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COVID-19-Induced School Closures and Disadvantaged Children's Post-COVID Academic Growth: A Longitudinal Cohort Study

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This study draws on unique, repeated-measures data on a diverse (51% female; 53% Latine, 22% Black, 11% White), low-income cohort of children (N = 680) whose academic skills were assessed before and after COVID-19-induced school closures. Longitudinal models predicted changes in children's literacy and math trajectories from before school closures (ages 4-6; 2017-2019) to after school reopening (ages 8-11; 2021-2023) and tested whether children's remote learning participation moderated these changes. Results suggest that academic growth stagnated during school closures, with "losses" ranging from 3 months of literacy growth to 14 months of math growth. Remote learning participation was protective for math only. After schools re-opened, children's growth rates were slower than they had been prior to school closures but bounced back to what we would expect based on their ages. These findings suggest that while being out of school resulted in stagnation in learning, once students were back in school, normal developmental growth in learning resumed, highlighting the resilience of students' ability to learn when in school.

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Abstract

This study draws on repeated-measures data on a diverse (51% female; 53% Latine, 22% Black, 11% White), low-income cohort of children ($N = 680$) whose academic skills were assessed before and after COVID-19-induced school closures. Longitudinal models predicted changes in children's literacy and math trajectories from before school closures (ages 4-6; 2017-2019) to after school reopening (ages 8-11; 2021-2023) and tested whether children's remote learning participation moderated these changes. Results suggest that academic growth stagnated during school closures, with "losses" ranging from 3 months of literacy growth to 14 months of math growth. Remote learning participation was protective for math only. After schools re-opened, children's growth rates were slower than they had been prior to school closures but bounced back to what we would expect based on their ages. These findings suggest that while being out of school resulted in stagnation in learning, once students were back in school, normal developmental growth in learning resumed, highlighting the resilience of students' ability to learn when in school.

Keywords: COVID-19; school closures; remote learning; math; literacy; low-income.

COVID-19-Induced School Closures and Disadvantaged Children's Post-COVID Academic Growth: A Longitudinal Cohort Study

The COVID-19 pandemic profoundly disrupted the education of millions of children in the U.S. (Benner & Mistry, 2020; Slavin & Storey, 2020). After the World Health Organization declared COVID-19 a global pandemic on March 11, 2020 (Cucinotta & Vanelli, 2020), most schools across the United States abruptly pivoted from in-person, face-to-face instruction to various forms of online remote learning (Donohue & Miller, 2020). In many districts this period of school closures lasted for a year or longer (IES, n.d.; NCES, n.d.), which likely resulted in lower levels of student academic achievement in literacy and math (Betthäuser et al., 2023; Cortés-Albornoz et al., 2023). The potential impact of these drastic educational disruptions on children's development continues to concern education and developmental researchers, policymakers, teachers, and parents.

These profound disruptions and the distress they caused has catalyzed a flurry of recent research, which together suggests that U.S. students of all ages suffered learning losses during school closures that persisted well beyond the return to school (Callen et al., 2024; Curriculum Associates, 2024; Domingue et al., 2022; Dorn et al., 2021; EmpowerK12, 2022; Goldhaber et al., 2022; Fahle et al., 2024; Furjanic et al., 2024; Hadley et al., 2024; Halloran et al., 2021; Kogan & Lavertu, 2021; Kuhfeld et al., 2020; 2022; Kuhfeld & Lewis, 2022a;2022b; 2024; Le et al., 2025; Lewis et al., 2021; Peters et al., 2023; Pier et al., 2021; Relyea et al., 2022; Renaissance Learning, 2021; Young & Young, 2024); learning loss has been documented most consistently in math (Bielinski et al., 2020; Goldhaber et al., 2022; Halloran et al., 202; Kuhfeld et al., 2022; Kuhfeld & Lewis, 2022a; Kogan & Lavertu, 2021; Lewis et al., 2021; Renaissance Learning, 2021). To fully understand the impact of the pandemic on children's learning, continued research is needed that follows the same cohort of children from before to well after the pandemic to assess *intra-individual* changes in learning trajectories. We build on the existing knowledge base by following a race-ethnically diverse, low-income cohort of children who were in the first grade at the onset of the pandemic, experienced the end of first grade and the entire second grade remotely, and returned to school in third grade. A key contribution of the present study is that we were able to assess the same cohort repeatedly both before and after COVID-19-induced educational disruptions: this allows us to compare children to themselves over time, instead of comparing different cohorts of children before and after COVID-19 as most prior literature has done. We model not just changes in children's skill *levels* from before schools closed to after they re-opened, but also children's *rates of growth* in literacy and math before and for *multiple* years following school re-opening. Further, we examine whether these changes in levels and rates of growth vary according to remote learning participation. Notably, the sample is entirely low-income and predominantly Hispanic/Latine and Black. Researchers have expressed concern about disproportionate academic setbacks among children from low-income and minoritized backgrounds in the pandemic's wake (Goldhaber et al., 2022; Halloran et al., 2021), directing attention to these under-resourced groups.

The Effects of School Closures on Children's Academic Outcomes

An emerging, rich body of reporting concludes that COVID-19 school closures led to declines in students' academic achievement (Amplify, 2023; Callen et al., 2024; Curriculum Associates, 2024; Kogan & Lavertu, 2022; Kuhfeld et al., 2022; Kuhfeld & Lewis, 2022a; 2022b; 2024; Peters et al., 2023; Solari, 2021; Young & Young, 2024). In the U.S., the National Assessment of Educational Progress (NAEP), a standardized test known as the Nation's Report Card, recorded significant declines in fourth and eighth grade students' math and reading skills in

2022 compared to before the pandemic (NAEP, 2022a; 2022b). For fourth graders, this represented the largest average decrease in reading scores since 1990, and the largest ever decline in math scores. Indeed, a growing body of research documents substantial drops following COVID-19 onset in U.S. elementary and middle school students' performance in literacy (Bielinski et al., 2021; Domingue et al., 2022; Pier et al., 2021; Relyea et al., 2022). Declines were even steeper in math (Bielinski et al., 2021; Kuhfeld et al., 2022; Kuhfeld & Lewis, 2022a; Lewis et al., 2021), particularly among economically disadvantaged students (Goldhaber et al., 2022; Halloran et al., 2021). Decreases in academic achievement were smaller in districts where school closures were shorter (Halloran et al., 2021; Kogan & Lavertu, 2022; Relyea et al., 2022; Uthappa et al., 2023), providing evidence for the specific role that school closures and remote learning played in these declines. However, the 2024 NAEP report and other studies suggest that even multiple years after school re-openings, children who experienced pandemic-induced school closures were still under-performing relative to historical same-age cohorts (Amplify, 2023; Curriculum Associates, 2024; Fahle et al., 2024; Kuhfeld & Lewis, 2024; NAEP, 2024a; 2024b; Young & Young, 2024).

