The effects of kindergarten and first grade schooling on children's executive function and academic skill development: Evidence from a school cutoff design

Matthew H. Kim,^{a*} Sammy F. Ahmed,^b & Frederick J. Morrison^c

^a University of Kentucky
Department of Psychology
Kastle Hall
Lexington, KY 40506
United States

^b University of Michigan
Institute for Social Research
426 Thompson Street
Ann Arbor, MI 48106-1248
United States

^c University of Michigan
Department of Psychology
530 Church Street
Ann Arbor, MI 48109-1043
United States

* Corresponding author
E-mail address: matthew.kim@uky.edu (M. H. Kim)

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Abstract

Early executive function (EF) skills reliably predict school readiness and future academic success. While children's skills undergo rapid development during the transition to formal schooling, it remains unclear the extent to which schooling exerts a unique influence on the accelerated development of EF and academic skills during the early years of schooling. In the present study, a quasi-experimental technique known as the school cutoff design was used to examine whether same-aged children who made versus missed the age cutoff for school entry significantly differed on EF, reading, and math outcomes. Data from 166 pre-k, kindergarten, and first grade children ($M = 5.74$ years, 92 girls) from a longitudinal study of literacy development were analyzed. Children were assessed on EF, reading, and math skills in fall and spring over multiple school years. Results revealed unique effects of kindergarten, but not first grade, on growth in EF and reading over and above the effect of age. Schooling was unrelated to growth in math. Because kindergarten represents the first year of elementary school and children's first exposure to a formal schooling environment, kindergarten schooling may be uniquely positioned to produce greater gains in academic and behavioral outcomes compared to other grades.

Keywords: executive function, reading, math, school cutoff, quasi-experimental design, schooling

Introduction

The transition to school is marked by dramatic changes at the individual and contextual levels. During the developmental period commonly known as the “five-to-seven-year shift,” children across cultures develop increasingly sophisticated cognitive and social capacities (Sameroff & Haith, 1996). In addition to biological maturation, school-based intervention programs have been shown to improve domain-general cognitive skills such as executive functions (Diamond et al., 2019; Weiland & Yoshikawa, 2013) that are associated with academic outcomes (Ahmed et al., 2019). However, effective interventions often require substantial training and resources, and can be difficult to scale. As a result, increasing attention has focused on whether typical, practice-as-usual schooling can influence the development of executive function (EF) and academic skills.

While aspects of formal schooling—characterized by an emphasis on achievement, salience of peer comparisons, and greater expectations for independent work and self-regulated behavior—are frequently observed in first grade, recent trends indicate that these aspects emerge as early as kindergarten (Bassok et al., 2016). Therefore, examining whether kindergarten and first grade schooling exert unique influences on the development of children’s cognitive and academic abilities can yield insights into the complex interplay between context and development during the school transition period.

In Western societies where school enrollment is compulsory, disentangling the effects of schooling from age (i.e., biological maturation) was thought to be largely impossible. Because children cannot be randomly assigned to attend or not attend school, many studies have been mostly correlational in nature. However, the insight that many school districts enforce cutoff dates for kindergarten entry based on a child’s date of birth has led to the application of novel techniques

such as the regression discontinuity design (RDD) and the school cutoff (SC) method (a form of RDD). These techniques take advantage of so-called natural experiments by dividing individuals into groups based on external factors, mimicking random assignment. By comparing outcomes between the two groups of children—who are virtually the same age but differ only in their schooling experiences—valid inferences regarding the causal impact of schooling on children’s outcomes can be drawn (Morrison et al., 2019).

Our understanding of the nature and magnitude of the causal impact of early schooling on academic and behavioral skills remains limited. While schooling has consistent effects on various aspects of literacy development, we know far less about the effects of schooling on math skills. Further, schooling effects on EF appear to depend on a number of factors, such as the nature of schooling, grade level, and how EF outcomes are measured. The present study seeks to add to this scholarly conversation by using a SC design to examine whether typical kindergarten and first grade schooling has a causal impact on children’s EF, reading, and math skills, over above the effects of chronological age.

Schooling and EF development

EF refers to a broad set of higher-order cognitive skills that enable individuals to exert control over basic cognitive processing skills to flexibly adapt to fluctuating environmental demands (Miyake et al., 2000; Posner & Rothbart, 2000). Although consisting of multiple distinguishable skills (e.g., working memory, inhibition, and cognitive flexibility), EF skills work in tandem to guide thoughts and behaviors by facilitating planning, problem solving, and enabling purposeful goal pursuits (Zelazo, 2015). This complex set of skills involves storing and manipulating information, inhibiting automatic responses to the environment, and focusing and shifting attention across multiple tasks, operations, or mental sets (Diamond, 2013; Monsell, 1996;

Miyake et al., 2000). Research has identified multiple periods of accelerated growth in EF skills across the lifespan (e.g., Diamond, 2002; Jacques & Marcovitch, 2010; Montroy et al., 2016; Zelazo et al., 2004). However, the early periods of development have and continue to be a focal point of research given their relevance for school readiness and early academic outcomes. Specifically, EF skills that require the monitoring of overt, deliberate activities are particularly useful in a learning environment where students are constantly expected to monitor their behavior, pay attention, follow rules, and concentrate on various cognitive and behavioral tasks (Anderson, 2002; Blair, 2002; Blair & Razza, 2007; Diamond & Lee, 2011; Samuels et al., 2016).

Given the relevance of EF skills as for supporting children's learning and adaptation to school (e.g., Blair, 2002), there has been a growing interest in understanding the degree to which early schooling experiences contribute to children's EF growth. Although the early schooling transition period has been characterized by rapid developmental changes in EF skills (e.g., Best et al., 2011; Shing et al., 2010; Wiebe et al., 2012; Willoughby et al. 2012), it remains unclear the degree to which schooling contributes to the observed acceleration of EF skills during this developmental stage, or is a result of age-related biological maturation. Estimating the role of schooling on children's EF development can provide insight regarding the nature, timing, and development of these skills, and can inform instructional practices, curricula development, and targeted interventions. However, the few studies that have examined schooling effects on EF development using a school cutoff design have yielded mixed results. For example, Burrage and colleagues (2008) found pre-k and kindergarten effects on working memory development, but only a pre-k effect on inhibitory control. In contrast, Skibbe and colleagues (2011) found no effect of pre-k on behavioral self-regulation. In another study, Brod and colleagues (2017) found unique effects of first grade on EF task accuracy. In the present study, we contribute to this literature by

exploring kindergarten and first grade schooling effects on children's EF development using a global measure of EF.

