Abstract Title Page

Title: The Groove of Growth: How Early Gains in Math Ability Influence Adolescent Achievement

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Background / Context:

High school math skills are related to a host of adult outcomes, including job selection and salary size (Rivera-Batiz, 1992), college degree attainment (Murnane, Willett, & Levy, 1995), and even health care choices (Reyna, Nelson, Han, & Dieckmann, 2009). A number of studies, both small scale (e.g. Geary, Hoard, Nugent, & Bailey, 2013; Stevenson & Newman, 1986) and of nationally-representative student samples (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007) have reported substantial associations between school entry math ability and later elementary school achievement. If these associations are causal, they suggest that interventions designed to boost math skills before and shortly after school entry would help narrow later math achievement gaps. Indeed, both experimental and correlational studies that have investigated the effect of growth in math during early grades have found associations with later elementary school achievement (Clements, Sarama, Wolfe, & Spitler, 2013; Jordan, Kaplan, Ramineni, & Locuniak, 2009). However, questions remain regarding the persistence of the association between early growth in math ability and later math achievement due to the increasing complexity of math knowledge required to be successful in middle and high school.

Purpose / Objective / Research Question / Focus of Study:

The current study relates both preschool level math skills and growth in math skills over kindergarten and 1st grade to math achievement measured into adolescence. Although we expected that the association between early math growth and later achievement would decline over time, we find that early math growth across kindergarten and 1st grade predicts age 15 math achievement as strongly as it predicts 3rd grade achievement.

Setting:

This research was conducted in a lab setting with secondary data. The original data collection process took place in both a laboratory setting and in the focus child's home environment.

Population / Participants / Subjects:

Our data are taken from the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development (SECCYD). Participants were recruited at birth from 10 different urban and rural hospitals across the United States in 1991 (n=1364 children). A conditionally random sampling design was implemented within hospitals to ensure the inclusion of mothers who planned to work or attend school and two parent and single parent families. The data is ethnically and economically diverse, but not nationally representative. For a full discussion of the NICHD SECCYD sampling design, see NICHD Early Child Care Research Network (ECCRN) (2002) and Duncan and Gibson (2000). We used the Full Information Maximum Likelihood (FIML) procedure in Stata 12.0 to account for missing data (see Enders, 2001). To ensure that missing data did not bias our final results, we also calculated models with only non-missing data, and results were not substantively different. .

Research Design:

This study uses longitudinal data to relate early academic and attention skills to later measures of achievement using multivariate regression analyses.

Data Collection and Analysis:

Math Achievement. The Woodcock Johnson-Revised (WJ-R) *Applied Problems* subtest was used to measure math achievement (Woodcock, McGrew, & Mather, 2001) and was administered at 54 months, 1st grade, 3rd grade, 5th grade and age 15. Questions designed for the preschool and 1st grade sections of the test ask students to perform simple counting tasks, and more advanced questions include addition and subtraction problems. By age 15, the subtest items involve more advanced concepts such as solving algebraic equations and using knowledge of geometry theorems.

Our analyses adjusted for a host of control variables, including concurrent measures of academic skill growth between age 54 months and grade 1 and age 54-month demographic conditions.

Additional Academic Skills. We included WJ-R measures of language and reading ability collected at 54 months and 1st grade. The *Letter-Word Identification* subtest is a measure of alphabet and reading ability. The *Memory for Sentences* subtest measures students' short-term memory and asks students to remember sentences and phrases presented by a tape player. The *Incomplete Words* subtest as a measure of auditory processing, and the *Picture Vocabulary* subtest is a measure of verbal comprehension and crystallized knowledge. All of these subtests are designed to take approximately 15 minutes to complete and are commonly used measures of cognitive and academic skills (see Duncan et al., 2007).

Attention and Impulsivity. To measure changes in attention between 54 months and 1st grade, we use the Continuous Performance Task (CPT). Attention is measured as the proportion of correct responses to target stimuli, and impulsivity is measured as the proportion of incorrect responses to non-target stimuli. The CPT is a commonly used measure of attention, and has been used in similar research investigating school entry skills (see Duncan et al., 2007).

Cognitive Functioning. In order to account for possible bias in our estimates of academic skills and attention due to underlying correlations with cognitive ability, we also include two measures of early cognitive functioning. The Bayley Mental Development Index (BMDI) (Bayley, 1993) at 24 months and the Bracken Basic Concept Scale (BBCS) (Bracken, 1984) at age 36 months.

