Pandemic effects on the reading trajectories of deaf and hard of hearing students: a pilot analysis

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Abstract
It is important to understand the nature of the effect that the COVID-19 pandemic had upon student learning, especially those at risk such as deaf students. The limited communication that many deaf students have at home may mean less support is available for learning remotely. Reading may be one of the areas where progress was diminished. We collected Measures of Academic Progress (MAP) scores in reading from deaf students in a residential school for the deaf in grades 3 to 12 every fall and spring from 2016 to 2021. A cohort-sequential approach yielded growth data (2570 observations), with 546 students measured up to 10 times each. As is typical of MAP reading achievement in grades 3 to 12, growth was steep in early grades, slowing in later grades. Students in the Alternative Curriculum performed lower and grew slower. Cohorts differed, with more recent cohorts typically having higher performance than older cohorts. Tenure had a substantial effect, suggesting that students who had been in the school for the deaf longer had higher performance compared to students who joined the school as older students. The pandemic appeared to have a strong, but diminishing effect in each semester, but this effect differed widely across demographic groups. This suggests that effects of the pandemic are neither clear nor simple for deaf students even within the same school. These findings have implications for understanding how the impact of pandemic may vary as a function of deaf students’ educational experiences and other demographic factors.

Keywords COVID impact on learning · Deaf students · Remote learning · Reading growth · Cohort-sequential approach

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Introduction

As the COVID-19 pandemic spread around the world, education at all levels was impacted on an unprecedented scale (Lewis et al., 2021; Juniper Education, 2022). Teachers and school administrators alike are concerned about the consequences caused by the pandemic upon student learning. The impact of less instructional time, missed learning opportunities, and the move of learning to a primarily online/distance format is still not fully understood (Kuhfeld et al., 2021). The goal of the article is to understand the impact of the pandemic on the trajectory of deaf\(^1\) students’ reading development. Reading is a topic with a long history of concern for this population. Some deaf students do not have high quality communication at home, and it is often the case for students with parents who have limited signing abilities (Allen, 2015). Those students will more likely receive less learning support from adults in their homes during remote learning. Reading is a subject that can be challenging to learn remotely when there is no one at home who can explain to the student what a word or sentence means. Teachers may also find it challenging in a remote learning environment to provide the kind of individualized support that the students normally get as part of their education.

In this paper, we examine reading development among deaf students at a large residential school where American Sign Language (ASL) was the language of instruction. There is more communication access at a large residential school than what many students have at home. The students at the school were not in the physical classroom for 17 months after the onset of the pandemic. We wanted to know how the sudden and lasting change from classroom learning to remote learning may affect the trajectory of reading development. We expected that the pandemic would have an impact and that the impact would vary across the student population.

Literature review

March of 2020 marks the date when the circumstances of learning changed for many students nationwide. The nature of change and its impact varied from one population to the other and from one geographical area to the next. Emerging evidence suggests that after the COVID-19 pandemic began, many students spent a lot of time in virtual or online schooling (Juniper Education, 2022; Lewis et al., 2021). This is an unprecedented event, and we are only just beginning to understand the potential consequences of these changes in instructional delivery. Prior research on schooling effects and the vulnerabilities of certain student populations suggests that the COVID-19 pandemic has affected learning and that the impact likely varies across different segments of the student population.

\(^1\) We chose to use the word “deaf” to refer to both deaf or hard of hearing children.
Schooling effects

There is evidence on the long-term impact of an external event that offers a preview of the possible consequences of the COVID-19 pandemic. A study on the effects of a prolonged teacher’s strike in Argentina showed that one of the negative impacts of missed school had resulted in lowering the students’ later job market prospects and levels of pay when compared to children who did not experience this learning disruption (Jaume & Willen, 2019). In addition to school disruption by external events, there is ample evidence to suggest that even the typical summer break impacts the academic growth of students. The effect of missed schooling results in slower growth trajectories. In some cases, it may result in growth regression (Alexander et al., 2001; McCoach et al., 2006). These effects have been found in domains related to literacy (e.g., vocabulary, phonological awareness, letter-word identification) among general student populations in preschool (Skibbe et al., 2012) and elementary school (Cooper et al., 1996). Though there is not much research on schooling effects that concerns deaf students, there is at least one study (Scott et al., 2019) that reported the negative effects of summer breaks in the development of vocabulary and letter word identification among deaf students in preschool through kindergarten. These findings suggest that the COVID-19 pandemic disruption of schooling may have negative effects on the literacy learning trajectories of students who are deaf.

Deaf students present a unique case with regard to the importance of in-person schooling for learning and development especially in literacy. While schooling impacts the literacy development of young learners in general (Cooper et al., 1996; Skibbe et al., 2012), the situation is more critical for deaf students. Literacy development is an important area of learning for which deaf students of all ages are very dependent on schooling. Many deaf children by the time they learn to read still do not know English. For many of them learning to read is also how they learn English. The pace at which those children develop reading skills grows in tandem with the increasing knowledge of English they have acquired through reading (Kuntze & Golos, 2019). This unique mode of learning to read is at the beginning teaching intensive and often requires individualized or small group instruction. For example, one approach is through translation and discussion in which ASL, the student’s language of strength, is used to bring meaning to what the student is reading. The student’s ability to benefit from the approach is aided if the student has competency in ASL (Kuntze, 2004).