Schooling and academic development

Studies that investigated school- and age-related effects using RDD and the school cutoff method have focused largely on children's academic skill development. The most studied academic domain across these studies has been various aspects of literacy development, from basic letter recognition and early phonological processing, to more advanced comprehension and writing skills (see Morrison et al., 2019, for a review). Not only have schooling effects been observed using intervention programs (Gormley et al., 2005; Weiland & Yoshikawa, 2013), but several studies have also demonstrated the effect of typical schooling programs on growth in reading and literacy skills across the transition to school (Burrage et al., 2008; Christian et al., 2000; Kim & Morrison, 2018; Morrison et al., 1995; Morrison et al., 1997; Skibbe et al., 2011).

Much less is known, however, about the unique effects of typical schooling experiences on children's mathematical development. Researchers have largely relied on highly specialized intervention programs to examine the impact of early schooling on children's math skills. Using an RDD, Weiland and Yoshikawa (2013) found that participation in a prekindergarten program that used evidence-based curricula and a teacher coaching system led to statistically significant improvements in numeracy and math skills. In another study, Gormley and colleagues (2005) examined the causal impact of Oklahoma's universal prekindergarten program using an RDD. The authors found that children who completed Oklahoma's statewide prekindergarten program had significantly higher scores on standardized tests of math achievement than similar aged children that missed the cut-off for prekindergarten entry. While these studies suggest that early schooling can exert a unique effect on children's math development over and above the effects of biological

maturation (and other non-schooling factors), they are less informative for our understanding of the impact of typical, practice-as-usual schooling on children's mathematical development.

Much of this work has focused on the impacts of pre-kindergarten given its role in preparing children for formal schooling (e.g., Wong et al., 2008). Fewer studies, however, have examined business-as-usual kindergarten and first grade schooling effects on children's math development. One study using a SC design showed a causal impact of first grade schooling on math skills (Christian et al., 2000). However, because those children were assessed in the 1990s, it is important to acknowledge the significant policy changes that occurred as a result of No Child Left Behind in the 2000s. Due to the greater emphasis on academic standards, these accountability pressures are likely to have migrated to earlier grades, fundamentally altering the nature of early childhood education (Stipek, 2006). Indeed, recent research has revealed that instructional features typically encountered in first grade are now increasingly present in kindergarten classrooms (Bassok et al., 2016). The present study will provide insights into whether the initial years of formal schooling—kindergarten and first grade—have causal impacts on the development of academic and behavioral skills.

Study aims and hypotheses

In the current study, we set out to investigate whether typical kindergarten and first grade schooling has a causal impact on children's EF and academic skills, over and above the effects of chronological age. While various studies have consistently demonstrated positive impacts of early schooling on children's literacy development, much less is known about the unique effects of typical schooling experiences on children's mathematical development. However, given the intervention studies that demonstrate significant improvements in numeracy and math skills as a result of participation in prekindergarten programs, we hypothesize that kindergarten children will

exhibit stronger end-of-year math skills compared to their same-aged pre-k peers. We expect to find a similar schooling effect for first grade children when compared to their same-aged kindergarten peers, and that these trends will also extend to literacy skills. For EF, despite the mixed findings in the literature based on EF subcomponents, we expect to see significant kindergarten and first grade schooling effects on a global measure of EF.

Materials and Methods

Sample

Data come from a longitudinal study of literacy development conducted in the mid 2000s. Children were recruited on a rolling basis from 13 elementary schools. Therefore, we examine data from pre-k, kindergarten, and first grade children assessed in the fall and spring over multiple years. The SC design compares two groups of children—“young” kindergarten (or first grade) children who made the cutoff for school entry, and “old” pre-k (or kindergarten) children who missed the cutoff—virtually identical in age but differing only in their schooling experiences. At the time of data collection, the age-cutoff enrollment date in Michigan was December 1. Previous studies have used either a two-month (Burrage et al., 2008; Skibbe et al., 2011) or three-month bandwidth (Brod et al., 2017; Zhang et al., 2018). In the present study, we adopt the more conservative two-month bandwidth; the “made cutoff” group consisted of children born in October and November, while the “missed cutoff” group consisted of children born in December and January. However, we also conduct robustness checks to examine whether our results are sensitive to one-month (more conservative) and three-month (more liberal) bandwidths.

The complete data set consisted of 391 children. However, for purposes of the present analysis, not all children were eligible for study inclusion. First, we removed observations from year 1 and year 5 of the study, as these observations did not include any assessment data from pre-

k, kindergarten, or first grade children; this removed 25 children ($N = 366$). Second, we removed three-year-old children and second grade children; this removed 15 children ($N = 351$). Third, we removed children who did not have a birth date within three months of the December 1 cutoff. (Even though our cutoff window was two months, we included children born within three months of the cutoff for robustness checks.) This removed 172 children ($N = 179$). Fourth, we removed pre-k children who were born in a three-month window before the cutoff (i.e., made the cutoff), as these children would not be in an analyzable group; this removed 11 children ($N = 168$). Fifth, we removed first grade children who were born in a three-month window after the cutoff (i.e., missed the cutoff), as these children would also not be in an analyzable group; this removed 2 children ($N = 166$). **Table 1** presents analytic sample sizes for each bandwidth.

Due to the longitudinal nature of the data set, children entered pre-k in years 2 and 3. Therefore, there were two separate cohorts of children examined in the present study. Mean age at testing was 5.74 years; children's ages at time of assessment at each wave are presented in **Table 2**. The multiple-cohort structure of the data set had implications for the data analysis, which is described in greater detail in sections 2.3 and 2.4. Demographic characteristics at baseline were as follows. Of the 166 children in the analytic sample, 74 were boys and 92 were girls. Of the 93 families who provided an open-ended response on race/ethnicity, 72 were White (77.4%) and 7 were African American (7.5%). Other responses were difficult to categorize due to the open-ended nature of the question. Of the 93 families who provided information on years of maternal education, 74 families (79.6%) reported at least 16 years of education, equivalent to a four-year college degree. Of the 65 families who provided information on household income, the median income was \$130,000 (Range: \$40,000 to \$637,000).

T-tests were conducted to examine whether demographic characteristics differed between children eligible for the school cutoff study (i.e., born within two months on either side of the cutoff) compared to children who are not eligible. There were no significant differences between the two groups on child gender, $t(164) = .77, p = .39$; and household income, $t(63) = .54, p = .27$. There was a significant difference between the two groups on maternal education, $t(91) = 2.70, p < .01$, indicating that mothers of children with birth months in October through January (study eligible) had about one less year of education compared to mothers of children with birth months in February through September (study ineligible).