The extant literature has focused primarily on children in third grade and older. Much of this valuable evidence comes from state and district standardized test data, including the NAEP and other summative state achievement tests (Fahle et al., 2024; Halloran et al., 2021; Kogan & Lavertu et al., 2021; NAEP, 2022a; 2022b; 2024a; 2024b). Most U.S. school districts do not begin routine summative standardized testing until it becomes federally mandated in the third grade (Every Student Succeeds Act, 2015); NAEP testing begins in fourth grade. Another body of literature has relied on interim test data drawn from formative assessments such as the NWEA MAP and iReady (Callen et al., 2024; Goldhaber et al., 2022; Kuhfeld et al., 2022; Kuhfeld &

Lewis, 2022a; 2024; Lewis et al., 2021; Peers et al., 2023; Pier et al., 2021; Relyea et al., 2022), a subset of which include data on kindergarten through second grade students (Amplify, 2023; Bielinski et al., 2020; Curriculum Associates, 2024; Dorn et al., 2021; Domingue et al., 2022; EmpowerK12, 2022; Furjanic et al., 2024; Kuhfeld & Lewis, 2022b; Renaissance Learning, 2021; Solari, 2021; Young & Young; 2024). Additionally, two studies comparing pre- and post-COVID cohorts of preschoolers suggest that children whose preschool year was disrupted by the pandemic lagged behind their pre-pandemic same-age peers in terms of subsequent kindergarten and first grade readiness (Hadley et al., 2025; Le et al., 2025). These studies of younger children whose preschool or early elementary years were interrupted by the pandemic are especially important considering this is a key developmental window for launching children's school trajectories (Eckert et al., 2008; Rimm-Kaufman & Pianta, 2000).

What is needed now are studies that follow the same cohort of young children for multiple years both before and after the pandemic. This is critical to assess not only intra-individual learning loss, but also possible recovery, which from a developmental perspective can only be defined relative to one's own prior performance. Ideally, such research would track children's growth not only from before to after the period of pandemic-induced school closures, but also for *multiple* out-years following school reopening. The few existing studies that have harnessed repeated measures data on the same cohort of children from before to after the pandemic (e.g., Callen et al., 2024; Kuhfeld et al., 2022) focused on post-pandemic achievement during the school year immediately following the return to in-person learning, which in many U.S. public schools did not occur until the fall of 2021 (National Center for Education Statistics, n.d.). More evidence is needed for how young children's learning trajectories continued to evolve in the years following the return to fully in-person instruction, relative to their pre-COVID trajectories. Perhaps children resumed their pre-COVID growth rates or even learned at a faster or “catch up” rate as their time back in classrooms increased. Alternatively, students may have experienced a slower rate of growth after schools re-opened due to prolonged absence from the classroom. If, however, there is slowdown in growth rates, it could reflect normative patterns of age-related growth in which rapid acquisition of academic skills in early childhood decelerates in middle childhood and pre-adolescence. We therefore compare the post-school-reopening patterns in our data against norming data from the Woodcock-Johnson publisher on same-age students who did not experience a pandemic, to better understand whether (a) school closures fundamentally altered children’s ability to learn in school, or (b) whether children’s rate of growth after school re-openings was on par with what would be expected in the absence of the pandemic, even if their skill levels remain lower.

Children’s Participation During COVID-Induced Remote Learning

Under ordinary circumstances, children’s level of participation in face-to-face learning affects their acquisition of academic skills (Ansari et al., 2021; Ehrlich et al., 2018). It is thus reasonable to expect that variation in children’s participation in remote learning when schools were closed similarly affected their skills. There is, in fact, evidence to suggest such variation occurred, as not all children complied with all requirements of remote instruction. For example, K-12 teachers in New York State reported that nearly 30% of their students were not completing assignments as requested during remote learning (Catalano et al., 2021).

Scholars have documented multiple barriers that hampered remote learning, particularly among children from low-resourced households: these include lack of reliable access to the internet and devices (Domina et al., 2021) and challenges faced by parents’ in their efforts to keep up with the added demands of supporting their child’s “school” participation from home

(Balayar & Langlais, 2022; Garbe et al., 2020). In addition, pandemic-related hardships such as loss of income (Kalil et al., 2020) and increases in household chaos and family dysfunction (Johnson et al., 2021; Schmeer et al., 2023; Thomson et al., 2023) exacerbated some parents' struggles to ensure their child(ren) participated fully in remote learning activities and completed work assignments (Garbe et al., 2020; Liu et al., 2022). Nevertheless, while teachers in high-needs districts reported lower levels of student participation during COVID-19-induced remote learning than teachers in other districts (Catalano et al., 2021), there was significant variation among low-resourced families in their experiences of health and material hardship and concomitant participation in remote learning (Haskett et al., 2022; Johnson et al., 2021).

The implications of variation in children's level of participation in remote learning for their learning trajectories following the resumption of in-person learning are unknown. Perhaps children who participated more in remote learning experienced less learning stagnation in their literacy and math skills during the period of school closures, rebounded to their pre-COVID rates of growth more quickly after schools re-opened, or both. Alternatively, even full participation in remote learning may have exposed children to such a minimal amount, or poorer quality, of academic instruction that it did not protect against learning stagnation or slowed rates of growth. A better understanding of the role of remote learning participation will inform approaches to education in the event that future emergencies disrupt "business as usual" in U.S. schools.

The Current Study

The current study examines academic outcomes in a diverse longitudinal cohort of children from low-income families in Tulsa, Oklahoma who were in first grade when the pandemic hit. With repeated-measures data, we test whether and how school closures during COVID-19 changed children's growth trajectories of literacy and math skill development from before when schools closed (fall 2017-fall 2019) to long after schools re-opened (fall 2021-fall 2023). Importantly, our repeated measurements of the same children's skills before and after the period of COVID-19-induced school closures permits examination of two dimensions of COVID-19 impacts on children's academic skills. The first is *stagnation* in children's skill levels during school closures, defined here as an intercept change reflecting lower scores following school reopening than would be expected based on those same children's previous trends. The second is *slowdown* in children's rate of growth following school re-openings, defined as slope changes reflecting growth in children's scores occurring at a slower rate following the return to in-person learning than demonstrated before schools closed (note there could also be speedup, reflecting growth occurring at a faster rate than before). In addition, to assess the possibility that any stagnation in level or slowdown in growth evident in our sample is due to school closures rather than normative patterns of development, we compare changes in our sample's scores over time with those from the test's normative sample over the same ages. Last, we test whether changes in the level and growth rate of literacy and math varied according to students' participation in remote learning during the period of school closures.

Method

Data Source and Sample

Data were drawn from an ongoing study of low-income children who have been followed since they were in preschool (2016). The Tulsa SEED Study initially recruited children enrolled in publicly funded preschool settings serving low-income children and families (household income was less than 185% of the federal poverty level OR they received any public benefit within the last 12 months) in Tulsa, Oklahoma. When study children entered Tulsa Public Schools (TPS) kindergarten in the fall of 2018, the Tulsa SEED Study recruited additional students from low-income families who had not attended preschool the prior year. Thus, the study sample is, by design, exclusively low-income. Study children's academic skills were repeatedly directly assessed in their schools from the fall of preschool (2017) through the fall of fifth grade (2023) with the exception of the period of school closures (see below).

