Longitudinal Models of Reading and Mathematics Achievement in Deaf and Hard of Hearing Students

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Abstract

Deaf and hard of hearing (DHH) students often experience systemic barriers to academic success, especially low expectations of what they know and can do. Longitudinal data analysis is critical to understanding how academic achievement for DHH students progresses over time and where they may need additional support on their academic journey to achieve at the level of their hearing peers. This study provides an analysis of NWEA MAP® Growth™ data from grades 2-8 across seven reading and mathematics domains over a period of five years. Results indicate that both DHH and hearing students continue to build skills through this period, and that DHH students, contrary to many previously held assumptions, do not necessarily plateau in the elementary grades.

Longitudinal Models of Reading and Mathematics Achievement in Deaf and Hard of Hearing Students

Misinformation about what students is capable of and can achieve often leads to low expectations, inequity, and lack of access (National Deaf Center, 2018). Deaf and hard of hearing (DHH) people have long faced barriers to language, learning, and employment opportunities, leading to significant gaps in postsecondary education and employment outcomes (Garberoglio, et al., 2019a, b; Palmer, et al., 2020). More specifically, statements such as "deaf people finish high school reading at a fourth-grade level" (e.g., McKeown & McKeown, 2019, p. 507) can still be found throughout the literature. The legacy of early studies (e.g., Conrad, 1979; Furth, 1966) lives on in these claims, with their findings of significant delays in 15 to 16 year old DHH children, often at the level of 9 year old hearing peers. The problem is that this belief is not only damaging in terms of the expectation it sets (Cawthon & Garberoglio, 2017) for what DHH children can achieve — it is also not necessarily true — and leads to an overly simplistic view of academic potential in this population.

Of the roughly 7 million students age 3-21 receiving special education services under the Individuals with Disabilities Education Act (IDEA), approximately 75,000 are considered deaf or hard of hearing (NCES, 2018). This figure is likely an undercount because it does not include students who are currently on 504 plans, or who have a hearing loss as a secondary disability to a primary used for IDEA Child Count purposes. Relatively small sample sizes make studies tracking academic trajectories of DHH students both challenging to conduct and difficult to draw inferences from to the broader population.

Much of the literature surrounding academic achievement for DHH students uses the synthesis by Qi and Mitchell (2012) as an anchor for further discussion. The Qi and Mitchell synthesis focused on the data collection on the Stanford Achievement Test Series (SAT) over the past three decades prior to the study's publication (a further discussion of the SAT 9th edition, national norms for DHH students, and performance standards can be found in Traxler, 2000). Although very helpful in providing context for future research, the reality is that students and curriculum were different across that time span, with students having varying opportunities to learn SAT content (Allen, et al. 1983; Cawthon, 2007), so the inferences that can be made based this study may differ from current trends. That said, their study highlights two overarching themes about DHH student academic performance relative to the norms based on hearing students: DHH students perform at a lower level for both reading and math, and the gap is larger for reading than for math. With only a few exceptions, the gaps have persisted throughout the time period included in the Qi and Mitchell analysis, particularly in reading.

Beyond a focus on individual student achievement, there are many systemic barriers that contribute to consistent delays in academic achievement for DHH students as a whole: negative attitudes about what DHH people can achieve (Cawthon & Garberoglio, 2017), lack of qualified, trained professionals, inaccessible learning environments, and resources that are few and far between (National Deaf Center, 2018). In addition, fewer than 10% of DHH children are born to DHH parents, which sometimes results in reduced access to robust language in early childhood because hearing parents need time to learn how to communicate with their child (Humphries, et al., 2019; Mitchell & Karchmer, 2004). This language deprivation can have long-lasting effects even into school years, influencing not only brain development and learning outcomes but also critical development in identity, peer relationships, and mental health (Cheng, et al., 2018; Hall, M. L. et al., 2019; Hall, W. C. 2017).