COVID-19 Impacts

Almost as soon as the pandemic began, researchers began to discuss and examine the ways in which it may have impacted student growth and achievement. Before data were even available, Kuhfeld and Tarasawa (2020) made inferences based upon the impact of schooling effects and absenteeism on MAP scores to predict a slowdown in growth resulting from the pandemic. It was confirmed that both average
reading and math scores in Fall 2021 were lower than average scores in these subjects in Fall 2019 (Kuhfeld et al., 2021).

Other researchers have confirmed those data. For instance, Lewis and colleagues (2021) compared student growth during the 2020–2021 school year to prior years and found that although students made gains on the MAP assessment, this growth was lower when compared to prior years. Similar findings were identified elsewhere such as in the United Kingdom (Juniper Education, 2022). This report found that in addition to the impact on the general student population, according to standardized assessment scores, the impact of the COVID-19 pandemic was greater for children with disabilities, children from lower socioeconomic status families, and younger students. According to the researchers, the gaps between higher and lower achieving students in terms of standardized test results appeared to be growing. They also found that writing was more impacted than other tested areas (Juniper Education, 2022; Lewis et al., 2021).

**Differential effects**

It is important to note that disruption to schooling may have a differential impact on students depending on a variety of factors such as age or English language learner status. For instance, there appears to be a more substantial impact on younger students as compared to older students (Georgiou, 2021; Juniper Education, 2022). The perception of parents in Hong Kong based on a survey done by Lau et al. (2021) was that their younger children’s online learning experience was not effective because it did not provide these children with the direction and support that they needed. The experience that deaf children have related to issues of language and their impact on learning parallels, in a respect, the educational experience that children from language minority homes have. Dustmann et al. (2012) suggest that language minority parents may be unable to effectively help their children access online learning materials that are written in English. In the case of deaf children, whether they are in a language minority home or not, the extent of support they have for learning at home depends on the level of signed communication they have with their parents. Further, it seems to be the case that the development of reading skills is sensitive to disruptions to learning (Sacerdote, 2011), and it is reasonable to speculate that this may be even more so for deaf students due to their unique experiences with language and literacy development.

**Impact on deaf students**

Despite the emerging research on the COVID-19 pandemic and how it has impacted student learning, there is very little research that has been published regarding the effect of the pandemic on deaf learners. Deaf students are not homogenous as a group. While it was expected that deaf students, like other students, have been affected by the pandemic, the question remains how the impact may vary across this diverse student population.
There are different educational programs that are available for deaf students. The focus of the paper is the impact on the students who go to a residential school for deaf students which is uniquely different from other educational options provided to deaf students. The residential school functions as a self-contained learning environment designed to meet the learning needs of deaf students. The experience of deaf students in local public schools varies widely. Some of them may be the only deaf students in the whole school. They may be provided an interpreter. Others may be placed in a special education program for non-deaf students whose needs are very different from those of a deaf student. Deaf students in a large urban area may go to public school that houses a self-contained program for deaf students. There they would have an opportunity to be educated alongside deaf peers, though the number is likely smaller than that in a residential school. The vast majority of deaf children are born to hearing parents (Mitchell & Karchmer, 2004), and these parents are unlikely to have known or learned to communicate in sign language, or even to have met a deaf person before their own child (Napier et al., 2007). Parents vary in the extent to which they may learn ASL and to which they may embrace it as a primary mode of communication with their deaf child.

For some deaf children, schools for the deaf serve as important centers of language transmission. For many of them, it is the major place they can access fluent language models and peers and adults who can understand them (Scott et al., under review). The school we studied, like most schools, transitioned to full remote learning during the early pandemic so the change in learning mode is not to be taken lightly. On top of the many challenges of teaching K-12 students remotely, technologically it is challenging to use ASL online. Communication through ASL can take place only through video and it requires a lot of bandwidth. Otherwise, a low video resolution makes remote communication between teachers and students impossible to understand. The unprecedented change in learning mode as a result of COVID-19 made it even more important to investigate the impact of pandemic on deaf students.

The goal of this article is to explore the effects the pandemic may have on the reading development of deaf students in one school for the deaf, and to investigate how the impact may be different across the student body. Specifically, we sought to answer the following research questions:

1. To what extent has the pandemic affected student trajectories in reading test scores?
2. To what extent did pandemic effects differ among students depending on their age, their age of enrollment at the school, and other demographic features?

Methods

Participants and site

This study is based on the data from a large school for the deaf in the United States. The school has residential facilities for students who live too far away to commute daily during the weekday. The students were immediately sent home in March 2020
in response to COVID-19 pandemic without any contingency plan on how their education might continue. The teachers and the residential personnel quickly embarked into uncharted waters to set up an infrastructure for remote learning so all students, some of whom live more than 200 miles from the school, may continue with their education.