On March 16, 2020, when study children were in first grade, TPS closed all schools in the district (as did most urban public-school districts around the U.S.) and moved to remote instruction. TPS schools remained fully remote through the spring of 2021 and did not offer a formal hybrid instruction model; thus, all study children experienced second grade remotely (2020-2021). Schools re-opened for full-time in-person instruction in the fall of 2021 when study children were entering third grade.

The analytic sample for the current study includes children with at least one academic skill (literacy or math) assessment between the fall of 2017 and the fall of 2023 and teacher ratings of remote learning participation in second grade ($N = 680$). We excluded 728 children whose second-grade teachers did not complete ratings of the child's participation in remote learning, 7 children whose skills were never directly assessed, and 56 children who did not attend public preschool and were not yet enrolled in the study in the fall of 2017. Compared to excluded cases, children who were included were more likely to be Hispanic/Latine ($p < .001$), and—perhaps as a function of this difference—were also less likely to be Black, non-Hispanic ($p < .001$), White, non-Hispanic ($p < .001$), or another race/ethnicity ($p < .01$), more likely to be dual language learners (DLLs; $p < .001$), less likely to have mothers who were unmarried at the time of the child's birth ($p < .01$), less likely to have a parent with more than a high school education ($p < .01$), and had lower household incomes on average ($p < .05$).

The sample was racially and ethnically diverse (Table 1). Approximately 53% of children were Hispanic/Latine[1], 22% were Black, 11% were White, 9% were Multiracial, 5% were American Indian or Alaskan Native, and 1% were another race/ethnicity. Nearly half (49%) of children in the analytic sample were DLLs, meaning their parent reported that a language other than English was spoken inside the home. In this sample, approximately 96% of DLLs were Hispanic/Latine and approximately 97% of DLLs lived in a home where Spanish was spoken. The average household income was $22,155, which is less than 100% of the federal poverty line for a family of four in 2017 ($24,600; ASPE, 2017). Mothers were on average 26 years old at the child's birth, and just over half (51%) were unmarried at the time of the child's birth. On average, children were 4.53 years old at the fall of their kindergarten year, and 50% were female.

Procedures

Trained assessors collected repeated measurements of children's literacy and math skills at the fall of each year of the study, from age 4 (2017) through the fifth grade (2023), except for the fall of second grade (2020), when TPS school buildings were closed to in-person instruction. During the school day, each child was individually escorted out of their classroom to a separate location in the school where a trained research assistant administered a series of tasks. Each session lasted approximately 35 minutes. Information about family and household demographic characteristics used as covariates in the current analysis was drawn from a survey parents completed in the spring of the preschool year. Surveys were distributed via text message, email, and in children's backpacks; parents received a $30 gift card for completing this survey. In the fall of 2020—during the period of COVID-19-induced remote learning—second grade teachers

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[1] Country of origin and immigrant status were not collected based on guidance from local community advisors who cautioned sensitivity of the sample to such questions.

were sent a Qualtrics survey link for each participating child in their classroom and asked to complete ratings of children's level of participation in remote learning. Each survey took approximately 6 minutes to complete, and teachers received $20-$60 in gift cards as compensation, depending on the number of participating children in their classroom. The [NAME OMITTED FOR REVIEW] Institutional Review Board reviewed and approved all study protocols.

Measures

Pandemic-Related School Closures

We constructed an indicator variable called "post-COVID" to capture the timing of child assessments relative to pandemic-related school closures. This variable was coded as a 0 for all timepoints before COVID-related school closures (i.e., prior to September 15, 2021) and a 1 for all timepoints following the return to full-time in-person learning (on or after September 15, 2021). Note that children were not assessed during the period of school closures; thus, all pre-COVID assessments occurred before March 15, 2020.

Remote Learning Participation

Children's second grade teachers rated two dimensions of each child's level of participation during remote learning from the period of September-December 2020: their contact with the child (1 = *none at all*, 2 = *less than you requested*, 3 = *as much as you requested*, 4 = *more than you requested*), and the amount of remote learning activities completed by the child (1 = *none at all*, 2 = *less than you requested*, 3 = *a moderate amount*, 4 = *a lot*, 5 = *a great deal*). We constructed two binary indicators of sufficient remote learning participation.

Sufficient contact with teacher. First, we categorized children as having sufficient contact with their teacher if their teacher reported that they had as much or more contact with the child than they requested (approximately 56% of children).

Sufficient work completion. Second, we categorized children as having sufficient remote work completion if their teacher reported that they completed a moderate amount, a lot, or a great deal of the assigned remote learning activities (approximately 60% of children).

Child Academic Outcomes

English Literacy. Children's literacy skills were assessed using the Woodcock-Johnson Letter-Word Identification subtest (Woodcock et al., 2001), which asks children to accurately identify letters and correctly pronounce sight words. Only English answers were accepted, but bilingual children were prompted once per item to respond in English if they responded in Spanish. Publisher-provided W scores, which adjust for the difficulty of individual items via IRT calibration, were used in all analyses. W scores are centered at 500, which is meant to represent the average score of a fifth grader, the grade of our sample children at the last measurement period.

Math. The Woodcock-Johnson Applied Problems subtest (Woodcock et al., 2001) measured children's mathematical problem-solving ability by asking them to solve computational word problems (e.g., "how many dogs are in this picture?"), and to perform basic addition and subtraction. If children preferred to give responses in Spanish, their answers were considered valid in either language. For this reason, bilingual children were always paired with a bilingual assessor. Publisher-provided W scores were used.

Covariates

We coded child race/ethnicity as Hispanic/Latine, Black, White, or Multiracial/another race (which, due to small sizes, combined children who were Asian American/Pacific Islander, Native American, or Multiracial). We coded children as DLLs if their parent reported that the household spoke a language other than or in addition to English at home. We drew household income from the spring of preschool (2018) log-transformed it in all analyses. Parent education and employment were coded as binary variables capturing whether the parent had more than a high school education and whether they were employed (full- or part-time) versus unemployed as of the spring of the preschool year (2018), respectively. Other covariates included mother's age and whether she was unmarried at the child's birth, child gender, and child age in months at the fall of the preschool year.

Analytic Strategy

We estimated two-level random intercept models with timepoints (Level 1) nested within children (Level 2) for each study outcome using the "mixed" command in Stata 18 (Robson & Pevalin, 2016; Singer & Willett, 2003). This approach allowed us to account for within-child correlations in assessment scores over time, while examining how children's skills evolved before and after COVID-19-related school closures. In all models, we treated time as a continuous variable (months), centered at September 15, 2021, the date corresponding with the return to in-person learning.