Additional Covariates. Information regarding child gender, ethnicity and birth weight were collected during an interview with the child's mother at one month of age. We also included a measure of the child's health taken at 24 months. The Early Infant Temperament Questionnaire (Medoff-Cooper, Carey, & McDevitt, 1993) was used to measure child temperament at 1 and 6 months and externalizing and internalizing behavior was measured at 24 months using the Child Behavior Checklist (Achenbach, 1992). Parenting quality of the home environment was assessed using the Home Observation Measurement of the Environment (HOME) at 36 months (Bradley & Caldwell, 1979). Additional covariates included familial and maternal characteristics: mother depression symptoms, education level, Peabody Picture Vocabulary Test- Revised (PPVT-R), as well as family poverty income-to-needs ratio measured at one month, family structure, and parent's marital status.

Analysis Plan

For our models examining the association between 54-month skills and later achievement, we follow the example set forth by previous work (e.g. Duncan et al., 2007), in which math achievement is a product of the math, language and attention skills a child possesses at school entry, as well as stable child and family characteristics:

$$MathAch_{ij} = a_1 + \beta_1 Math_{i54months} + \beta_2 Lang_{i54months} + \beta_3 Attn_{i54months} + \gamma_1 Family_i + \gamma_2 Child_i + e_{it}$$

where $MathAch_{ij}$ is the math achievement of the *i*th child measured at time *j* (1st grade, 3rd grade, 5th grade, or age 15). $Math_{i54months}$ is a measure of a given students' math achievement just prior to school entry; $Lang_{i54months}$ is the collection of language are reading skills for the *i*th student at school entry; $Attn_{i54months}$ is an assessment of attention skills at 54 months.

$Family_i$ and $Child_i$ are measures of family and child characteristics all collected prior to school entry. It should be noted that in our model, child characteristics includes measures of both socio-emotional skills and cognitive functioning.

Because our data contain measurements of the same academic and attention skills at both 1st grade and 54 months, we can also relate the *change* between these two measurement points to later achievement:

$$MathAch_{ij} = a_1 + \beta_1 Math_{i1st\ grade} + \beta_2 Lang_{i1st\ grade} + \beta_3 Attn_{i1stGrade} + \beta_4 Math_{i54months} + \beta_5 Lang_{i54months} + \beta_6 Attn_{i54months} + \gamma_1 Family_i + \gamma_2 Child_i + e_{it}$$

with the 54 month skills defined as before. The addition of the same measurements taken at 1st grade, $Math_{i1st\ grade}$, $Lang_{i1st\ grade}$, and $Attn_{i1stGrade}$, allow us to interpret β_1, β_2, and β_3, as estimates of the impact of *changes* in these skills on later math achievement, holding 54 month skills constant. This approach has been adopted in similar analyses, as Jordan et al. (2009) related growth measured over 6 time points during kindergarten and 1st grade to 3rd grade achievement, and Claessens et al. (2009) modeled growth during kindergarten with two measurement points. Our model is most similar Claessens et al. model, yet we measure later achievement at 3rd grade, 5th grade and age 15.

Findings / Results:

Table 1 shows descriptive statistics and correlations for our key analysis variables. For measures of math and language skills, we use the WJ-R standard scores, which have been normed to the national average (M= 100, SD= 15). In our sample, the *Applied Problems* scores at 1st grade, 3rd grade and 5th grade and the *Letter-Word Identification* score at 1st grade were significantly higher than the national average ($p < .05$). Also, the *Memory for Sentences* score at 54 months was significantly lower than the national average ($p < .05$). For our regression models, all continuous variables were standardized, and WJ-R subtests were standardized to the national norms.

(Insert Table 1 Here)

As expected, we observed high correlations between our measures of math ability. The age 15 *Applied Problems* math test was highly correlated with both the 54 month math test, $r(828)= .504$, $p < .001$, and the 1st grade test, $r(827)= .641$, $p < .001$. Furthermore, all the measures of academic skills and attention were positively correlated with math achievement, and impulsivity was negatively correlated with math ability. While all the correlations presented are high and statistically significant ($p < .001$), there was no evidence of multicolinearity problems in our fully controlled models.