The school provided archival MAP (Measuring Academic Performance) scores from the tests that the students in grades 3 to 12 participated in at both the start and the end of school year from 2016 to 2021, yielding 2691 observations on 561 students across ten semesters (no testing was conducted in spring 2020). MAP is a computer-adaptive test, meaning every student gets a unique set of test questions based on responses to previous questions. There are two levels of the test in reading depending on the grade the student is in. One is for students in grades 3–5 and the other for students in grade 6 throughout high school. The typical length of time for the MAP test in reading is one hour but the actual length for each student varies because of the adaptive nature of the test. The test was administered in the classroom by the students’ teachers on either laptop or desktop computers with the test synchronized at real time with NWEA. During the period of remote learning, the test was proctored through Zoom. Fifteen students repeated twelfth grade and their repeated semesters were excluded from the analysis. Sixteen students were retained in grades before 12th and for those students their scores during the year they repeated in the same grade were excluded, as their repetitions could not be dependably modeled.

The school as an educational setting served between 350 and 400 students from the infant program to high school. The number of students increased from one grade level to the next. The average number of students in 3rd grade over 5 years up to 2021 was 9.4, and the average number of seniors was 41.5. There are various reasons, largely anecdotal, for the large number of students in the latter grades relative to the earlier grades. Some of the important reasons are that families vary in their understanding about different language options and educational placement options. The distance between the family home and the school is an important factor for some families.

The students’ fluency in ASL varied for different reasons. An important factor for many students is the length of time they have been enrolled at the school. The COVID-19 pandemic meant 17 months of remote learning away from the language community at the school. It meant being connected to the teachers and peers only through Zoom, Flipgrid, and other video-based apps. The quality of signed language communication at home varies widely for students with non-deaf parents.

The student body at this school is diverse (Table 1). There was no clear ethnic majority as the school was 46% Hispanic/Latinx and 30% White. Students in other racial/ethnic categories comprised the remaining 24% of the sample. There were more male (54%) than female students.

In addition to the regular curriculum that follows the state standards, the school has an alternative curriculum program for a small population of students who either have cognitive disabilities or have experienced significant language deprivation (caused by impoverished communication access to others). The Alternative Curriculum program provides educational experiences that are more application-oriented
and hands-on in nature, and it focuses upon life skills. 23% of the students in the sample were enrolled in the Alternative Curriculum program.

### Statistical analysis

There are two important design features of the model for analyzing the effect of the pandemic. First, we wished to plausibly model nonlinear trajectories over years, including summer learning loss. Students were not all tested on the same day, and the use of a simple evenly spaced grade-as-wave coding would not accurately reflect students’ change over time (Seltzer et al., 1994). In order to effectively model trajectories, we used each student’s date of testing and not merely wave. Summary statistics for these dates are shown in Table 2 which shows that test dates ranged from 32 to 97 days within a semester. Also, with the tests in the fall and in the spring, it is possible to model effects of summer loss because performance in the fall may reflect the extent to which the absence of regular instruction may have had an effect on student reading performance.

| Semester     | Mean   | Min   | Max   | Range (days) |
|--------------|--------|-------|-------|--------------|
| Fall 2016    | 9/22   | 8/23  | 11/16 | 85           |
| Spring 2017  | 4/30   | 4/11  | 5/19  | 38           |
| Fall 2017    | 9/8    | 8/30  | 11/27 | 89           |
| Spring 2018  | 4/30   | 3/7   | 5/22  | 76           |
| Fall 2018    | 9/5    | 8/21  | 11/26 | 97           |
| Spring 2019  | 4/24   | 4/8   | 5/17  | 39           |
| Fall 2019    | 8/30   | 8/26  | 11/12 | 78           |
| Spring 2020  |        |       |       |              |
| Fall 2020    | 11/24  | 11/16 | 12/18 | 32           |
| Spring 2021  | 3/25   | 3/15  | 5/18  | 64           |
| Fall 2021    | 9/21   | 9/13  | 12/9  | 87           |

Numbers represent calendar dates within that year (month/day). Range represents the number of days between the earliest and latest testing within that semester. No testing was conducted in Spring 2020.
Second, we wished to account for two aspects of age-related effects. The first one is related to age-based cohorts which are students of the same birth year range who moved together from one grade to the next. We will henceforth label them as “Kindergarten cohorts.” Students’ reading performance may differ in important but mostly unknown ways across cohorts. We therefore used age-based cohorts as a proxy to estimate differences due to year of birth among students who move through each respective grade (e.g., 6th grade reading performance among each cohort of students who were in sixth grade between 2016 and 2021). The second age-related effect is the age of enrollment at the school, which gives us the duration of exposure to the school’s curriculum, pedagogy, and language use. Each Kindergarten cohort, while similar in the age ranges, varied in the ages at the time they were enrolled at the school—i.e., their tenure. Therefore, we attempted to model those two effects of age-related differences, if any, to help clarify our estimates of the pandemic effects.