Our first set of models examine children's growth in skills as a function of COVID-19-related school closures. Predictors at level 1 include time, the "post-COVID" indicator variable capturing whether the timepoint was before or after the period of COVID-19-related school closures, and the interaction between time and the post-COVID indicator. Level 2 predictors were time-invariant child and household characteristics, including child race/ethnicity, gender, DLL status, age at the fall of the preschool year, mothers' age and marital status at the child's birth, parent education and employment, and the natural log of household income. All models included random intercepts to account for variability in children's baseline skills, while treating the effects of time and COVID-19-related school closures as fixed predictors with consistent effects across individual children. These models can be summarized by the following equation:

$$Y_{ti} = \gamma_{00} + \gamma_{10}(\text{time})_{ti} + \gamma_{20}(\text{postCOVID})_{ti} + \gamma_{30}(\text{time x postCOVID})_{ti} + \sum \gamma_{01-9}(\text{covariates})_{ti} + \mu_{0i} + r_{ti}$$

In the above equation, Y_{ti} represents the outcome score for child *i* at time *t,* and γ_{00} is the overall model intercept (i.e., the mean value across all children when time = 0, or upon the return to in-person learning). The random portion of the intercept for child *i* is represented by μ_{0i}. γ_{10} represents the average monthly change in children's scores prior to school closures. γ_{20} represents the average change in children's predicted scores from before to after the period of school closures (i.e., the shift in the intercept when time = 0). This is the term capturing suspected stagnation in skill level occasioned by the pandemic. γ_{30} represents the difference in children's average monthly rate of growth from before school closures to after the return to in-person learning. This difference captures suspected slowdown (or speedup) in growth rate. The simple slope following the period of school closures can be computed as the sum of γ_{10} and γ_{30}. The term $\sum \gamma_{01-9}$ represents a vector of covariates on children's average scores over time. Finally, r_{ti} is the error term capturing the unexplained variation within children over time.

In order to assess whether any stagnation or slowdown suggested by our first set of models was indeed a function of school closures as opposed to normative age-related deceleration in children's growth, we conducted two additional, albeit informal tests. First, we plotted children's over-time Woodcock-Johnson standard scores, which are based on the test publisher's national norming sample and centered at a mean of 100 and a standard deviation of 15. If stagnation in children's skill levels during school closures was normative, we would expect children's standard scores to remain relatively stable between the fall of first grade—right before schools closed—and the fall of third grade—right after schools re-opened. Second, we plotted the average Woodcock-Johnson W scores over time among children in our sample alongside the average W scores of same-age children in the norming sample. If any slowdown detected in children's rate of growth after school re-opening was in fact normative, we would expect the rate of growth in W scores in our sample between the fall of third grade and the fall of fifth grade to mirror the rate of growth suggested by corresponding age-based means in the norming sample.

Regardless of the reason for any detected stagnation and slowdown in children's growth, it is still of interest to know whether the degree varied by children's level of participation in remote learning. To examine this question, our second and third set of models added a 3-way interaction between time, the post-COVID indicator, and each of our binary variables capturing sufficient remote learning participation ("participate"), respectively. These models can be summarized by the following equation:

$$\begin{aligned} Y_{ti} = \gamma_{00} &+ \gamma_{10}(\text{time})_{ti} + \gamma_{20}(\text{postCOVID})_{ti} + \gamma_{30}(\text{time x postCOVID})_{ti} \\ &+ \gamma_{01}(\text{participate})_{ti} + \gamma_{11}(\text{time x participate})_{ti} \\ &+ \gamma_{21}(\text{postCOVID x participate})_{ti} + \gamma_{31}(\text{time x postCOVID x participate})_{ti} \\ &+ \sum\gamma_{02-010}(\text{covariates})_{ti} + \mu_{0i} + r_{ti} \end{aligned}$$

In the above equation, γ_{10}- γ_{30} are interpreted similarly to the first set of models, but specifically with respect to children whose level of contact with their teacher or completion of remote work during distance learning did not meet their second-grade teachers' expectations. γ_{01} represents the average difference in the intercept associated with having sufficient contact with their teacher (Model 2) or completing sufficient work (Model 3) during school closures. γ_{11} represents the average difference in children's pre-COVID monthly rate of growth associated with the indicator of sufficient remote learning participation they experienced later. γ_{21} represents the difference in the change in intercept from before to after the period of COVID-induced school closures associated with the indicator of sufficient remote learning participation they experienced during school closures. Finally, γ_{31} represents the difference in the pre-school-closure to post-school-reopening change in children's monthly rate of growth (i.e., the difference in the slope change) associated with the indicator of sufficient remote learning participation during school closures.

Rates of missing covariate data ranged from <1% on DLL status to 34% on parent employment. The *ice* command in Stata created 25 multiply imputed data sets from a model that included all the child assessment variables at each timepoint, the associated dates of assessment, the indicators of insufficient remote learning participation, and time-invariant child covariates. Dependent variables were not imputed. We ran all models on the imputed data sets.

Results

School Closures and Children's Growth Trajectories

Table 2 and Figure 1 display the results of multilevel models predicting children's growth in academic outcomes as a function of COVID-19-related school closures. In Table 2, the Time coefficient represents children's average pre-COVID monthly rate of growth in skills. The Post-COVID coefficient represents the change in children's scores from before schools closed to after schools re-opened—or what we refer to as possible stagnation in children's skill levels during school closures. The coefficient for the interaction between Time and Post-COVID represents the change in children's rate of growth from before schools closed to after they re-opened—or what we refer to as possible slowdown (or speedup) in children's rate of growth.

Results suggest that children's literacy skill levels stagnated during school closures—in other words, they demonstrated lower skill levels than would be expected based on their pre-COVID performance (B = -8.90, SE = .35, p < .001). Furthermore, after schools re-opened, children's literacy skills improved at a slower rate than prior to school closures (B = -1.51, SE = .01, p < .001): before COVID, children's rate of growth in literacy skills was equal to a W score increase of approximately 3.06 points per month, but after the period of school closures, it was equal to an increase of approximately 1.55 points per month. Children's math skills followed a similar pattern: their skill levels stagnated during school closures (B = -31.85, SE = .23, p < .001) and continued to improve at a slower rate following the return to in-person learning than prior to school closures (B = -1.26, SE = .01, p < .001). Specifically, before COVID, children's rate of growth in math skills was equal to a W score increase of approximately 2.20 points per month, but after the period of school closures, it was equal to an increase of approximately 0.94 points per month. In sum, children experienced learning stagnation and slowdown in both their literacy and math skills.

Comparing Children's Pre-Post-COVID Trajectories to Age-Based Norms

As depicted in Figure 4, Woodcock-Johnson standard scores in our sample dropped precipitously on both literacy and math after the second-grade year, corresponding precisely to the period of COVID-induced school closures. This implicates the school closures rather than normal age-related development in the stagnation in skill levels we observed in our analytic sample. Figure 5 graphs average W scores in literacy and math between ages 4 and 10, both in the Woodcock-Johnson norming sample (age-based norms obtained from McGrew et al., 2007) and in our sample (timepoints corresponding with the fall of pre-k through the fall of fifth grade). The rate of change in math scores in our sample after the return to school appears exactly parallel to that implied by the age-based means of children in the norming sample, and the rate of change in literacy seems slightly steeper. This suggests that children's rate of growth after the return to school (third grade) on both academic outcomes in our sample was normative, and thus the slowdown in growth rates relative to before school closures is likely attributable to normal developmental patterns rather than school closures per se. While this is an admittedly informal test, it suggests that slowdown in skill growth after school re-openings may have been expected to occur even in the absence of school closures. Nevertheless, skill levels were still lower than they would have been without school closures.