We hypothesized that both 54 month math ability and growth in math skills between 54 months and 1st grade would be highly associated with math achievement through adolescence. Although we did observe these associations, the strength of the relationship between 54 month ability and later achievement diminishes by age 15, while the association between growth and later achievement maintains a high magnitude through adolescence. The different trajectories of achievement between school entry skills and growth during kindergarten and 1st grade can be clearly seen in Figures 1 and 2, respectively.

(Insert Figures 1 and 2 Here)

Table 2 presents key regression results for all fully controlled models. The shaded cells correspond to the key coefficients for both the 54 month and change models between early math ability and later math achievement. Models 1, 2, 4, and 6 show the relationship between 54 month skills and math achievement at 1st grade, 3rd grade, 5th grade, and age 15, respectively.

54-month math ability is highly associated with 1st grade math achievement (β= .40, *SE*= .04). By Age 15, this relationship has diminished by 40% (β= .24, *SE*= .04). In contrast, Models 2, 4, and 6 display the association between *growth* in key skills between 54 months and 1st grade and later math achievement. The stability of the association between early growth in math and later math achievement can be seen by the coefficient produced by 1st grade skills (the 54-month variables only serve as controls). The association between early grade growth in math and math achievement at 3rd grade is highly significant (β= .36, *SE*= .03) and remains surprisingly consistent through age 15 (β= .35, *SE*= .03).

(Insert Table 2 Here)

At 54 months, reading skills, as measured by the *Letter Word Identification* subtest were also significantly predictive of later math achievement at 1st, 3rd, 5th grade and age 15 (β= .17, *SE*= .04). When accounting for early growth in key skills, the effect of reading diminished from significant at 3rd grade (β= .17, *SE*= .03) to non-significant at age 15. A similar pattern was also observed for short-term memory, which was a positive and significant predictor of later achievement when measured at 54 months. However, growth in short-term memory was the only non-math skill that significantly predicted age 15 math (β= .11, *SE*= .03). Surprisingly, attention and impulsivity were only predictive of 1st grade achievement when measured at 54 months. While these non-math academic and attention skills should not be overlooked, only early math ability was consistently predictive of achievement at all time-points measured.

Conclusions:

We found both school entry math skills and early growth in math ability to be highly associated with later achievement. However, this association was most impressive for growth in math ability and later achievement, as early grade growth was consistently predictive of later achievement through age 15. These findings demonstrate the remarkable consistency and durability of the relationship between early math skills and later achievement, even when considering other academic skills, attention, and personal and family background characteristics such as the home environment and cognitive ability.

Although the predictive ability of early math on later math achievement was not surprising, the consistent and high magnitude of the relationship between growth in early math skills and adolescent achievement was not expected. This strong relationship implies that students who gain more skills early on are able to benefit most from future instruction in math, a subject in which learning future skills depends on the mastery of previous concepts. These findings also suggest that some students are primed to benefit most from early instruction. If kindergarten and 1st grade classroom instruction are thought of as a type of “treatment” in which learning is the desired outcome, students who respond the most to this treatment during the early schooling years appear to have a stable achievement trajectory in math through adolescence.

As with any study of longitudinal, non-experimental data, omitted variable bias is of concern. Our growth models attempt to address this concern by forcing any sources of omitted variable bias to be correlated with later math achievement and *growth* in key skills between 54 months and 1st grade. Nevertheless, models that account for skills that correlate with math achievement, such as approximate number system or executive functioning, could provide a more robust and unbiased estimate. The present study implies the need for high quality math instruction and interventions during the period in which students first begin their primary schooling, as growth during in math ability during early elementary school appears to pay large dividends for achievement into adolescence.