We fit individual quadratic growth models for MAP reading achievement for the shape of growth, summer learning loss, and for the effect of the pandemic. The following equation represents the prediction of MAP scores for each student in any given grade with a conceptual grouping of four types of predictors.

\[
\text{MAP} = \text{growth} + \text{pandemic} + \text{demographics} + \text{cohort} + \text{error}
\]

Overall, this is a mixed-effects regression for time within student—an individual growth model. (The full listing of parameters is discussed in the results section related to Tables 4 and 5.) Growth represents a quadratic growth model for year of schooling with an intercept centered at grade 8 and linear and quadratic terms for years, with random effects for intercept, linear slope, and quadratic slope (i.e., students differ in level, linear rate of change, and curvature over time). Time is measured as year of schooling (grade), shifted for students’ individual date of testing (proportion of the calendar year). An effect for fall, to represent summer learning loss, is also estimated and allowed to interact with grade (as summer loss may differ across grade levels). Because the program is a fundamental grouping variable, an intercept and linear component for students in the alternative curriculum program are also estimated. Students in the alternative curriculum program may perform lower and grow slower compared to students in the regular curriculum program.

Pandemic is a set of three semester-specific effects after the onset of the pandemic for Fall 2020, Spring 2021, and Fall 2021. This also allows for the pandemic effect upon students’ trajectories to differ across semesters (i.e., we are not assuming it to be linear or an overall average).

Demographics include gender and race/ethnicity. These are allowed to interact with the pandemic effects, but not with time, as group sizes were too small to dependably estimate group-specific slopes.

Cohort is a set of two variables to control for age-related effects: kindergarten cohort and tenure in the school. Kindergarten cohort reflects potential shifts in the population (i.e., outside of the school). The oldest cohort was in Kindergarten in the year 2004 and the youngest cohort was in Kindergarten in the year 2018. Kindergarten cohort was centered at year 2010. Tenure reflects the potential effect of being within the school longer than other students within the same grade (e.g., a
The final sample used for analysis contained 2570 observations on 546 students (Table 3), measured up to 10 times each (median = 4 semesters). The number of students who participated in the MAP testing averaged 281 during the pre-pandemic years but dropped to an average of 188 during the time of remote learning. There were some challenges in administering the test to everyone online during the period of remote learning. The school opened in the Fall of 2021 with a somewhat smaller student enrollment.

Grade 3 had the smallest total of observations (94). The total enrollment generally increased for each grade, and by grade 12 the total observations was 415. An average of 4 new students were enrolled at each grade each year. The number of students for each grade remained similar over the years but the number of students increased over each succeeding grade. Students took MAP remotely in Fall 2020 and Spring 2021 and the logistics of testing remotely caused lowered test participation. The bottom two rows in Table 3 show the mean and SD for reading scores based on the total observations in each grade (top row) over the span of 5 years (first
column). Although average reading scores increase every semester, the increases later, especially in the high school grades, appear to slow down substantially. The SD also grows at each grade showing the increasing variance in the student population in the later grades.

Figure 1 shows the individual trajectories for all 546 students across grades. Each line represents an individual trajectory in reading performance over time. The wide variance in the scores reflects the wide variability in the student population in terms of reading performance. The figure shows a pattern in growth that is typical of MAP reading achievement in grades 3 to 12. Growth was steep in early grades, slowing in later grades. Figure 1 also shows overall quadratic fit lines (black line), one for the regular and one for the alternative curriculum students.

We fit three types of models to evaluate the effect of the pandemic: average effects, shocks, and persistent effects. These models are explained in the appendix. The models for shocks and persistent effects suggested that the three semesters had different effects, and that therefore the single average effect was not appropriate for the potentially different effects across the three semesters. The estimates for the shocks and persistent effects were nearly identical (specifications are shown in appendix Table 7). We therefore present results for the simpler semester-shocks model.

Table 4 shows the fixed effect estimates (regression parameters) for the predictors, grouped for their conceptual types. The top block of predictors shows the growth model portion. The intercept implies that the average student would be
Table 4: Fixed effects for the individual growth model