Remote Learning Participation and Children's Growth Trajectories

Table 3 and Figure 2 display the results of our second set of multilevel models predicting children's growth in academic skills as a function of whether they had sufficient contact with their teacher during remote learning. For literacy skills, the results suggest that children who had sufficient contact with their teacher during remote learning experienced comparable learning stagnation during school closures as children who had insufficient contact with their teachers. Surprisingly, however, children who had sufficient contact with their teacher during remote learning demonstrated more slowdown in their literacy skill growth after schools re-opened than children who had insufficient contact with their teachers (B = -.36, SE = .03, p < .001). Specifically, children who had sufficient contact with their teachers had a simple slope of 3.17 points per month before schools closed, and a simple slope of 1.50 points per month after schools re-opened. Children who had insufficient contact with their teacher had a simple slope of 2.93 points per month before schools closed, and a simple slope of 1.62 points per month after schools re-opened. Regarding math skills, the results suggest that children who had sufficient contact with their teacher experienced less math learning stagnation during school closures than children who had insufficient contact with their teachers (*B* = 2.65, *SE* = .46, $p < .001$). However, their degree of math learning slowdown following school re-opening was no different than that of children who had insufficient contact with their teachers.

Table 4 and Figure 3 display the results of our third set of multilevel models predicting children's growth in academic skills as a function of sufficient work completion during remote learning. For literacy skills, the findings mirror those above: children who completed sufficient remote work demonstrated comparable learning stagnation during school closures as children with insufficient remote work completion. However, children who completed sufficient remote work demonstrated more slowdown in literacy skill growth after school re-opening than children with insufficient remote work completion (*B* = -.38, *SE* = .03, $p < .001$). Children who completed sufficient remote work had a simple slope of 3.16 points per month before schools closed, and a simple slope of 1.50 points per month after schools re-opened. Children who completed insufficient remote work had a simple slope of 2.92 points per month before schools closed, and a simple slope of 1.64 points per month after schools re-opened.

Turning to math skills, the results suggest that children who completed sufficient remote work showed less stagnation in math skills during school closures than children who completed insufficient remote work (*B* = 3.90, *SE* = .47, $p < .001$), and they also demonstrated less slowdown in growth after schools re-opened (*B* = 0.11, *SE* = .02, $p < .001$). Children who completed sufficient remote work had a simple slope of 2.18 points per month before schools closed, and a simple slope of 0.96 points per month after schools re-opened. Children who completed insufficient remote work had a simple slope of 2.23 points per month before schools closed, and a simple slope of 0.90 points per month after schools re-opened.

Discussion

This study was designed to examine how children's academic skills were affected by COVID-19-induced school closures. We modeled children's growth in literacy and math, measured repeatedly before and after the period of school closures, and we attended to changes in both the intercept—representing children's possible stagnation in skill levels—as well as changes in the slope—representing slowdown in children's rate of growth in the years following school reopening. We also explored whether any stagnation in levels or slowdown in rates varied with children's extent of participation in remote learning during school closures. These data are significant in that they provide measures of academic growth of children too young for standardized tests and do so using longitudinal data in which the same children were assessed repeatedly both before and in multiple years after pandemic-related school closures. Consistent with other studies, we find that students returned to in-person schooling with lower literacy and math scores than expected. Extending beyond other studies, we find that children's rate of growth across the first two years back in school was slower than their own pre-COVID rate of growth.

Academic Outcomes Before and After COVID-19-Induced School Closures

Like others (e.g., NAEP, 2022a; 2022b; 2024a; 2024b), we found stagnation in math and reading during school closures in our younger, diverse cohort of low-income children. We also documented greater stagnation in math than in literacy, similar to recent studies (Goldhaber et al., 2022; Kuhfeld et al., 2022). In our analysis, the amount of stagnation in math skills was over three times the amount of stagnation in literacy skills. These results have great practical importance. One way to conceptualize the magnitude of this loss is relative to months of learning gain that would have occurred under usual face-to-face instruction. Per that metric, children lost roughly 2.91 months of growth in literacy and roughly 14.48 months of growth in math learning during school closures. In other words, children experienced almost no growth in their math skills during school closures. The magnitude of this loss is roughly consistent with the worst-case estimates of Kogan and Lavertu (2021), who concluded—based on a comparison of standardized test scores among pre- and post-COVID cohorts—that pandemic-related losses in children's math skills were equivalent to roughly one-half to one full year of math learning.

Children's development of math skills may be more reliant on school instruction than literacy skills. For example, studies of summer learning loss often demonstrate a greater decline in math compared to reading (Cooper et al., 1996; Kuhfeld et al., 2020). These trends may reflect differences in the extent to which children are exposed to math-related, as opposed to language-related, learning opportunities outside of school. Parents frequently engage with children in activities that might nurture development of literacy skills, like reading, writing, and back-and-forth verbal interactions (NCES, 2021). Additionally, most children are regularly exposed to print in their day-to-day lives outside of the classroom, via books, digital media, product labels, and public signage (Neumann et al., 2012). By contrast, math learning and practice typically occur in structured school environments (Skwarchuk et al., 2014; Tudge & Doucet, 2004). The period of remote learning is likely to have disproportionately deprived children of these math learning opportunities. It is also possible that teachers found it more challenging to support children's math than reading learning remotely, with some elementary school teachers entirely foregoing direct math instruction during emergency remote teaching (Goodrich et al., 2022). Given the possibility of future emergencies that necessitate school closures, there is an urgent need to identify strategies that promote parents' self-efficacy and skills in supporting their children's math learning (Eason et al., 2021), as well as effective strategies and supports for teachers delivering math instruction virtually.

This study also finds that children's rate of growth in literacy and math skills in the two years following the return to in-person learning was in fact slower than it had been before school closures, although our comparison to normative test data suggest that slowdown was developmentally expected between third and fifth grades. Patterns of non-linear growth are abundant in the developmental literature; indeed, most intellectual abilities demonstrate rapid acceleration followed by a plateau over time (McArdle et al., 2002), but the inflection point when deceleration sets in varies across measures and observation windows. For example, in the NICHD ECCRN, children's WJ III reading (a composite including Letter-Word ID) W scores skills developed faster between 54 months and first grade than between first grade and fifth grade (Skibbe et al., 2008). Of course, we are unable to rule out the possibility that children's experiences of remote learning – or other features of the COVID-19 pandemic – also contributed to the slowdown in academic skill acquisition after the return to in-person learning in our sample. Additional research is needed to test the possibility that pandemic-related school closures not only impaired how much children learned, but also their rate of learning in the succeeding years.

Moderation of Outcomes by Remote Learning Participation

Our examination of children's remote learning participation during school closures as moderators of their pre-post-COVID-19 literacy and math skill trajectories revealed that participation in remote learning – like attendance at school during normal in-person instruction (Ansari et al., 2021; Ehrlich et al., 2018; Fuhs et al., 2018) – mattered, but in some unexpected ways. More participation measured in terms of contact with the teacher and work completion was associated with less stagnation and slowdown on math scores, on the one hand, but also a slower rate of growth in literacy following school re-opening, on the other.