Appendix A. References

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Appendix B. Tables and Figures

Table 1

Descriptive Statistics and Correlations for Key Independent and Dependent Variables

	Mean (SD)	Correlation (N)				
		Applied Problems				
		54 mos	1st grade	3rd grade	5th grade	Age 15
Applied Problems						
54 months	102.94	1				
	(15.63)	(1053)				
1st grade	110.80	0.642	1			
	(17.14)	(984)	(1023)			
3rd grade	115.05	0.584	0.703	1		
	(15.00)	(934)	(933)	(1013)		
5th grade	109.31	0.561	0.707	0.758	1	
	(13.54)	(908)	(907)	(931)	(993)	
Age 15	102.92	0.504	0.641	0.650	0.729	1
	(14.22)	(828)	(827)	(838)	(851)	(887)
Letter-Word Identification						
54 months	98.93	0.584	0.527	0.468	0.449	0.450
	(13.52)	(1053)	(987)	(937)	(911)	(831)
1st grade	111.99	0.452	0.570	0.556	0.503	0.439
	(15.79)	(986)	(1023)	(935)	(909)	(829)
Incomplete Words						
54 months	96.67	0.463	0.389	0.373	0.332	0.268
	(13.63)	(1049)	(981)	(931)	(905)	(825)
1st grade	95.92	0.348	0.357	0.368	0.326	0.296
	(11.18)	(979)	(1016)	(928)	(902)	(822)
Memory for Sentences						
54 months	91.74	0.479	0.449	0.399	0.390	0.341
	(18.49)	(1050)	(984)	(934)	(909)	(828)
1st grade	98.51	0.498	0.519	0.481	0.485	0.461
	(14.94)	(979)	(1016)	(928)	(903)	(822)
Picture Vocabulary						
54 months	100.24	0.534	0.441	0.437	0.423	0.414
	(15.03)	(1053)	(990)	(940)	(914)	(834)
1st grade	105.46	0.485	0.466	0.465	0.486	0.460
	(15.57)	(980)	(1017)	(930)	(904)	(824)
Attention (CPT % Correct)						
54 months	0.72	0.343	0.313	0.262	0.252	0.231
	(0.22)	(1020)	(961)	(915)	(890)	(815)
1st grade	0.95	0.214	0.208	0.255	0.195	0.175
	(0.08)	(965)	(993)	(912)	(886)	(812)
Impulsivity (CPT % Incorrect)						
54 months	0.08	-0.302	-0.253	-0.214	-0.193	-0.177
	(0.11)	(1020)	(961)	(915)	(890)	(815)
1st grade	0.02	-0.213	-0.187	-0.220	-0.214	-0.200
	(0.04)	(965)	(993)	(912)	(886)	(812)

Note: All Woodcock-Johnson subtests are age-normed standard scores. All correlations displayed are statistically significant ($p < .001$).

Table 2

Regression Estimates for the Association between Early Academic and Attention Skills and Later Math Achievement

	1st grade	3rd Grade		5th Grade		Age 15	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Applied Problems							
54 months	0.40***	0.31***	0.13***	0.27***	0.10***	0.24***	0.08*
	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.04)	(0.04)
1st grade (Change)			0.36***		0.37***		0.35***
			(0.03)		(0.03)		(0.03)
Letter Word Id.							
54 months	0.22***	0.14**	-0.04	0.12**	-0.02	0.17***	0.06
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)
1st grade (Change)			0.17***		0.08*		0.03
			(0.03)		(0.02)		(0.03)
Incomplete Words							
54 months	0.03	0.06	0.02	0.02	-0.01	-0.03	-0.04
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
1st grade (Change)			0.08		0.03		0.03
			(0.03)		(0.03)		(0.04)
Memory for Sentences							
54 months	0.10***	0.05	-0.01	0.07**	0.00	0.07*	-0.02
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
1st grade (Change)			0.03		0.06*		0.11**
			(0.03)		(0.03)		(0.03)
Picture Vocabulary							
54 months	-0.04	0.01	0.01	-0.01	-0.04	0.02	0.00
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)
1st grade (Change)			0.05		0.09**		0.05
			(0.03)		(0.03)		(0.03)
Attention							
54 months	0.08*	0.02	-0.02	0.02	-0.01	0.02	0.00
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
1st grade (Change)			0.03		0.00		0.00
			(0.03)		(0.02)		(0.03)
Impulsivity							
54 months	-0.06*	-0.01	-0.01	0.03	0.04	0.00	0.03