| Type             | Effect          | Estimate | SE   | df  | t    | p     |
|------------------|-----------------|----------|------|-----|------|-------|
| Growth           | Intercept       | 199.02   | 1.59 | 905 | 124.85 | < .01 |
|                  | Grade           | 3.73     | 0.26 | 689 | 14.18 | < .01 |
|                  | Grade^2         | −0.33    | 0.04 | 368 | −8.13 | < .01 |
|                  | Summer          | −1.08    | 0.65 | 1713| −1.66 | 0.10  |
|                  | Grade*Summer    | 0.28     | 0.12 | 1782| 2.43  | 0.02  |
|                  | AC              | −31.64   | 1.78 | 554 | −17.79| < .01 |
|                  | Grade*AC        | −1.60    | 0.32 | 412 | −5.03 | < .01 |
| Pandemic         | Fall20          | −2.17    | 1.20 | 1977| −1.80 | 0.07  |
|                  | Spring21        | −1.10    | 1.35 | 1881| −0.82 | 0.41  |
|                  | Fall21          | 1.70     | 1.42 | 1642| 1.20  | 0.23  |
|                  | Grade*Fall20    | 0.41     | 0.25 | 1511| 1.64  | 0.10  |
|                  | Grade*Spring21  | 0.40     | 0.27 | 1407| 1.48  | 0.14  |
|                  | Grade*Fall21    | 0.63     | 0.30 | 1302| 2.06  | 0.04  |
| Demographic      | Female          | 2.82     | 1.52 | 616 | 1.85  | 0.06  |
|                  | Grade*Female    | 0.39     | 0.29 | 591 | 1.32  | 0.19  |
|                  | African-American| −2.61    | 2.73 | 700 | −0.96 | 0.34  |
|                  | Asian           | −1.47    | 2.45 | 1008| −0.60 | 0.55  |
|                  | Hispanic        | −5.41    | 1.51 | 1323| −3.58 | < .01 |
|                  | Other           | −1.17    | 2.70 | 1612| −0.43 | 0.67  |
|                  | Summer*Female   | 0.12     | 0.60 | 1712| 0.20  | 0.84  |
|                  | Summer*Af-Am    | 1.47     | 1.13 | 1729| 1.30  | 0.19  |
|                  | Summer*Asian    | 0.56     | 1.08 | 1702| 0.52  | 0.60  |
|                  | Summer*Hispanic | −0.52    | 0.70 | 1715| −0.74 | 0.46  |
|                  | Summer*Other    | −0.96    | 1.48 | 1725| −0.65 | 0.51  |
| Demog.*Pandemic  | Fall20*Female   | 2.26     | 1.19 | 2297| 1.90  | 0.06  |
|                  | Spring21*Female | 1.88     | 1.30 | 2138| 1.45  | 0.15  |
|                  | Fall21*Female   | −0.08    | 1.35 | 2122| −0.06 | 0.95  |
|                  | Fall20*Af-Am    | 3.00     | 2.22 | 1609| 1.35  | 0.18  |
|                  | Spring21*Af-Am  | −1.16    | 2.35 | 1441| −0.49 | 0.62  |
|                  | Fall21*Af-Am    | −4.18    | 2.34 | 961 | −1.79 | 0.07  |
|                  | Fall20*Asian    | 4.74     | 1.92 | 1582| 2.47  | 0.01  |
|                  | Spring21*Asian  | 0.26     | 2.16 | 1483| 0.12  | 0.90  |
|                  | Fall21*Asian    | −4.82    | 2.15 | 1036| −2.24 | 0.03  |
|                  | Fall20*Hispanic | −0.28    | 1.29 | 1678| −0.21 | 0.83  |
|                  | Spring21*Hispanic| −2.58   | 1.41 | 1558| −1.83 | 0.07  |
|                  | Fall21*Hispanic | −2.64    | 1.43 | 1148| −1.85 | 0.06  |
|                  | Fall20*Other    | 1.09     | 2.44 | 1581| 0.45  | 0.65  |
|                  | Spring21*Other  | −3.18    | 2.87 | 1471| −1.11 | 0.27  |
|                  | Fall21*Other    | −1.84    | 2.88 | 1006| −0.64 | 0.52  |
| Cohort           | Tenure          | −1.05    | 0.19 | 557 | −5.54 | < .01 |
|                  | Kindergarten year| 0.70    | 0.29 | 1050| 2.45  | 0.01  |

“Type” refers to a conceptual grouping for the model. “AC” = alternative curriculum. The reference group for race/ethnicity was chosen alphabetically (white)
expected to have a reading score of 199.02 units, grow at a linear rate of 3.73 units per year, and curve at a rate of −0.33 units per year away from 8th grade. The average effect for summer loss (fall) was −1.08 units, but that interacted with grade at 0.28 units per year away from 8th grade (see Fig. 2 for a graphic display of the trajectory that these estimates imply). Students in the Alternative Curriculum performed lower and grew slower.

The pandemic effects for the three semesters were −2.17, −1.10, and 1.70 RIT units for each of the three semesters. However, these pandemic effects had sizable interactions with grade, suggesting that losses in lower grades were greater (these grade-related pandemic effects will be shown graphically in Fig. 2).

The demographic effects suggested that Hispanic students performed lower than White students on average. Other racial categories did not have statistically significant differences, likely due to small group sizes. However, these are main effects and there were numerically large interactions, suggesting that different groups may have had different levels of pandemic effects in different semesters.

The next section of Table 4 presents interactions of the three semesters of pandemic effects for each demographic group. For African American students and Asian students, effects were positive but then negative, suggesting the possibility that reading effects were small at first, but potentially cumulative. The interactions suggest that Hispanic students may not have recovered from the pandemic as quickly as white students, given that the pandemic effects were increasingly

![Fig. 2 Model-implied trajectories. The solid line shows the model-implied mean trajectory (e.g., an average student, not in any comparison categories). The dotted lines show model-implied trajectories for students one SD above and below the mean intercept. The circles represent the grade-specific effects of the pandemic from Fall 2020. See Table 4 for estimates. The dashed line represents the model-implied mean trajectory for the Alternative Curriculum students.](image)
negative. Because of the small group sizes, we must interpret the interactions with the pandemic effects cautiously, but these are also additive with the overall pandemic effects at the top of Table 4. (These demographic effects are discussed further at the end of the results section.)

