & Cox, M. J. (2000). Teachers' judgments of problems in the transition to kindergarten. *Early Childhood Research Quarterly, 15,* 147-166.

Turner, K., Fuhs, M. W., Farran, D., Norvell, J., & Newman, K. M. (2013). Adaptive classroom behaviors mediate effects of executive function skills on academic achievement in prekindergarten. Paper presented at the biennial meeting of the Society for Research in Child Development, Seattle, WA.

Webster-Stratton, C., & Reid, M. J. (2004). Strengthening social and emotional competence in young children—The foundation for early school readiness and success: Incredible years classroom social skills and problem-solving curriculum. *Infants & Young Children*, *17*, 96-113.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology, 102,* 43-53.

Welsh, M., Parke, R. D., Widaman, K., & O'Neil, R. (2001). Linkages between children's social and academic competence: A longitudinal analysis. *Journal of School Psychology, 39,* 463-481.

Welsh, M., & Peterson, E. (2014). Issues in the conceptualization and assessment of hot executive functions in childhood. *Journal of the International Neuropsychological Society, 20,* 152-156.

Willoughby, M., Kupersmidt, J., Voegler-Lee, M., & Bryant, D. (2011). Contributions of hot and cool self-regulation to preschool disruptive behavior and academic achievement. *Developmental Neuropsychology, 36,* 162-180.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Test of Achievement.* Itasca: IL: Riverside Publishing Co.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), Handbook of childhood cognitive development (pp. 445-469). Oxford, UK: Blackwell.

Zelazo, P. D., & Carlson, S. M. (2013). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives, 6,* 354-360.

Zelazo, P. D., Qu, L., & Müller, U. (2005). Hot and cool aspects of executive function: Relations in early development. In W. Schneider, R. Schumann-Hengsteler, & B. Sodian (Eds.), *Young children's cognitive development: Interrelationships among executive functioning, working memory, verbal ability, and theory of mind* (pp. 71-93). Mahwah, NJ: Erlbaum.

Table 1

Bivariate correlations and descriptive statistics for hot and cool executive functioning, academic readiness, social-emotional readiness, vocabulary, and age

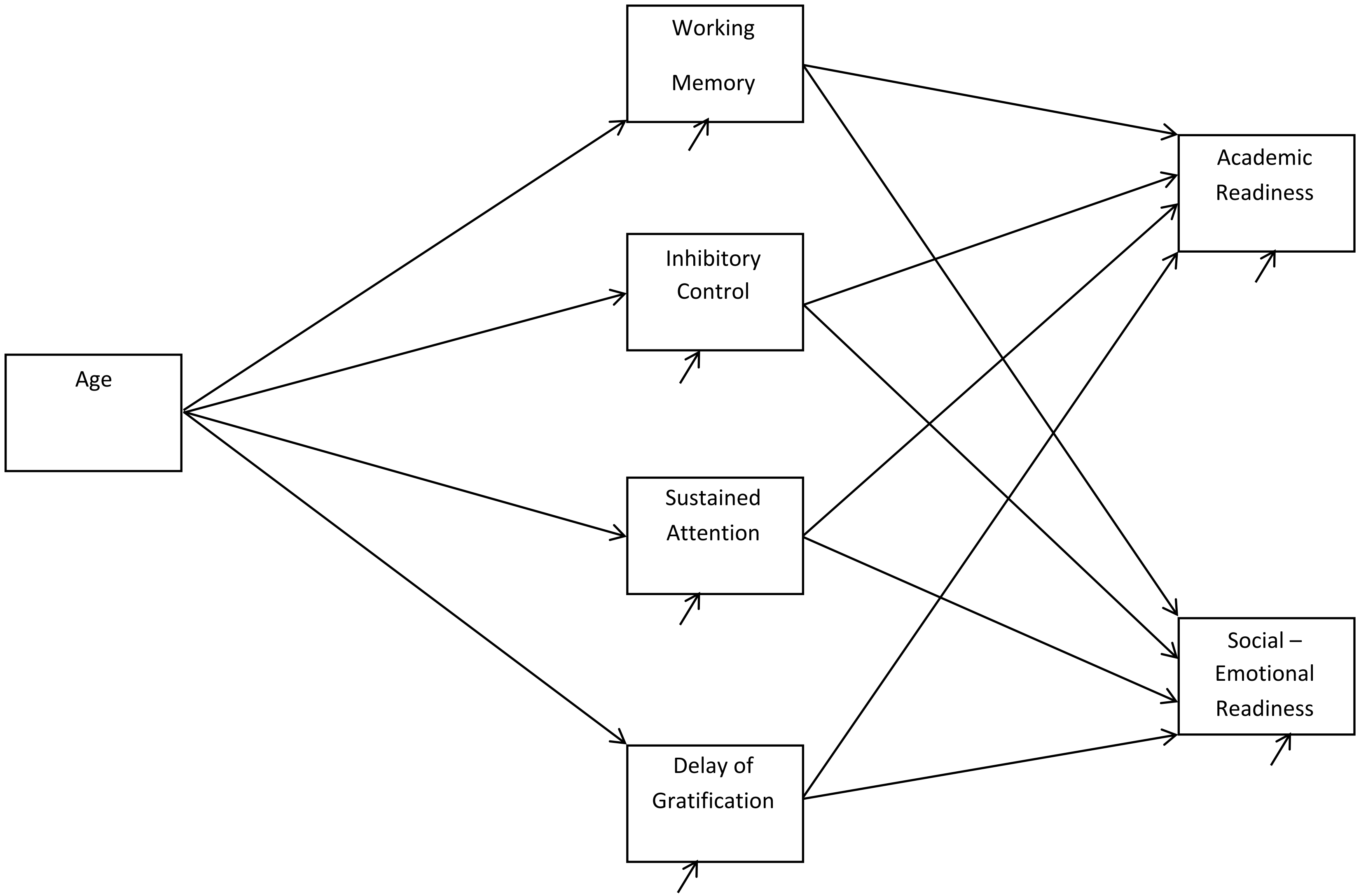
Variable	1	2	3	4	5	6	7	8
1) Working memory	---	-.09	.23*	.50**	.61**	.44**	.53**	.50**
2) Sustained attention errors		---	-.20	.08	-.03	-.15	-.11	-.24*
3) Inhibitory control			---	.28**	.35**	.34**	.32**	.35**
4) Delay of gratification				---	.41**	.47**	.46**	.33**
5) Academic readiness					---	.53**	.58**	.54**
6) Social-emotional readiness						---	.57**	.60**
7) Vocabulary							---	.63**
8) Age (in months)								---
Mean	10.10	12.69	11.91	362.36	13.35	7.28	77.86	54.22
Standard deviation	3.85	16.12	3.73	254.96	5.53	2.03	23.19	9.83
Number completed	97	97	102	103	103	101	93	104