Measures

Executive function. EF was measured using a global, ecologically-valid measure of behavioral self-regulation called the Head-Toes-Knees-Shoulders (HTKS; McClelland et al., 2014). In the HTKS, children respond behaviorally to a series of commands (“touch your head”) by doing the opposite of the stated command (child touches their toes). The task consists of two parts; Part I consists of a combination of two commands (e.g., “touch your head” and “touch your toes”) and Part II adds two additional commands (e.g., “touch your knees” and “touch your shoulders”) to increase task difficulty. Children receive two points for a correct behavioral response and zero points for an incorrect response. If children initiate an incorrect movement but then self-corrects, the child receives one point. Parts I and II are each scored out of 20 points.

The HTKS was administered differently depending on the grade of the child. For pre-k children, only Part I of the HTKS was administered. For kindergarten and first grade children, Parts I and II were administered. This is in contrast to the current task guidelines, which specify that children who score at least 4 points on Part I should proceed to Part II, regardless of the child’s age or grade (McClelland et al., 2018). This difference in task administration has potentially

significant implications on scoring, which in turn has an impact on how schooling effects are calculated. Examining the effect of kindergarten schooling involves comparing pre-k children who missed the cutoff for school entry with kindergarten children who made the cutoff. Similarly, examining the effect of first grade schooling involves comparing kindergarten children who missed the cutoff for school entry (one year prior) with first grade children who made the cutoff. Because kindergarten and first grade children both completed Parts I and II of the HTKS and have scores on the same metric, calculating the first grade effect is straightforward. However, the HTKS score for pre-k children is based only on Part I performance, while the HTKS score for kindergarten children is based on both Part I and II performance.

Two possibilities, imputation of missing data and variable standardization, are likely to generate biased estimates. First, Part II HTKS data could be imputed for pre-k children. While data that are missing by design can often satisfy the condition of data being missing completely at random, these situations typically deal with variations on matrix sampling, where different participants are purposely asked to complete surveys of different lengths (Graham et al., 2006). However, in this case, because all pre-k children did not complete Part II of the HTKS by rule, imputation of missing data is not appropriate. Second, converting HTKS scores to standard deviation units is another possibility. However, by standardizing scores, information on mean-level change over time is lost (Moeller, 2015). Because the school cutoff design involves assessing children's growth from fall to spring over a number of years, variable standardization is also not appropriate.

Instead, we pursue two alternative strategies in the present study. One strategy is to use only Part I HTKS scores for kindergarten children while disregarding their Part II scores. In this arrangement, both pre-k and kindergarten children would have HTKS scores on the same scale

(out of 20 points). However, because most kindergarten children perform well on Part I, a ceiling effect might emerge for kindergarten children, which could artificially mask a kindergarten effect. Another strategy is to retain the HTKS scores as administered for pre-k (Part I only) and kindergarten children (Parts I and II). Because the upper bound for kindergarten HTKS scores is higher (40 points instead of 20 points), this strategy might exaggerate any observed kindergarten effect. However, this concern would be mitigated under the assumption that pre-k children, given their young age, would have been unlikely to perform well, or perhaps may not have even scored any points, on Part II. In the present study, we pursue the more conservative strategy of considering only Part I scores for both pre-k and kindergarten children. However, we also pursue the second strategy of retaining the HTKS scores as administered as a robustness check.

Academic skills. Literacy and numeracy skills were assessed using the Letter-Word Identification and Applied Problems subtests, respectively, of the Woodcock Johnson III Tests of Achievement (Woodcock et al., 2001). The Letter-Word Identification subtest (decoding) required children to identify and pronounce letters and words, while the Applied Problems subtest presented oral word problems that assess basic mathematical concepts. The WJ is specifically designed to generate scores on an equal-interval scale that are comparable across ages (Jaffe, 2009). Means for the HTKS and WJ variables are presented in **Table 3**.

Data structure

As previously described, due to the rolling nature of recruitment and data collection, there were separate cohorts of children examined in the present study. **Figure 1** shows how data were structured. In Year 2 of the study, there were two groups of children that were assessed—a group of children who missed the December 1 cutoff and were therefore in pre-k (Group A1), and another group of same-aged children who made the December 1 cutoff and enrolled in kindergarten (Group

B1). These same children were followed into Year 3 of the study, when pre-k children entered kindergarten (Group C1—same set of children as Group A1) and kindergarten children entered first grade (Group D1—same set of children as Group B1). The same pattern occurred in Year 3—a new group of pre-k (Group A2) and kindergarten children (Group B2) were assessed in Year 3 and transitioned to kindergarten (Group C2) and first grade (Group D2), respectively, in Year 4. As shown in the legend on the left-hand side, children in the A group (shaded in red) are the pre-k children who missed the cutoff, and children in the D group (shaded in blue) are the first grade children who made the cutoff. Importantly, there are two separate groups of kindergarten children—children in the B group are kindergarten children who made the cutoff in Years 2 and 3, and children in the C group are kindergarten children who missed the cutoff (i.e., these children were in pre-k the previous year).

As shown in the legend on the right-hand side, the schooling effects are determined by a comparison between two groups. Figure 1 shows that groups of the same letter are combined before the analysis is conducted. To illustrate, when calculating the kindergarten effect, children in Group A1 and A2 are combined and comprise the pre-k group; this group is compared against children in Groups B1 and B2 combined, which comprise the kindergarten group. In summary, the kindergarten effect is measured by comparing outcomes between children who *made* the cutoff for kindergarten entry (B group) compared to children who missed the cutoff and are in pre-k (A group). When calculating the first grade effect, the comparison is between first grade children who made the cutoff for kindergarten entry the previous year (D group) and kindergarten children who *missed* the cutoff the previous year (C group). Therefore, two separate groups of kindergarten children are used to calculate both schooling effects.

Data analysis

We used a two-level nested linear mixed model, with time (time 1: fall and time 2: spring) as a within-subjects factor and group (e.g., pre-k and kindergarten; kindergarten and first grade) as a between-subjects factor. In addition to main effects of time and group, a Time $\times$ Group interaction would reveal whether there is an interactive effect of development and schooling (i.e., whether growth in EF or academic skills depend on whether the child missed or made the cutoff for school entry). Children were nested within classrooms that are nested within schools, and standard errors were clustered on schools and estimated using the delta method (Dowd et al., 2013). Estimation was by maximum likelihood, and the model allowed for a random intercept and a random time slope for each child.