Tenure had a substantial effect (−1.05 RIT units per year, from the time of enrollment at age ten), suggesting that students who had been in the school for the deaf longer had higher performance compared to students who joined the school as older students (i.e., transfer students). This tenure effect would imply a bonus of 6.03 RIT units for a student who entered the school at age four, while a student who entered the school at age 13 would be expected to perform 4.20 RIT units lower than the average student.

Lastly, kindergarten cohorts differed, with more recent cohorts typically having higher performance than older cohorts (0.70 RIT units per year). For example, students entering kindergarten in the year 2014 would be expected to perform on average 7.0 RIT units better than students entering in the year 2004. This represents an estimate of performance difference that is beyond the typical growth from grade to grade.

Table 5 presents the random effects of the model, with variances on the diagonal, covariances below, and correlations above in italics. The variances correspond to SDs of 17.21, 1.45, and 0.32 RIT units for student variability in intercept, linear change, and quadratic curvature. These estimates suggest that students varied considerably in their individual shapes of trajectories. These SDs could be compared to the respective fixed effects in Table 4 for how high or low-performing students may have differed from those average effects.

However, this model is fairly complex, with several features which need to be combined in order to understand their predictions for a student’s trajectory. Moreover, in a growth model, we should be careful not to ignore time-based effects solely due to large p-values, as those effects interact with time and can produce educationally meaningful differences (especially because we have a span of nine grades). We therefore present Fig. 2 to show the model-implied trajectories for a few interesting features. Figure 2 is patterned after Fig. 1, with the MAP reading score on the vertical axis and grade on the horizontal axis. The solid line represents the overall model-implied mean trajectory, from which any interesting estimates could be compared (e.g., for group estimates in Table 4). This line shows an overall decelerating trend, with sharper decelerations every fall, representing summer learning loss.
These decelerations in the fall decrease over time, becoming nearly zero in high school.

The dotted lines in Fig. 2 show the random effects of the model (Table 5), with one standard deviation above the mean for intercept (and the corresponding slopes, based on their covariance). The circles in Fig. 2 show the grade-specific effect of the pandemic, based on Fall 2020 (−2.17, plus a 0.41 interaction with grade). These are shown as a maximal estimate of the pandemic effect (acknowledging that effects differed by semester and by demographic characteristics). Finally, the model-predicted mean for the alternative curriculum program is also shown with a dashed line.

In order to better understand the demographic differences in the pandemic effects, together with semester differences, we present Table 6, which shows for each semester of the pandemic, the model-implied deviation from an average score (ignoring grade and summer effects). Table 6 shows the race/ethnic categories, gender, and then three columns for each of the semesters following the onset of the pandemic. Each cell in the table represents the total model-implied difference for a student in that category. For reference, we may consider that 3.73 RIT units represents the expected amount of change in one year for a student in eighth grade. Based on this standard, any estimate or difference around three could represent an educationally meaningful difference.

The estimates in Table 6 suggest that gender, race, and ethnicity may reflect large differences in the level and shape of pandemic effects. Overall, girls performed better than boys and had less negative effects of the pandemic. White girls outperformed white boys and seemed to have rebounded well. There could be a cumulative effect of the pandemic for African American students, as the effects seemed to increase across the semesters, from 0.5 to more than −5 RIT units by fall of 2021. Estimates for Hispanic students were extremely large, ranging from −5.6 to −9.1. Estimates for Asian students were small, but increased in Fall 2021, suggesting the possibility of lagging or cumulative effects.

Table 6  Model-implied pandemic effects for demographic groups

| Race/ethnicity | Gender | Fall 2020 | Spring 2021 | Fall 2021 |
|---------------|--------|-----------|-------------|-----------|
| White         | Male   | −2.2      | −1.1        | 1.7       |
|               | Female | 2.9       | 3.6         | 4.4       |
| African American | Male  | −1.8      | −4.9        | −5.1      |
|               | Female | 0.5       | −3.0        | −5.2      |
| Hispanic      | Male   | −7.8      | −9.1        | −6.3      |
|               | Female | −5.6      | −7.2        | −6.4      |
| Asian         | Male   | 1.1       | −2.3        | −4.6      |
|               | Female | 3.4       | −0.4        | −4.7      |
| Other         | Male   | −2.2      | −5.4        | −1.3      |
|               | Female | 0.0       | −3.6        | −1.4      |

Estimates are based on fixed effects for the pandemic reported in Table 4, excluding grade and summer effects. See text for discussion.
Discussion

The current study found that in this school for the deaf, student reading performance slowed in high school, and there were noticeable decelerations in fall, suggesting summer learning loss, as has been found in prior research on MAP scores (McNeish & Dumas, 2021; Scott et al., 2019). In order to better understand these data, the first author engaged in informal conversations with faculty members at the school, which inform our discussion below. The effects of the pandemic were complex and differed in each of the three semesters in which they were observed. These pandemic effects were also different across grades, being far larger in lower grades than in higher grades, a finding also made by Georgiou (2021).