What explains this? One possibility is selection, whereby children who were already performing better academically pre-COVID, participated more in remote learning during COVID. A unique benefit of our prospective pre-COVID data is the ability to examine the same children's scores *before* remote learning; and indeed, we see that children who went on to sufficiently participate in remote learning had both higher literacy scores and more rapid literacy growth pre-COVID than other children. When schools re-opened, the "sufficient participators" still scored higher on literacy than children, but were unable to meet their pre-COVID rate of growth. It is possible that children who participated fully during remote learning had parents who were more involved in their education, which could explain not only their level of participation but their higher levels and growth rates of literacy skills before the onset of COVID-19. Yet this pattern was not true for math: children who participated more during remote learning had no advantage over other children on math before COVID-19, suggesting that even if their parents were more promotive of literacy skills than other parents, they were not more promotive of math skills. This is consistent with the literature showing that parents of young children are more comfortable supporting reading than math development (Cannon & Ginsburg, 2008; Sonnenschein et al., 2021). That sufficient participation in remote learning protected against stagnation and slowdown in math skills after school closures is novel and noteworthy: our sample represents children from exclusively low-income families who disproportionately suffered the health and economic consequences of COVID-19 (Karpman et al., 2020; Koma et al., 2020) and were more likely to report documented obstacles to remote learning participation such as lack of internet and device access (Domina et al., 2021; Francis & Weller, 2022; Golden et al., 2023; Haderlein et al., 2021). In spite of these challenges, remote learning participation was protective for math. School districts should thus prioritize remote learning access for families with low resources in any future disaster that closes schools for an extended time.

Limitations

The current study has several limitations that should be noted alongside its contributions. First, our measure of remote learning participation was captured in the fall of second grade, which may not fully characterize children's earlier participation in remote learning when schools first closed during the spring of first grade, or their later participation as remote learning continued into the spring of second grade. It is also a blunt measure: teacher reports may not be sufficiently sensitive to capture other types of remote learning participation that may matter for children's outcomes, such as children's level of attention and engagement during remote lessons. It also does not capture learning that occurred at home outside of remote instruction such as time parents or siblings spent reading to the children in our sample. Second, our sample was entirely low-income and drawn from a single school district in Tulsa where most schools remained closed for at least one full year (March 2020 – September 2021). Future studies should seek to replicate these findings with other cohorts of children of varying socioeconomic status and grade level, and who experienced more variety in school closure lengths throughout the U.S.

Conclusion

Using prospective data collected both before and long after the COVID-19 pandemic closed schools, on a sample too young for standardized testing and thus excluded from much media and research coverage, we find stagnation in children's literacy and, to a greater extent, math skills. Further, insufficient participation in remote learning predicted greater stagnation in math skills. This is a noteworthy finding with policy implications, because many families reported obstacles to full participation during remote learning, including those that correlate with economic resources such as internet access and device availability. Indeed, the period of school closures opened a gap between the low-income children in our sample and national norms – a gap that had been appearing to close prior to the pandemic. Should the need for remote learning arise in the future, intensive efforts to support learning in low-resourced home environments will be needed to avert the introduction or exaggeration of inequities in academic achievement, particularly in math, based on family background.

A novel finding of this study is its modeling of the rate of change in children's learning following school re-opening through 2023. While prior studies have compared the longitudinal growth rates of different pre- and post-pandemic cohorts, ours is the first to model intra-individual changes in children's growth trajectories from before school closures to multiple years after school re-openings. While we found slowdown in the rates of academic skills growth compared to pre-pandemic rates, our comparison to a norming sample suggests this may be attributable to normal age-related deceleration. However, in order for children to fully catch up to their pre-COVID levels of learning, we would have needed to see speedup in growth rates following the return to school; instead, we observed slowdown. That the slowdown was (in our estimation) developmentally normative does not lessen the pandemic's negative impact on children's academic skills.

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Table 1.
Sample Descriptive Statistics

	M/Prop.	SD	n
Child race/ethnicity			
Hispanic/Latinx	.53		680
Black	.22		680
White	.11		680
Other race/ethnicity	.15		680
Child age in months at fall of preschool	54.37	3.69	680
Child is female	.51		680
Child is dual language learner	.49		679
Mother was single at child's birth	.51		555
Mother's age at child's birth	26.25	6.08	548
Parent has more than a high school education	.38	.49	557
Parent is employed (full- or part-time)	.68	.47	450
Monthly household Income ($)	1877.43	1201.12	530
Child remote learning participation			
Sufficient contact with teacher	.56	.50	679
Sufficient remote work completed	.60	.49	680

Note. Descriptive statistics are computed on unimputed data.

Table 2.
Longitudinal growth models predicting children's academic outcomes from COVID-19-related school closures.

	Literacy		Math	
	B	SE	B	SE
Time	3.06***	0.01	2.20***	0.01
Post-COVID	-8.90***	0.35	-31.85***	0.23
Time x Post-COVID	-1.51***	0.01	-1.26***	0.01
Constant	393.04***	16.51	436.44***	10.31
n	680		680	

Notes. All models control for child race/ethnicity, gender, age at the fall of preschool, dual language learner status, mother's age and marital status at child's birth, parent education and employment, and the natural log of household income. Models include random intercepts to account for the nesting of timepoints in children. Missing covariates are multiply imputed.
* $p < .05$; ** $p < .01$; *** $p < .001$

Table 3.
Longitudinal growth models predicting children's academic outcomes from whether they had sufficient contact with their teacher during remote learning

	Literacy		Math	
	B	SE	B	SE
Time	2.93***	0.01	2.20***	0.01
Post-COVID	-8.12***	0.53	-33.31***	0.35
Time x Post-COVID	-1.31***	0.02	-1.28***	0.01
Sufficient contact with teacher	16.34***	2.28	1.65	1.44
Time x Sufficient contact with teacher	0.24***	0.02	0.01	0.01
Post-COVID x Sufficient contact with teacher	-1.25	0.7	2.65***	0.46
Time x Post-COVID x Sufficient contact with teacher	-0.36***	0.03	0.03	0.02
Constant	383.75***	16.31	435.31***	10.31
n	679		679	

Notes. All models control for child race/ethnicity, gender, age at the fall of preschool, dual language learner status, mother's age and marital status at child's birth, parent education and employment, and the natural log of household income. Models include random intercepts to account for the nesting of timepoints in children. Missing covariates are multiply imputed.
* $p < .05$; ** $p < .01$; *** $p < .001$

Table 4.
Longitudinal growth models predicting children's academic outcomes from whether they had sufficient remote work completion during remote learning

	Literacy		Math	
	B	SE	B	SE
Time	2.92***	0.01	2.23***	0.01
Post-COVID	-9.70***	0.55	-34.24***	0.37
Time x Post-COVID	-1.28***	0.02	-1.33***	0.01
Sufficient remote work completion	17.72***	2.28	1.69	1.45
Time x Sufficient remote work completion	0.24***	0.02	-0.05***	0.01
Post-COVID x Sufficient remote work completion	1.3	0.71	3.90***	0.47
Time x Post-COVID x Sufficient remote work completion	-0.38***	0.03	0.11***	0.02
Constant	383.27***	16.15	435.76***	10.24
n	680		680	