In calculating the kindergarten schooling effect, we constrained the sample such that only pre-k children who missed the cutoff and kindergarten children who made the cutoff were included in the analysis. (Pre-k children who made the cutoff and kindergarten children who missed the cutoff are not needed in determining the kindergarten schooling effect.) In calculating the first grade schooling effect, we constrained the sample such that only kindergarten children who missed the cutoff and first grade children who made the cutoff (in the previous year) were included in the analysis. (Kindergarten children who made the cutoff and first grade children who missed the cutoff are not needed in determining the first grade schooling effect.) Due to the small attrition rate, missing data were removed using listwise deletion. The xtmixed command in Stata 13 was used to analyze the data. The code used to generate the estimates can be found at <https://osf.io/guh2f/>.

Results

Balance checks

Balance checks were conducted in order to determine whether the two schooling groups (i.e., made cutoff vs. missed cutoff) were equivalent on demographic characteristics such as gender, household income, and highest maternal education. When examining the two schooling groups that would determine the kindergarten schooling effect (i.e., pre-k children who missed the cutoff vs. kindergarten children who made the cutoff), there were no significant differences between the two groups on child age at testing, $t(263) = 1.43, p = .15$; child gender, $t(265) = -.40, p = .69$; household income, $t(98) = -.72, p = .47$; and years of maternal education, $t(128) = -1.49, p = .14$. When examining the two schooling groups that would determine the first grade schooling effect (i.e., kindergarten children who missed the cutoff vs. first grade children who made the cutoff), there were no significant differences between the two groups on child age at testing, $t(302) = 1.11, p = .27$; child gender, $t(302) = -1.46, p = .15$; household income, $t(90) = .78, p = .44$; and years of maternal education, $t(119) = -1.50, p = .14$. These results indicated that the two groups were essentially equivalent on demographic characteristics, strengthening our ability to make valid causal inferences regarding the unique impact of schooling on children's academic and cognitive outcomes.

Are there kindergarten and first grade effects on EF?

We examined whether kindergarten schooling had a unique impact on children's EF skills. We did this by performing a mixed-effects regression with group, time, and group $\times$ time predicting children's HTKS scores (out of 20 points, hereafter referred to as HTKS20). Results showed that the model was significant, Wald $\chi^2(3) = 17.56, p < .001$, indicating that the three-predictor model meaningfully predicted variability in HTKS20. Then, the contrast command—which permits ANOVA-style tests of main effects and interactions—was used. The top panel of **Figure 2** presents graphs of the kindergarten (time 1 and time 2) main effects and interaction on

HTKS20 scores. There was a significant main effect of group, $\chi^2(1) = 9.00, p < .01$: Kindergarten children who made the cutoff for school entry have stronger HTKS20 scores than their same-aged pre-k peers who missed the cutoff. There was also a significant main effect of time, $\chi^2(1) = 8.88, p < .001$: Both pre-k and kindergarten children increased their HTKS20 scores from fall (time 1) to spring (time 2). **Supplementary Table 1** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating kindergarten schooling effects on EF.

We also examined whether first grade schooling had a unique impact on children's EF skills. Results showed that the overall model predicting HTKS20 scores was significant, $\chi^2(3) = 26.75, p < .001$. The bottom panel of **Figure 2** presents graphs of the first grade (time 3 and time 4) main effects and interaction on HTKS20 scores. There was a significant main effect of group, $\chi^2(1) = 19.20, p < .001$: First grade children who made the cutoff have stronger HTKS20 scores than their same-aged kindergarten peers who missed the cutoff for school entry the year before. There was also a significant main effect of time: $\chi^2(1) = 11.97, p < .001$: Both kindergarten and first grade children increased their HTKS20 scores from fall (time 3) to spring (time 4). **Supplementary Table 2** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating first grade schooling effects on EF.

The group $\times$ interaction in both models allows us to determine whether there is a unique impact of schooling, over and above the effects of age. When comparing pre-k and kindergarten children, the group $\times$ time interaction was not significant, $\chi^2(1) = 2.21, p = .14$. While pre-k children who missed the cutoff appeared to show greater improvement in EF skills compared to kindergarten children who made the cutoff, this group $\times$ time interaction was not statistically significant. In contrast, when comparing kindergarten children and first grade children, the group $\times$ time interaction was significant, $\chi^2(1) = 4.20, p = .04$. Specifically, kindergarten children who

missed the cutoff for school entry the previous year show greater improvement in EF skills from fall to spring (time 3 to time 4) compared to first grade children who made the cutoff for school entry the previous year.

Are there kindergarten and first grade effects on reading?

We examined whether kindergarten schooling had a unique impact on children's reading skills. A mixed-effects regression with group, time, and group $\times$ time predicting children's scores on the Woodcock Johnson Letter-Word Identification subtest (reading) was conducted. Results showed that the overall model predicting reading was significant, $\chi^2(3) = 718.32, p < .001$. The top panel of **Figure 3** presents graphs of the kindergarten (time 1 and time 2) main effects and interaction. There was a significant main effect of group, $\chi^2(1) = 50.75, p < .001$: Kindergarten children who made the cutoff have stronger reading scores than their virtually same-aged pre-k peers who missed the cutoff. There was also a significant main effect of time, $\chi^2(1) = 208.97, p < .001$: Both pre-k and kindergarten children increased their reading scores from fall to spring. **Supplementary Table 3** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating kindergarten schooling effects on reading.

We also examined whether first grade schooling had a unique impact on children's reading skills. Results revealed that the overall model predicting reading was significant, $\chi^2(3) = 476.75, p < .001$. The bottom panel of **Figure 3** presents graphs of the first grade (time 3 and time 4) main effects and interaction. There was a significant main effect of group, $\chi^2(1) = 53.13, p < .001$: First grade children who made the cutoff have stronger reading scores than their virtually same-aged kindergarten peers who missed the cutoff for school entry the year before. There was also a main effect of time, $\chi^2(1) = 110.95, p < .001$: Both kindergarten and first grade children increased their reading scores from fall to spring. **Supplementary Table 4** presents the predicted outcomes,

standard errors, and 95% confidence intervals for the model estimating first grade schooling effects on reading.

An interesting pattern of results emerged when examining the group $\times$ time interaction for both models. When comparing pre-k and kindergarten children the group $\times$ time interaction was significant, $\chi^2(1) = 36.53, p < .001$. This is evidenced by the fact that kindergarten children show greater improvement from fall to spring (i.e., time 1 to time 2) compared to their same aged pre-k peers. However, when comparing kindergarten and first grade children, the group $\times$ time interaction was not significant, $\chi^2(1) = 0.00, p = .97$. The slopes for kindergarten and first grade children were virtually equivalent, indicating that a unique first grade schooling effect was not present. In summary, we revealed that kindergarten schooling, but not first grade schooling, had a positive causal impact on reading growth from fall to spring.