Moreover, the pandemic effects by semesters differed for students of various demographic characteristics. Hispanic students’ reading appeared to have suffered greatly. Most of these individual estimates had large standard errors, reflecting small group sizes. However, their combinations suggest the possibility of large (if widely uncertain) effects on reading performance. African American and Asian students appeared to have increasingly negative effects, which could suggest lagging or compounding effects as time has gone on. Further, detailed examination of the experiences of these minoritized groups may be needed to understand the causes and potential solutions for these apparent increases in the negative effects. Based on several conversations with the curriculum specialists who worked with the teachers in coming up with ideas for remote teaching, teaching a class online was overall perceived to be more successful than expected. The school was able to provide computers to all students who needed one. However, these results suggest that pandemic effects were unequal, depending upon a number of demographic factors–these may reflect issues such as the level of resources and support within the home (e.g., Agostinelli et al., 2020; Duan et al., 2018; Dustmann et al., 2012).

School tenure was found to have a positive effect on reading development. Students who spent more years in this school where ASL was used had better reading performance. This could be taken to imply compensation for impacts such as the pandemic. Deaf children learn more optimally if learning takes place through a language that is more accessible and more natural for them (Kuntze et al., 2014). A school where ASL is the language of instruction functions as a self-contained language community where all teachers and administrators are fluent in ASL (Scott et al., under review). For many deaf children, especially those with hearing parents, the school served as the only place where communication takes place spontaneously. The extent of exposure to ASL is one of the variables captured by the tenure variable.

In this model, these tenure effects could compensate for other effects (i.e., the model is additive). It is possible that the curriculum, instructional approach, and potentially the social support in the school contributed to higher performance and greater resiliency toward the negative effects of remote learning. This is an important point, especially as increasing numbers of students are educated in educational environments not designed for deaf students (Gallaudet Research Institute, 2012). If it is indeed true that students who are enrolled in this type of
highly accessible and purposefully designed educational environment for a longer tenure experience greater levels of growth, it is worth exploring how deaf students who are currently educated in schools that are designed for others (i.e., students who can hear) compare in their responses to the pandemic.

The kindergarten cohort differences (e.g., students of similar ages based on the year they entered kindergarten in any school) may reflect wider changes in resources, parenting, and the community that occur over time. It may also reflect changes over time in the curriculum and the level of signing abilities of the hearing parents. The difference is small per year, but it is important to note that it implies that children are reading better than children who came before them. Further research may be needed to evaluate access to early language, hearing screening, interventions, and home practices to better understand this effect.

**Limitations**

The current study has several limitations worth considering. First, students were all from the same school for the deaf, and thus these findings may be limited in their generalizability in other school settings. The total number of students was not large enough to produce dependable differences among some of the groups examined. Student grouping based on gender, program, and race/ethnicity yielded wildly unstable trajectory lines. We therefore chose only to model overall (intercept) differences as well as interactions with the pandemic effect. We hope that further research with larger, more representative samples can better detail potential slope differences in important and minoritized groups.

Although we have attempted three specifications of the pandemic effect (see Appendix), other possible forms for the pandemic effect could be examined, such as a second growth segment in piecewise fashion or other ways of estimating persistence (e.g., a diminishing effect with time). With only three semesters, many of these approaches are limited in their sensitivity and distinctiveness. Further semesters of data will provide opportunities to empirically test the shape and extent of the pandemic effects. Similarly, use of multiple types of reading tasks may provide a fuller picture of reading development.

Nonlinear models can be informative for decelerating trajectories and summer learning loss (McNeish & Dumas, 2021), but such models require large samples for dependable estimates and are complex to fit, especially considering a large set of predictors. Given the small group sizes and the availability of only two semesters per year, we propose this quadratic random effects model as an informative preliminary step in understanding pandemic effects for deaf students.

Age effects are complex, and the current model reflects one possible way to model development over years, kindergarten cohorts and tenure in the school. We fit several alternatives to each of these effects by treating them as categorical rather than continuous predictors. The solutions were similar, so we have chosen to present the simpler model with kindergarten cohort and tenure as continuous predictors. It is possible that such time-based effects are not continuous, but it would take a larger sample size to reliably distinguish such complex effects.
Technically, students were instructed in classrooms, but this level of nesting was not available to us and not modeled here. Such switching classification could be an important source of variance but would also represent a heavy estimation burden.

Importantly, there may be other educational background or family information which may be related to performance differences here, especially with respect to the demographic effects. Such data were not available to us but could help future examinations.