Notes. All models control for child race/ethnicity, gender, age at the fall of preschool, dual language learner status, mother's age and marital status at child's birth, parent education and employment, and the natural log of household income. Models include random intercepts to account for the nesting of timepoints in children. Missing covariates are multiply imputed.
* $p < .05$; ** $p < .01$; *** $p < .001$

Figure 1. ***Children's academic development before and after school closures.***

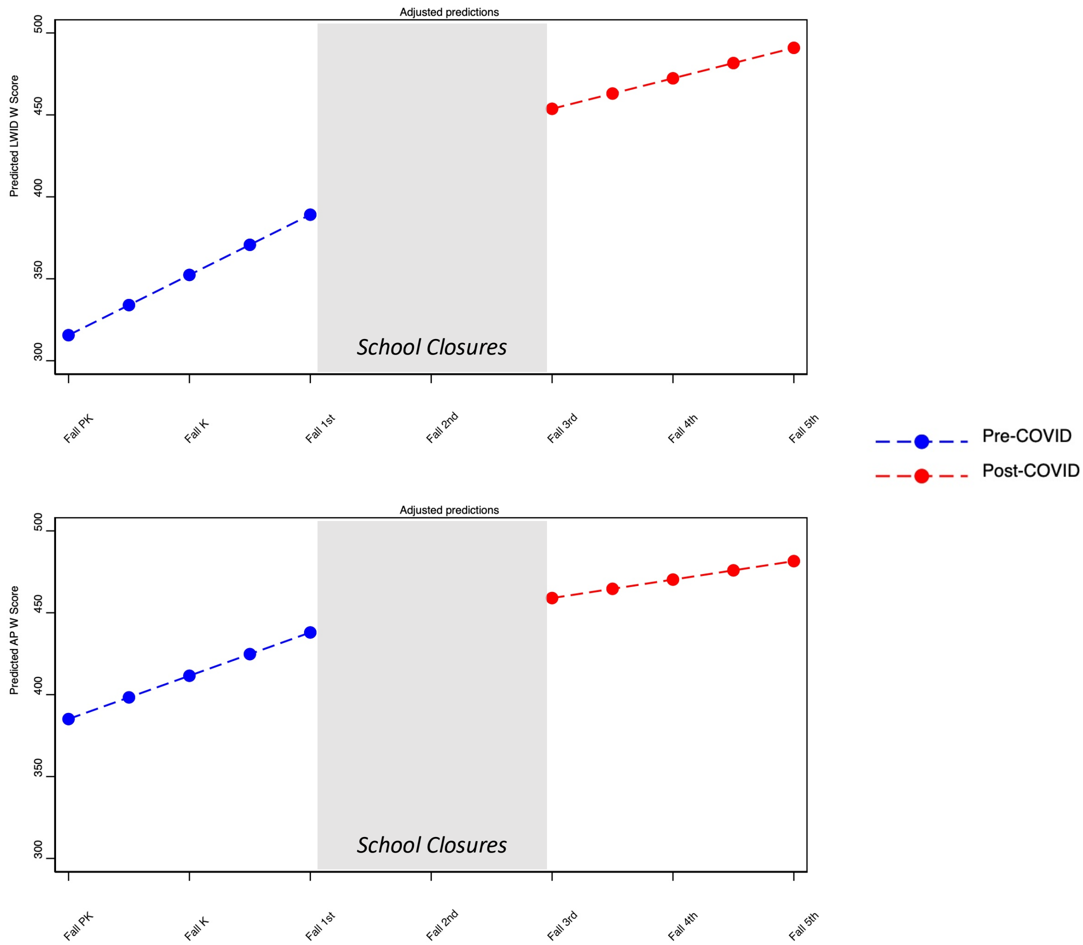

Figure 2. ***Children's academic development before and after school closures as a function of whether they had sufficient contact with their teacher during school closures***

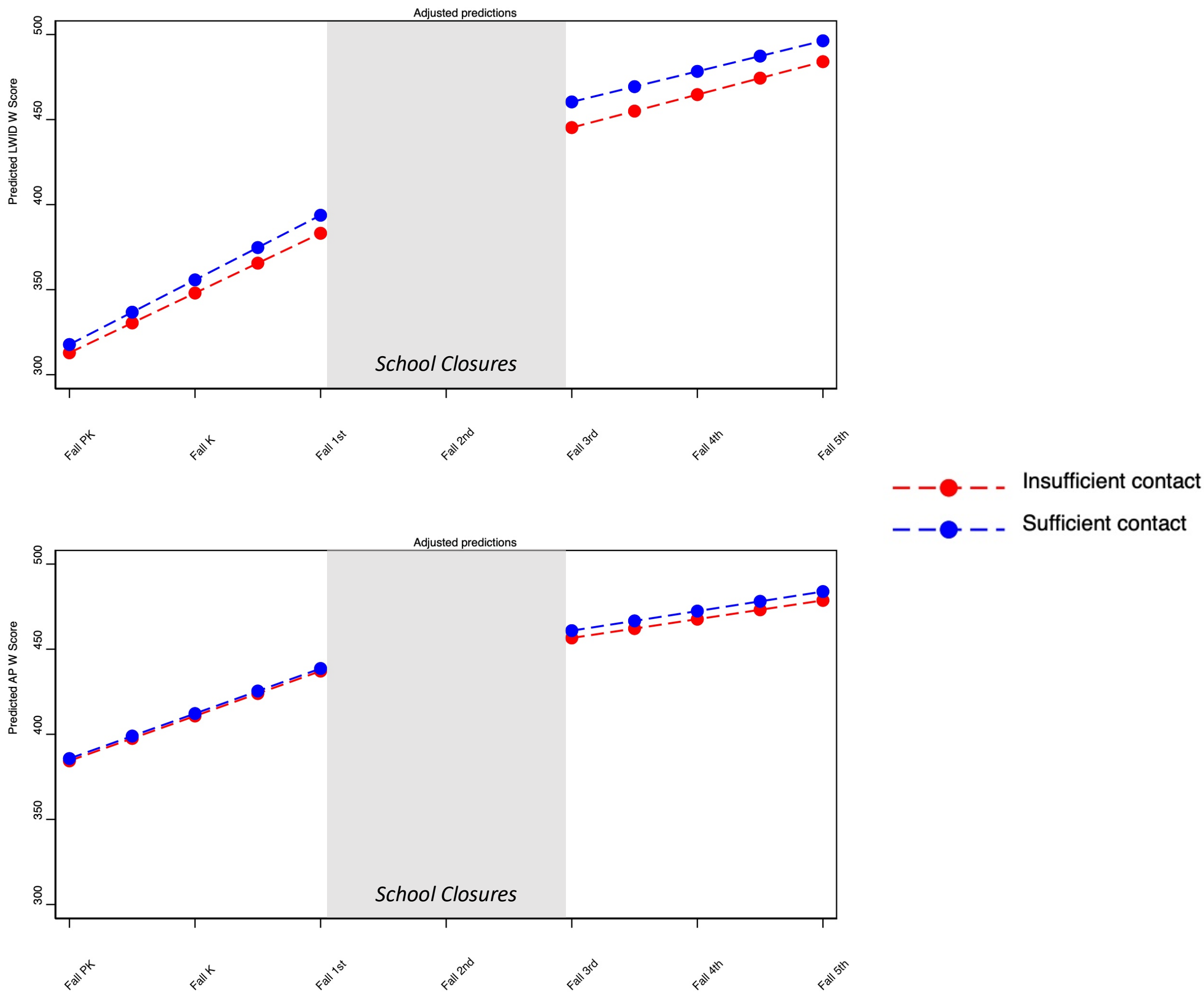

Figure 3. ***Children's academic development before and after school closures as a function of whether they had sufficient remote work completion during school closures***