Are there kindergarten and first grade effects on math?

Finally, we examined whether kindergarten schooling had a unique impact on children's math skills. A mixed-effects regression with group, time, and group $\times$ time predicting children's scores on the Woodcock Johnson Applied Problems subtest (math) was conducted. Results showed that the model predicting math was significant, $\chi^2(3) = 210.84, p < .001$. The top panel of **Figure 4** presents graphs of the kindergarten (time 1 and time 2) main effects and interaction. There was a significant main effect of group, $\chi^2(1) = 128.86, p < .001$: Kindergarten children who made the cutoff have stronger math scores than their virtually same-aged pre-k peers who missed the cutoff. There was also a significant main effect of time, $\chi^2(1) = 44.17, p < .001$: Both pre-k and kindergarten children increased their math scores from fall to spring. **Supplementary Table 5** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating kindergarten schooling effects on math.

We also examined whether first grade schooling had a unique impact on children's math skills. Results revealed that the overall model predicting math was significant, $\chi^2(3) = 573.52, p < .001$. The bottom panel of **Figure 4** presents graphs of the first grade (time 3 and time 4) main effects and interaction. There was a significant main effect of group, $\chi^2(1) = 56.18, p < .001$: First grade children who made the cutoff have stronger math scores than their virtually same-aged kindergarten peers who missed the cutoff for school entry the year before. There was also a significant main effect of time, $\chi^2(1) = 153.04, p < .001$: Both kindergarten children and first grade children increased their math scores from fall to spring. **Supplementary Table 6** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating first grade schooling effects on math.

In contrast to the models predicting reading, the group $\times$ time interaction was not significant for both models predicting math. When comparing pre-k and kindergarten children, the group $\times$ time interaction was not significant, $\chi^2(1) = 0.38, p = .54$: The slopes for pre-k and kindergarten children (time 1 and time 2) were virtually equivalent, indicating that a kindergarten schooling effect on math was not present. Likewise, when comparing kindergarten children and first grade children, the group $\times$ time interaction was not significant, $\chi^2(1) = 0.26, p = .61$: The slopes for kindergarten and first grade children (time 3 and time 4) were virtually equivalent, indicating that a first grade schooling effect on math was also not present.

Robustness checks

Using an alternative calculation of HTKS scores. We examined whether our kindergarten schooling results were sensitive to how children's HTKS scores were calculated. Rather than considering only Part I of the HTKS for kindergarten children (i.e., HTKS20), an alternative method of measuring HTKS scores for kindergarten children was to consider their

performance on both Parts I and II of the task, yielding a HTKS score out of 40 points (hereafter referred to as HTKS40). Results showed that this alternative model was significant, $\chi^2(3) = 701.14$, $p < .001$, indicating that the three-predictor model (group, time, and group $\times$ time) meaningfully predicted variability in HTKS40. Figure 5 shows a graph of the kindergarten (time 1 and time 2) main effects and interaction on HTKS40 scores. There was a significant main effect of group, $\chi^2(1) = 237.59$, $p < .001$: As before, kindergarten children who made the cutoff have stronger HTKS40 scores than their virtually same-aged pre-k peers who missed the cutoff. There was also a significant main effect of time, $\chi^2(1) = 39.83$, $p < .001$: Both pre-k and kindergarten children increased their HTKS40 scores from fall to spring. Finally, the group $\times$ time interaction was not significant, $\chi^2(1) = 2.00$, $p = .16$: The rate of change in EF between the two groups were not statistically different from each other. **Supplementary Table 7** presents the predicted outcomes, standard errors, and 95% confidence intervals for the model estimating kindergarten schooling effects on the HTKS40. In summary, our kindergarten schooling results did not depend on how the HTKS score was calculated for kindergarten children.

Sensitivity to different bandwidths. Our preferred bandwidth was a two-month window before and after the cutoff. We also conducted a series of robustness checks by examining bandwidths of one month and three months to examine whether our findings were sensitive to the size of the bandwidth. **Table 4** shows the results for the three bandwidths. Results were completely unchanged for reading and math outcomes. However, results for EF appeared to be somewhat sensitive to bandwidth. Schooling effects were not detected when using a one-month bandwidth. However, when a three-month bandwidth was used, kindergarten and first grade effects on EF were found (at trend level).

Discussion

The present study used a school cutoff design to examine the unique effects of kindergarten and first grade schooling on children's EF and academic skills. Quasi-experimental methods permit an examination of causal mechanisms that are not possible using correlational designs. A complex pattern of findings emerged. While children who made the cutoff for school entry performed better compared to children who missed the cutoff, growth in EF skills over the school year tended to be strongest for children who missed the cutoff, especially when comparing kindergarten children who missed the cutoff for school entry the previous year with first grade children who made the cutoff the previous year. Turning to academic skills, kindergarten schooling, but not first grade schooling, had a unique causal impact on children's growth in EF and reading. However, no schooling effects on growth in math emerged.

Schooling effects on EF

Schooling, over and above chronological age, uniquely predicted children's EF skills as measured by the HTKS task. However, our findings were not entirely consistent with our predictions. We found that kindergarten children who missed the cutoff the previous year exhibited stronger EF growth compared to their same-aged first grade peers who made the cutoff the previous year. Therefore, while both groups improved their EF skills throughout the year, the rate of growth was strongest for the kindergarten children who missed the cutoff the year prior. In other words, there appears to be a "catch up effect" for these children.

We offer several interpretations to explain this finding. For some children, missing the cutoff for school entry means that they need to repeat an extra year of pre-k. This additional year of pre-k might be beneficial for some children who would benefit from a second year with the same teachers and caregivers. This continuity across years might allow children to continue to

practice and build their behavioral regulation skills in a setting that is familiar and comfortable. In fact, a body of research has shown benefits for children attending two years of preschool compared to just one (e.g. Domitrovich et al., 2013). Therefore, this additional year of pre-k might catalyze greater growth in EF skills during kindergarten for these children. That said, we must acknowledge that we did not have access to information on previous childcare experiences in the present analysis. Subgroup analyses based on childcare histories would be an important contribution in future work.

The interpretation provided above does not downplay the importance of kindergarten in building behavioral skills. In fact, our data show that children who made the cutoff for school entry—both kindergarten children as well as first grade children who made the cutoff the previous year—experience stronger EF skills compared to their same-aged peers who missed the cutoff. Our data also show that both groups show growth in EF skills from fall to spring, indicating that biological maturation and family/home influences matter for the development of these skills. Our data also appear to strengthen the argument that delayed school entry might not be detrimental to children's skill growth, at least in the short term.