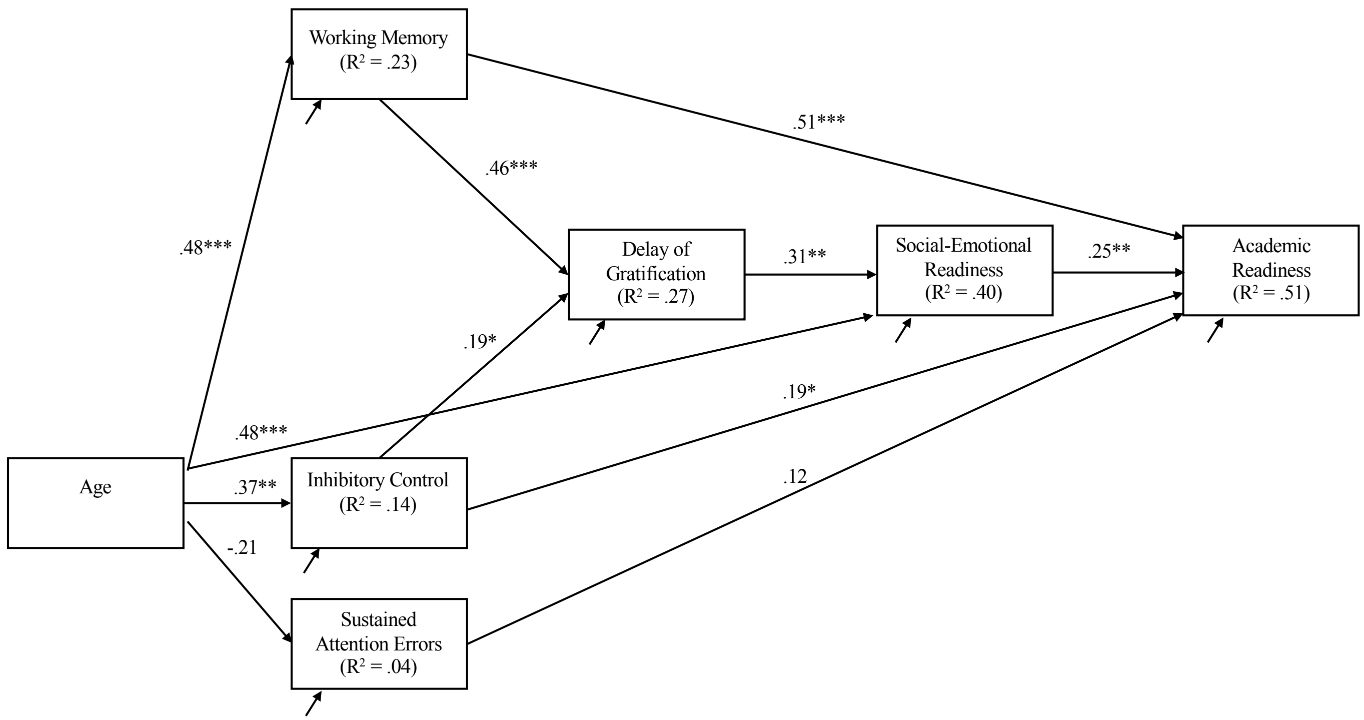
Note. Asterisks denote significant bivariate correlations (* $p < .05$, ** $p < .01$).

Figure Captions

Figure 1. Theoretical model of the mediation of age effects on school readiness by executive functioning components.

Figure 2. Standardized parameter estimates for the adopted multiple mediation model of the effects of age on academic school readiness, *N* = 93, RMSEA = .02, NNFI = 1.05, CFI = 1.00, SRMR = .06.


Working Memory
Inhibitory Control
Age
Sustained Attention
Delay of Gratification
Academic Readiness
Social – Emotional Readiness


Working Memory
(R² = .23)
Delay of
Gratification
(R² = .27)
Social-Emotional
Readiness
(R² = .40)
Academic
Readiness
(R² = .51)
Age
Inhibitory Control
(R² = .14)
Sustained
Attention Errors
(R² = .04)
.51***
.46***
.48***
.31**
.25**
.19*
.19*
.48***
.37**
.12
-.21