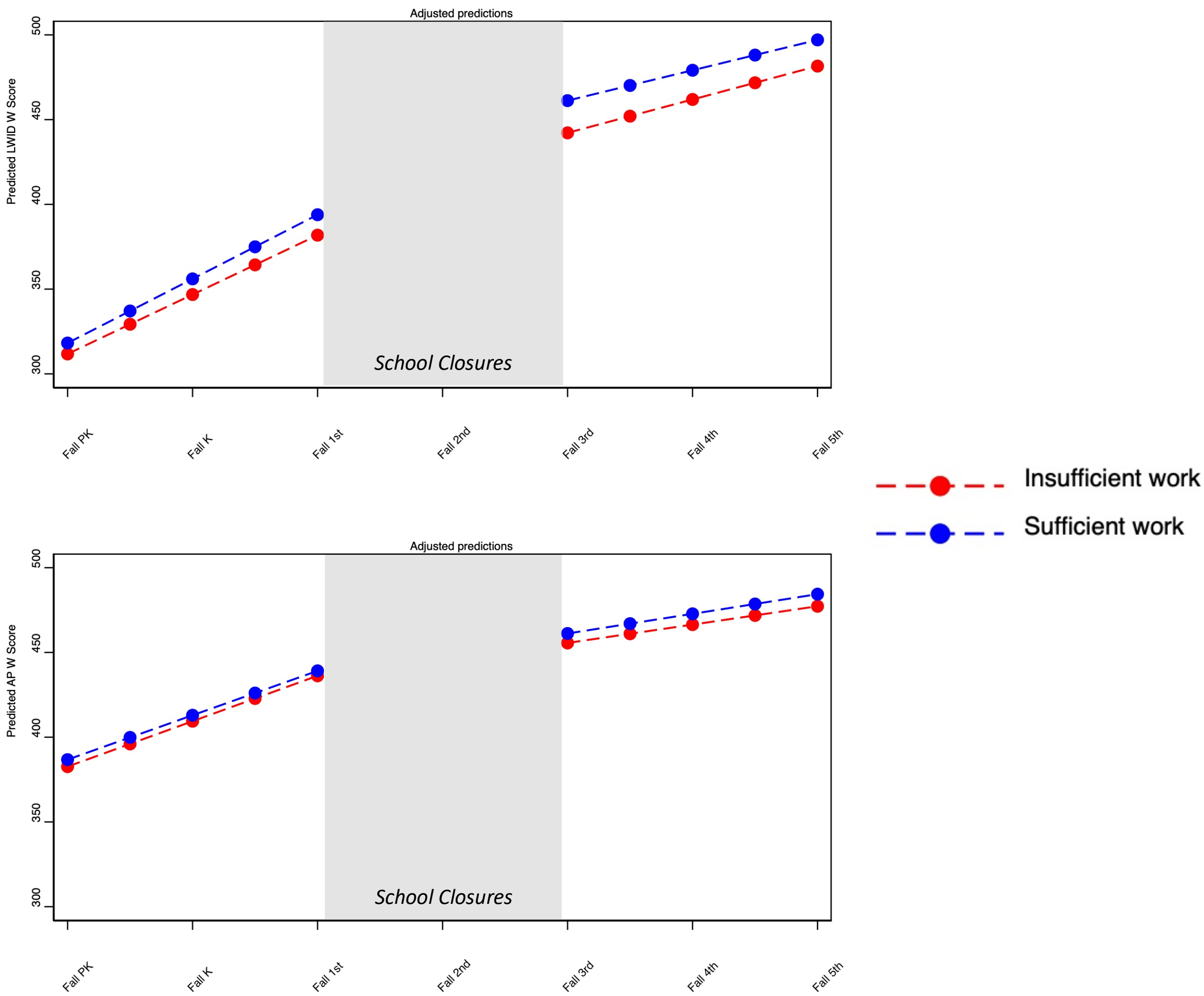

Figure 4. ***Children's standard scores before and after school closures.***

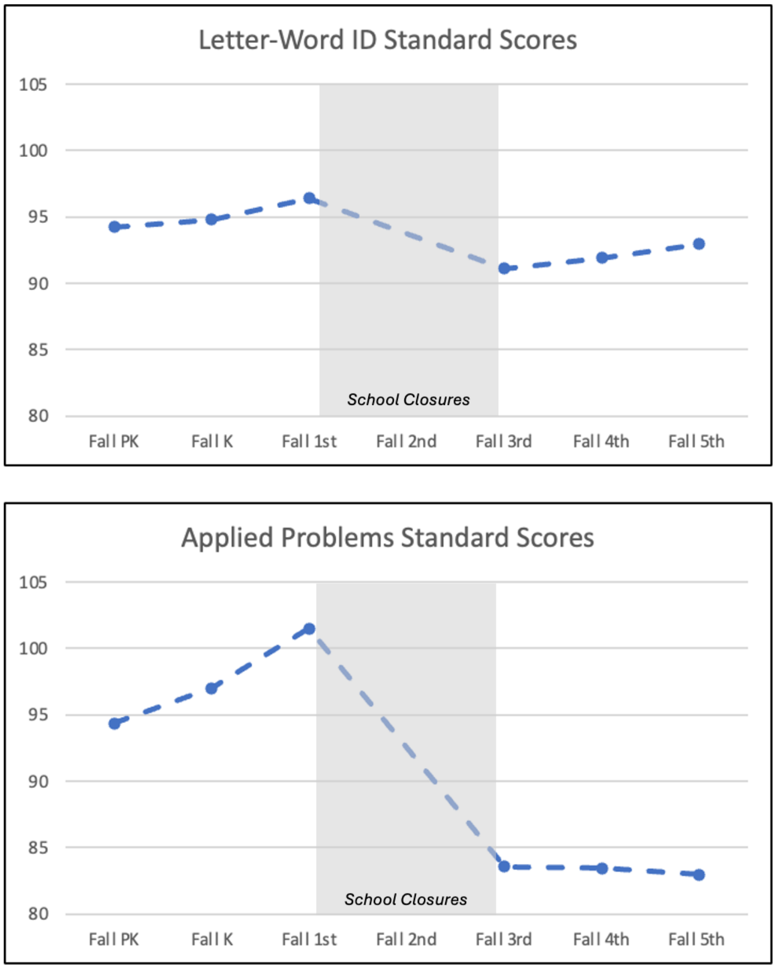

Figure 5. ***Norming sample means by age versus growth trajectories in the current sample***