Another important consideration is understanding the role of summer learning loss for young children. A body of research has pointed to skill loss during the summer months when children are typically not in school, which may compound and exacerbate achievement and opportunity gaps (e.g., Alexander, Entwisle, & Olson, 2007), while recent research casts doubt on this finding (e.g., Kuhfield, 2019; von Hippel & Hamrock, 2019). Our data are unable to speak directly to this question, as we did not examine the same children from the spring of one year to the fall of the following year. Rather, we conducted two separate cutoff analyses that were limited to the fall and spring of the school year. However, Figures 2 and 3 appear to indicate that the

increase in EF skills between spring and fall for children who missed the cutoff is much smaller than the increase in EF skills for children who made the cutoff. This suggests that while there might be a “catch up effect” for children who missed the cutoff, earlier entry to kindergarten might actually benefit children through greater increases in EF skill growth during the summer months. In fact, in a separate study, children from low-income households appear to experience faster growth in working memory skills during the first two years of school *and* the intervening summer compared to their higher-income peers (Finch, 2019). While we cannot test this particular interpretation using the present data, how schooling effects (during the year) and summer loss (or gain) interact is an important direction for continued research.

Schooling effects on reading skills

Schooling, over and above chronological age, uniquely predicted children’s academic skills. Again, our findings were not entirely consistent with our predictions. When examining pre-k and kindergarten children, we found that kindergarten schooling was a stronger predictor of children’s growth in decoding skills from fall to spring of the school year. This was evidenced by a steeper positive slope for kindergarten children who made the cutoff for school entry, compared to the pre-k children who missed the cutoff for school entry. Interestingly, when examining kindergarten and first grade children, the group $\times$ time interaction was not significant. That is, the slopes for kindergarten and first grade children were not significantly different from each other, indicating that both groups of children showed growth in reading skills at an equivalent rate. Our findings are consistent with and extend previous research using RDD that showed unique effects of pre-k, kindergarten, and first grade schooling on decoding skills (Kim & Morrison, 2018). That study examined schooling effects but was unable to examine growth in literacy skills across the

school year. The present study adds to this work by demonstrating that kindergarten children exhibit stronger growth in decoding skills during the year compared to their same-aged pre-k peers.

We offer one interpretation of this finding. It may be that there is a meaningful difference in reading instruction between pre-k and kindergarten, evidenced by the stronger growth in reading skills for kindergarten children compared to their same-aged pre-k peers. However, there appears to be no meaningful difference between kindergarten and first grade schooling as it relates to children's growth in reading skills. Because kindergarten is often children's first exposure to a formal schooling environment, the transition from pre-k to kindergarten might be more dramatic than the transition from kindergarten to first grade. This is consistent with research revealing that kindergarten is increasingly resembling first grade in terms of behavioral expectations and academic rigor (Bassok et al., 2016), suggesting that first grade might be simply a continuation of the academic emphasis that has begun in kindergarten. In particular, the nature of reading instruction in first grade may not be markedly different from kindergarten. Future studies should incorporate classroom-level instructional data to determine whether these trends remain today.

Schooling effects on math skills

Children's scores on standardized tests of math achievement increased from fall to spring during kindergarten and first grade. However, we did not find unique influences of kindergarten or first grade on children's math development. These findings suggest that the observed changes in children's math scores were attributable to age-related development, rather than specific schooling experiences. This pattern of finding contrasts with previous research showing a positive effect of preschool intervention programs (Gormley et al., 2005; Weiland & Yoshikawa, 2013), as well as statewide preschool programs on children's math development (Wong et al., 2009). One explanation of these findings is that while children's math skills gradually develop across

kindergarten and first grade, the impact of schooling on math development becomes more prominent in later grades when greater emphasis is placed on explicit math instruction. Further, it is possible that kindergarten and first grade have an impact on rudimentary math skills such as cardinality and counting and not on more advanced skills such as calculation and word problems. However, examining the impact on distinct aspects of math development was not possible using the Applied Problems subtest of the Woodcock Johnson. Future research would benefit from examining the impact of schooling using finer grained and developmentally sensitive measures of math skills.

Limitations and future directions

We did not have access to teacher and classroom data that would help us understand the nature, type, quality, and duration of reading instruction in pre-k, kindergarten, and first grade classrooms. That is, what makes kindergarten reading instruction more effective than reading instruction in pre-k and first grade? Is the lack of early schooling effects on math achievement explained by the type of instructional activities, or the duration of instruction, or something else occurring during the first years of formal schooling? Without this information, we can only speculate as to why certain grade-level schooling experiences are more or less effective. Fortunately, large data sets such as the ECLS-K contain information regarding school- and classroom-level data. Combined with information on children's age at school entry, it is possible to examine whether and how differences in age at school entry, combined with instructional factors, impact different groups of young learners. This would be an important question for future research.

A strength of our study was that we examined pre-k, kindergarten, and first grade children across time. This allowed us to examine multiple grade-level schooling effects during the school

transition period. However, greater attention must be placed on examining children beyond first grade, especially given our findings. For example, we found that kindergarten children experienced greater gains in EF compared to their same-aged first grade peers. We also found that there was no difference in reading growth rates between same-aged kindergarten and first grade children. What would these growth trajectories look like in the years that follow? That is, what are the longer-term cognitive and academic impacts of making (or missing) the cutoff date for school entry? And if there are any impacts, do those impacts depend on the nature of classroom instruction that children receive? These questions deserve greater consideration in order to better inform parents, educators, and policymakers regarding the impact of age-cutoff thresholds that school districts use to determine which children can and cannot enter school. Again, data sets that have repeated measures data on large groups of children across the elementary school years can provide ample opportunities to examine the longer-run impacts of variation in school entry.

References

- Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology, 111*, 446-458.
- Alexander, K.L., Entwisle, D.R., Olson, L.S. (2007). Lasting consequences of the summer learning gap. *American Sociological Review, 72*(2), 167–180.
- Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology, 8*(2), 71–82.
- Bassok, D., Latham, S., & Rorem, A. (2016). Is kindergarten the new first grade? *AERA Open, 1*(4), 1–31.
- Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences, 21*(4), 327–336.
- Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist, 57*(2), 111–127.
- Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*(2), 647–663.
- Brod, G., Bunge, S. A., & Shing, Y. L. (2017). Does one year of schooling improve children's cognitive control and alter associated brain function? *Psychological Science, 28*(7), 967–978.