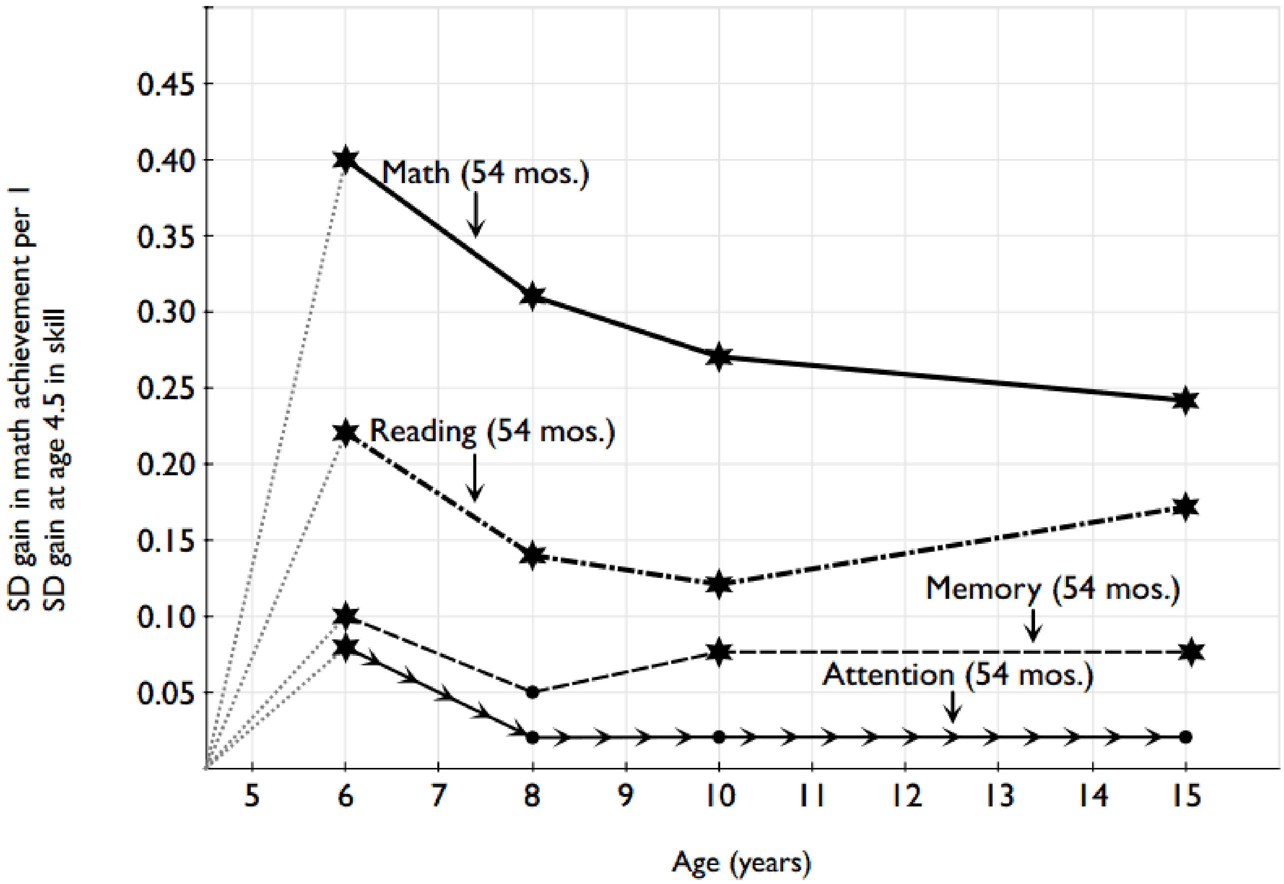
	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)
1st grade (Change)			-0.01		-0.03		-0.03
			(0.02)		(0.02)		(0.03)

Note. Standard errors are in parentheses. All models presented include the full list of control variables. All predictor and dependent variables were standardized. Shaded cells denote the key coefficients for associations between early math and later math achievement: the coefficients produced by the 54 month math skills in models 1, 2, 4, and 6; coefficients produced by the 1st grade measure of math skills (interpreted as the change between 54 months and 1st grade) in models 3, 5, and 7. Control variables include: measures of early cognitive skills (Bracken 36 months and Bayley at 24 months), gender, ethnicity, birthweight, health (24 months), internalizing and externalizing (24 months), temperament (1 month and 6 months), age at 54 months exam, home environment at 36 months, family income to needs ratio, family composition, mother marital status, mother's education, mother's PPVT score, mother's age at childbirth, mother's depression.