**Conclusion and implications for future research**

These findings suggest that effects of the pandemic are neither clear nor simple for deaf students. The overall pandemic effects for each grade are similar to those published by the makers of the MAP test (Kuhfeld et al., 2021). While the effects are largely negative, the effects differ by gender, race, and ethnicity. Some of our results suggest that students may be bouncing back from the negative impacts, but for some groups, the impacts may be continuing or even deepening. Moreover, the effects of the pandemic seem more serious for students in younger grades. Although we only had three semesters of post-onset pandemic scores, negative impacts early in schooling could have long-term educational effects. As noted by prior research, this could be due to shorter attention spans or less ability to work independently among younger students (Juniper Education, 2022). As we continue to navigate the lingering effects of the pandemic on schools and students, it will be important to further explore not only to determine whether this differential impact holds true across a larger number of students but also to identify ways to increase effective learning opportunities for younger students through distance learning.

Importantly, the findings for tenure suggest that early entry into a deaf school accrues cumulative benefits which improve performance and may offset the negative impacts of a pandemic. This study is the first one to examine the impact of tenure at a school for the deaf in this way. These findings have two important implications—for understanding how the impact of pandemic may vary as a function of deaf students’ educational experiences and—for understanding how tenure in a school for the deaf supports deaf students’ cumulative academic growth. Future research should expand into other schools for the deaf to explore the possibility of tenure at a deaf school as a potential benefit for growth in reading as well as in other domains.

Overall, this study contributes novel and important information regarding the reading development of deaf students both generally and specifically in relation to the COVID-19 pandemic. While this study explores only a single school, the findings are important for deaf education in general, and may also be informative for schools serving other minoritized populations. It helps spotlight the more vulnerable segments of the student population as well as the conditions that have ameliorating effects as the areas that merit further research. As the field of education continues to grapple with the ways that the pandemic has changed the landscape, our first and primary goal should be understanding how to better support the students in our schools.
Appendix

There are two important complexities with respect to modeling this data set as a cohort-sequential design: the nature of the pandemic effect and the roles of cohort or control variables. First, with three semesters after the onset, we evaluated three possibilities for the pandemic effect: (i) an overall average effect, (ii) separate, instantaneous shocks, or (iii) cumulative, persistent deviations. Each of these was fit as a model and will be explained in turn.

The overall average approach estimated a single effect for the three pandemic semesters. Although this approach is simple (and could allow random effects across students), it assumes that every semester counts evenly across time (if not also across students).

The separate, instantaneous shocks effectively amount to a time-varying covariate approach for each specific semester, Fall 2020 to Fall 2021 (i.e., each semester gets a zero/one indicator). This approach allows the effect of each semester to be freely estimated. However, this approach assumes the pandemic effect in each semester immediately disappears the following semester.

The cumulative, persistent deviations approach estimates a pandemic effect as a deflection from the growth trajectory. These effects are a permanent deflection, which add to previous deflections and also persist for all subsequent semesters.

Examples of how these effects were coded is given in Table 7. Comparisons between these models and other approaches will be discussed.

The second large complexity in this design is that cohort-related differences could be complex and overlapping, including birth or calendar cohort, tenure within the school, and grade of enrollment. Differences due to birth or calendar cohort

Table 7 Coding of time for the models of the pandemic effect

| Semester   | Linear | Single | Shocks 1 | Shocks 2 | Shocks 3 | Persist 1 | Persist 2 | Persist 3 |
|------------|--------|--------|----------|----------|----------|-----------|-----------|-----------|
| Fall 2016  | 2.33   | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Spring 2017| 3      | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Fall 2017  | 3.33   | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Spring 2018| 4      | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Fall 2018  | 4.33   | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Spring 2019| 5      | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Fall 2019  | 5.33   | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Spring 2020| 6      | 0      | 0        | 0        | 0        | 0         | 0         | 0         |
| Fall 2020  | 6.33   | 1      | 1        | 0        | 0        | 1         | 0         | 0         |
| Spring 2021| 7      | 1      | 0        | 1        | 0        | 1         | 1         | 0         |
| Fall 2021  | 7.33   | 1      | 0        | 0        | 1        | 1         | 1         | 1         |

“Linear” refers to the coding for the linear slope effect for a third-grade cohort, with example time-coding each semester (e.g., fall = 1/3 of calendar year). Actual time values were set as a proportion of the school year based on the individual student’s testing date for that semester. “Single” refers to the overall average effect models. “Shocks” refers to the semester-specific effects model, with one column for each post-onset semester indicator. “Persist” refers to the cumulative effects model, with one column for each post-onset indicator. Shading indicates the onset of the pandemic, with no data collected in Spring 2020.
can be modeled as part of a cohort-sequential design (Schaie, 1965). For the present analysis, we identified each child’s year of kindergarten as an indicator of their birth cohort. Tenure is identified as the current number of years that child had been enrolled in the school. For example, if the child entered in third grade, then their tenure value in sixth grade would be three years. Lastly, students entering the school earlier than others may show greater benefits. For example, entering at third grade and staying for six years may be different from entering at sixth grade and staying for six years. Overall, cohort, tenure, and grade of entry are all highly related, as the only way to have high values is to be a child with more years. Moreover, we are also modeling the effects of grade (time). Therefore, we evaluated models using different combinations of these three cohort-based variables.

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