- Burrage, M. S., Ponitz, C. C., McCreedy, E. A., Shah, P., Sims, B. C., Jewkes, A. M., & Morrison, F. J. (2008). Age- and schooling-related effects on executive functions in young children: A natural experiment. *Child Neuropsychology*, *14*, 510–524.
- Christian, K., Morrison, F. J., Frazier, J. A., & Massetti, G. (2000). Specificity in the nature and timing of cognitive growth in kindergarten and first grade. *Journal of Cognition and Development*, *1*(4), 429–448.
- Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*(6045), 959–964.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168.
- Diamond, A., Lee, C., Senften, P., Lam, A., & Abbott, D. (2019). Randomized control trial of Tools of the Mind: Marked benefits to kindergarten children and their teachers. *PLoS One*, *14*(9), e0222447.
- Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 466–503). Oxford University Press.
- Domitrovich, C. E., Morgan, N. R., Moore, J. E., Cooper, B. R., Shah, H. K., Jacobson, L., & Greenberg, M. T. (2013). One versus two years: Does length of exposure to an enhanced preschool program impact the academic functioning of disadvantaged children in kindergarten? *Early Childhood Research Quarterly*, *28*(4), 704–713.
- Dowd, B. E., Greene, W. H., & Norton, E. C. (2014). Computation of standard errors. *Health Services Research*, *49*(2), 731–750.
- Finch, J. E. (2019). Do schools promote executive functions? Differential working memory growth across school-year and summer months. *AERA Open*, *5*(2), 1–14.

- Gormley, W. T., Gayer, T., Phillips, D., & Dawson, B. (2005). The effects of universal pre-K on cognitive development. *Developmental Psychology*, 41(6), 872–884. doi: 10.1037/0012-1649.41.6.872
- Graham, J. W., Taylor, B. J., Olchowski, A. E., & Cumsille, P. E. (2006). Planned missing data designs in psychological research. *Psychological Methods*, 11(4), 323–343.
- Jacques, S., & Marcovitch, S. (2010). Development of executive function across the lifespan. In W. F. Overton (Ed.), *Handbook of life-span development: Vol. 1. Cognition, biology, and methods across the lifespan* (pp. 431–466). Hoboken, NJ: Wiley.
- Jaffe, L. E. (2009). *Development, interpretation, and application of the W score and the relative proficiency index* (Woodcock-Johnson III Assessment Service Bulletin No. 11). Rolling Meadows, IL: Riverside Publishing.
- Kim, M. H., & Morrison, F. J. (2018). Schooling effects on literacy skills during the transition to school. *AERA Open*, 4(3), 1–15.
- Kuhfeld, M. (2019). Surprising new evidence on summer learning loss. *Phi Delta Kappan*, 101(1), 25–29.
- McClelland, M. M., Cameron, C., Bowles, R., & Geldhof, G. (2018). *Developing a measure of self-regulation for at-risk children*. U.S. Department of Education, Institute for Education Sciences.
- McClelland, M. M., Cameron, C., Duncan, R., Bowles, R., Acock, A., Miao, A., & Pratt, M. (2014). Predictors of early growth in academic achievement: The Head-Toes-Knees-Shoulders task. *Frontiers in Psychology*, 5, 1-14.

- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49–100.
- Moeller, J. (2015). A word on standardization in longitudinal studies: don't. *Frontiers in Psychology*, 6, 1389.
- Monsell, S. (1996). Control of mental processes. In V. Bruce (Ed.), *Unsolved mysteries of the mind: Tutorial essays in cognition* (pp. 93–148). Hove, UK: Erlbaum.
- Montroy, J. J., Bowles, R. P., Skibbe, L. E., McClelland, M. M., & Morrison, F. J. (2016). The development of self-regulation across early childhood. *Developmental Psychology*, 52(11), 1744.
- Morrison, F. J., Kim, M. H., Connor, C. M., & Grammer, J. K. (2019). The causal impact of schooling on children's development: Lessons for developmental science. *Current Directions in Psychological Science*, 28(5), 441–449.
- Morrison, F. J., Griffith, E. M., & Alberts, D. M. (1997). Nature-nurture in the classroom: Entrance age, school readiness, and learning in children. *Developmental Psychology*, 33(2), 254–262.
- Morrison, F. J., Smith, L., & Dow-Ehrensberger, M. (1995). Education and cognitive development: A natural experiment. *Developmental Psychology*, 31(5), 789–799. doi: 10.1037/0012-1649.31.5.789
- Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and Psychopathology*, 12(3), 427–441.
- Sameroff, A., & Haith, M. M. (1996). *Reason and responsibility: The passage through childhood*. Chicago, Illinois: University of Chicago Press.

- Samuels, W. E., Tournaki, N., Blackman, S., & Zilinski, C. (2016). Executive functioning predicts academic achievement in middle school: A four-year longitudinal study. *The Journal of Educational Research, 109*(5), 478–490.
- Shing, Y. L., Lindenberger, U., Diamond, A., Li, S. C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. *Developmental Neuropsychology, 35*(6), 679–697.
- Skibbe, L. E., Connor, C. M., Morrison, F. J., & Jewkes, A. M. (2011). Schooling effects on preschoolers' self-regulation, early literacy, and language growth. *Early Childhood Research Quarterly, 26*, 42–49.
- Stipek, D. (2006). No child left behind comes to preschool. *The Elementary School Journal, 106*(5), 455–466.
- von Hippel, P.T., Hamrock, C. (2019). Do test score gaps grow before, during, or between the school years? Measurement artifacts and what we can know in spite of them. *Sociological Science, 6*, 43–80.
- Weiland, C., & Yoshikawa, H. (2013). Impacts of a prekindergarten program on children's mathematics, language, literacy, executive function, and emotional skills. *Child Development, 84*(6), 2112–2130. doi: 10.1111/cdev.12099
- Wiebe, S. A., Sheffield, T. D., & Espy, K. A. (2012). Separating the fish from the sharks: A longitudinal study of preschool response inhibition. *Child Development, 83*(4), 1245–1261.
- Willoughby, M. T., Wirth, R. J., & Blair, C. B. (2012). Executive function in early childhood: Longitudinal measurement invariance and developmental change. *Psychological Assessment, 24*(2), 418–431. doi: 10.1037/a0025779

- Zelazo, P. D. (2015). Executive function: Reflection, iterative reprocessing, complexity, and the developing brain. *Developmental Review*, 38, 55–68.
- Zelazo, P. D., Craik, F. I., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica*, 115(2-3), 167–183.
- Zhang, Q., Wang, C., Zhao, Q., Yang, L., Buschkuehl, M., & Jaeggi, S. M. (2018). The malleability of executive function in early childhood: Effects of schooling and targeted training. *Developmental Science*. doi:10.1111/desc.12748

Figures and Tables

Table 1. Sample sizes for each analytic group by bandwidth

Bandwidth	Total sample		Kindergarten effect		First grade effect	
	Missed cutoff	Made cutoff	Missed cutoff	Made cutoff	Missed cutoff	Made cutoff
One month	20	33	20	31	20	33
Two month	45	68	44	65	42	68
Three month	79	87	78	82	70	87

Table 2. Average age at each data collection wave

Grade	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5	Wave 6
	Year 2		Year 3		Year 4	
Pre-kindergarten	4.62	5.19	4.84	5.39	N/A	N/A
Kindergarten	5.27	5.85	5.50	6.04	5.46	5.96
First grade	N/A	N/A	6.09	6.66	6.41	6.93

Note. Data reflect a two-month bandwidth. Age is in years.