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Figure 1

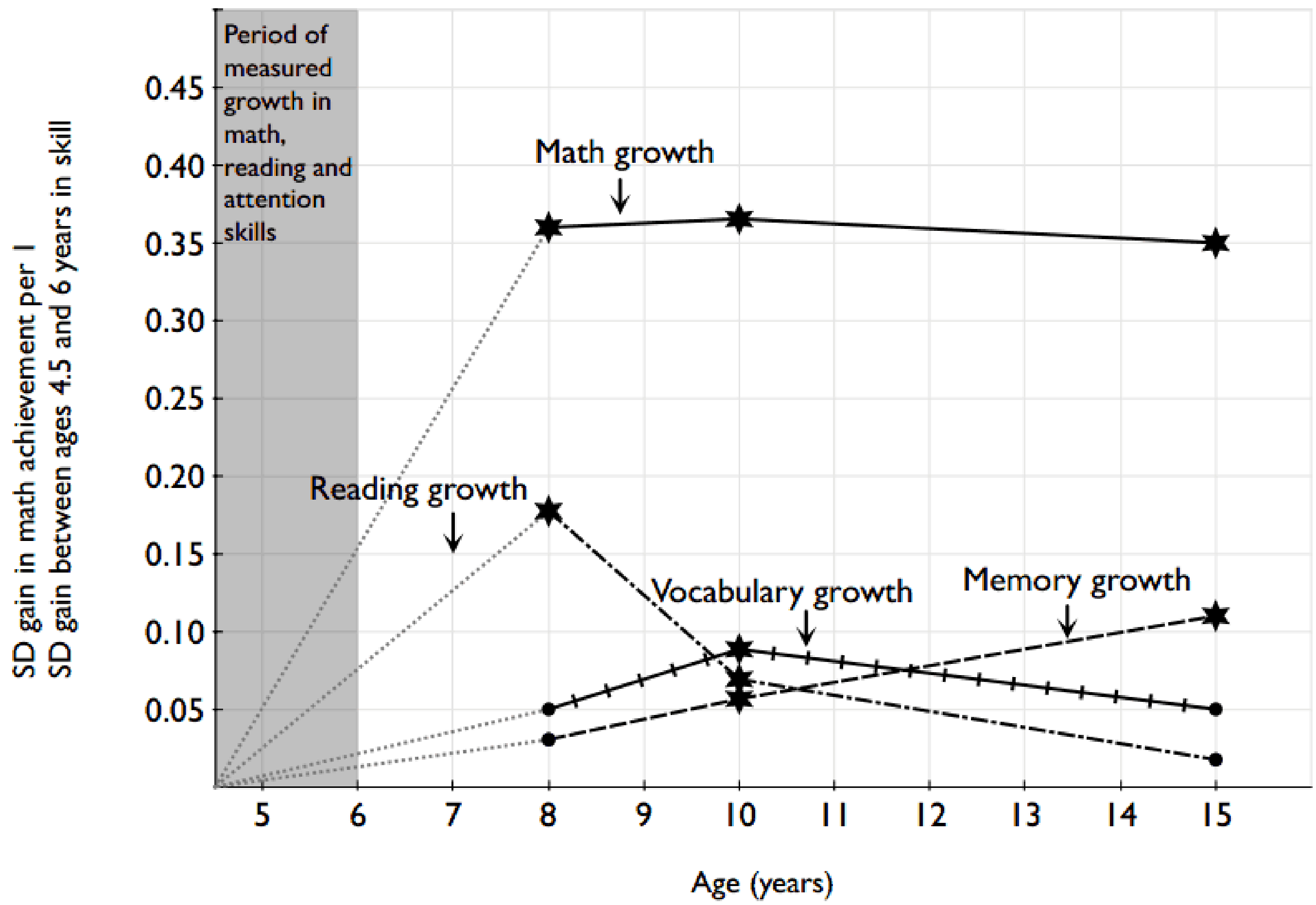
The Association between School-Entry Math, Language, and Attention Skills and Later Math Achievement



Note: Only 54 month skills producing a statistically significant (p < .05; denoted by the star symbol) positive association with later achievement are displayed.

Figure 2

The Association between 54 month – 1st grade Growth in Math, Language, and Attention Skills and Later Math Achievement



Note: Only the skills that produced a statistically significant ($p < .05$; denoted by the star symbol) positive association with later achievement are displayed.