Figure 1. Cohort data structure. Children were assessed in the fall and spring across multiple years. Pre-k and kindergarten children were used in calculating the kindergarten schooling effect. Kindergarten and first grade children were used in calculating the first grade schooling effect.

Table 3. Descriptive statistics for the HTKS and Woodcock Johnson academic measures

Variable	Pre-kindergarten		Kindergarten		First grade	
	Fall	Spring	Fall	Spring	Fall	Spring
HTKS (out of 20) K effect	14.2 (7.5)	16.9 (5.4)	17.4 (4.2)	17.6 (4.8)	N/A	
HTKS (out of 40) K effect	14.2 (7.5)	16.9 (5.4)	28.7 (9.3)	32.1 (8.7)	N/A	
HTKS (out of 40) First grade effect	N/A		28.7 (9.3)	32.1 (8.7)	34.6 (5.0)	36.5 (3.7)
WJ Letter-Word Identification W score	348.3 (17.4)	359.1 (24.8)	371.0 (28.1)	404.2 (28.6)	428.4 (34.3)	460.4 (25.6)
WJ Applied Problems W score	415.4 (10.8)	427.7 (15.2)	432.6 (15.9)	444.5 (15.8)	459.5 (16.7)	475.0 (18.4)

Note. Data reflect a two-month bandwidth. Standard deviations are in parentheses.

Figure 2. The top panel presents graphs of the kindergarten (time 1 and time 2) main effects and interaction on HTKS20 scores. The bottom panel presents graphs of the first grade (time 3 and time 4) main effects and interaction on HTKS scores (out of 40 points).

Figure 3. The top panel presents graphs of the kindergarten (time 1 and time 2) main effects and interaction on decoding scores. The bottom panel presents graphs of the first grade (time 3 and time 4) main effects and interaction on decoding scores.

Figure 4. The top panel presents graphs of the kindergarten (time 1 and time 2) main effects and interaction on math scores. The bottom panel presents graphs of the first grade (time 3 and time 4) main effects and interaction on math scores.

Figure 5 shows a graph of the kindergarten (time 1 and time 2) main effects and interaction on HTKS40 scores as a robustness check.

Table 4. Main effects and interaction effects by bandwidth

	Group			Time			Group $\times$ Time		
	1mo	2mo	3mo	1mo	2mo	3mo	1mo	2mo	3mo
Kindergarten effect on HTKS20	***	**	***	*	**	***	ns	ns	+
First grade effect on HTKS	*	***	***	+	***	***	ns	*	+
Kindergarten effect on reading	***	***	***	***	***	***	***	***	***
First grade effect on reading	***	***	***	***	***	***	ns	ns	ns
Kindergarten effect on math	***	***	***	***	***	***	ns	ns	ns
First grade effect on math	***	***	***	***	***	***	ns	ns	ns

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, + $p < .01$, ns = not significant. The preferred bandwidth is two months. Bandwidths of one and three months were used to determine the robustness of the findings.

Supplementary Material

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	14.01	1.24	11.59—16.45
Missed cutoff	Spring	16.90	0.66	15.60—18.19
Made cutoff	Fall	17.54	0.43	16.69–18.39
Made cutoff	Spring	18.42	0.37	17.69–19.14

Supplementary Table 1. Kindergarten schooling effect on EF. Predicted outcomes represent scores on the HTKS (out of 20 points). SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	29.12	1.37	26.44–31.80
Missed cutoff	Spring	34.06	0.99	32.12–36.01
Made cutoff	Fall	34.62	0.63	33.39–35.86
Made cutoff	Spring	36.51	0.40	35.72–37.29

Supplementary Table 2. First grade schooling effect on EF. Predicted outcomes represent scores on the HTKS. SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	347.22	2.54	342.24–352.20
Missed cutoff	Spring	360.69	4.73	351.41–369.96
Made cutoff	Fall	369.73	2.65	364.53–374.93
Made cutoff	Spring	401.23	2.58	396.18–406.27

Supplementary Table 3. Kindergarten schooling effect on reading. Predicted outcomes represent W scores on the Woodcock Johnson Letter-Word Identification subtest. SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	373.13	9.46	354.59–391.68
Missed cutoff	Spring	406.32	5.65	395.24–417.39
Made cutoff	Fall	428.63	3.17	422.42–434.84
Made cutoff	Spring	461.61	2.50	456.71–466.51

Supplementary Table 4. First grade schooling effect on reading. Predicted outcomes represent W scores on the Woodcock Johnson Letter-Word Identification subtest. SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	414.83	1.45	411.99–417.68
Missed cutoff	Spring	428.34	1.90	424.62–432.06
Made cutoff	Fall	433.85	2.58	428.81–438.90
Made cutoff	Spring	444.76	1.65	441.53–447.98

Supplementary Table 5. Kindergarten schooling effect on math. Predicted outcomes represent W scores on the Woodcock Johnson Applied Problems subtest. SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	433.01	2.75	427.62–438.41
Missed cutoff	Spring	450.50	3.55	443.55–457.45
Made cutoff	Fall	459.50	2.57	454.46–464.54
Made cutoff	Spring	475.13	1.86	471.48–478.77

Supplementary Table 6. First grade schooling effect on math. Predicted outcomes represent W scores on the Woodcock Johnson Applied Problems subtest. SE: Standard error. CI: Confidence interval.

Cutoff status	Wave	Predicted outcome	SE	95% CI
Missed cutoff	Fall	13.95	1.21	11.57–16.33
Missed cutoff	Spring	16.90	0.67	15.60–18.20
Made cutoff	Fall	29.27	1.04	27.23–31.31
Made cutoff	Spring	34.41	0.89	32.68–36.15

Supplementary Table 7. Kindergarten schooling effect on EF—robustness check. Predicted outcomes represent scores on the HTKS (out of 40 points). SE: Standard error. CI: Confidence interval.