Achievement and opportunity gaps for DHH students are a pervasive theme in the discussion regarding academic outcomes. There is unquestionably a disparity in both the opportunity to learn literacy skills and systemic barriers to DHH children in accessing the language, social, and educational contexts that provide the foundation for literacy. On the one hand, there are certainly significant segments of the DHH population that experience academic delays due to early language deprivation, paucity of evidence-based literacy instruction, and inaccessible learning environments. On the other hand, assumptions that draw upon a deficit model of what DHH people can do, and lowered expectations based on those assumptions, have only contributed to long term disparities in educational outcomes for DHH people. The remainder of this literature review explores what we know about reading and math achievement in DHH students, as well as inferences that may be available with a longitudinal approach to measuring academic achievement trajectories.

Fourth Grade Reading Achievement for DHH Students: Fact or Fiction?

The field often defaults to the assumption of a significant, eight-year delay in reading outcomes for DHH students when they complete secondary education. However, more recent research debunks the fourth grade “average” as a myth, showing that some DHH people reach much higher than fourth-grade level by their late adolescent years (e.g., Lund, 2020; Sarant et al., 2015; Tomblin et al., 2018). While this is still a delay and certainly one that needs to be robustly addressed in early childhood education, there are opportunities to stem the gap of eight years previously predicted for DHH students by the time they leave compulsory education. That said, age level matters when examining potential deficits in reading. Reading achievement levels vary greatly in the early grades across all students (Paris & Hoffman, 2004), and measures of reaching achievement into the elementary and secondary grades are more salient indicators of life-long literacy achievement. This current study seeks to add to the literature that examines developmental trajectories in reading skills for DHH students.

There are several contextual factors to keep in mind when interpreting the practical significance of scores on reading tests. First, it is crucial to remember that literacy is not one skill, but a carefully coordinated set of skills (Webb, et al., 2015). Students may be at different grade levels of proficiency in fluency, decoding, spelling, vocabulary knowledge, reading comprehension, and so forth, depending on any number of factors, including additional disabilities (which is up to half of the DHH population, GRI, 2011). There are also many kinds of literacies that we use, not just the academic literacy typically measured on standardized tests and used in research and benchmarks of academic achievement. For example, there is digital literacy, financial literacy, navigation literacy (e.g., transportation routes), and so forth. These different literacies also draw upon the understanding that there is a difference between learning to read and reading to learn. These are two powerful and related processes, now understood to be happening in parallel: both the development of literacy skills and the application of those skills in content areas such as social studies, science, and other text-based delivery of information. Research suggests that *how* DHH students use the literacy skills they have is as important to secondary and postsecondary success as their scores on standardized assessments of reading ability (Garberoglio, et al., 2015).

The Case of Mathematics Achievement

Although there is relatively limited research on math achievement in DHH children compared with reading achievement (Qi & Mitchell, 2012), recent work has highlighted critical factors influencing the math performance of DHH students. In addition to language proficiency, Henner et al. (2021) examined the effects of age, signing status, gender, American Sign

Language (ASL) vocabulary, and learning disabilities on the math ability and achievement of 257 DHH students. Results suggested that all five factors were significant predictors of mathematics achievement on the MAP subtest. In addition, researchers found DHH students surpassed the sample's mean score of age-related hearing students. As a result, these findings call attention to the complexity of multifaceted identities and contextual factors that influence the academic experience of deaf students (see Goldstein, 2018 for an exploration of math identities and the complex impact of classroom context).

Chen and Wang (2021) add to the literature by exploring this relationship between general and specific cognitive abilities and math performance in 198 DHH students to identify predictors and trends within this population. Using numerous processing tasks and computerized tests, these researchers found various underlying factors such as spatial ability and processing speed that uniquely contributed to and significantly predicted a student’s mathematical performance. Furthermore, this evidence suggests that math achievement for DHH students increasingly relies on general cognitive abilities than specific numerical skills. As a result, for DHH students who are at risk of falling behind, strengthening these cognitive abilities may significantly improve their math performance.

Analyzing Growth Trends: Is it a Deficit or a Delay?

In both reading and math, achievement for disabled students increases over time, but growth rate slows down as students reach middle school (Wei, et al., 2011; Wei, et al., 2013). These two studies from SEELS dataset (Special Education Elementary Longitudinal Study) examined reading and math growth trajectories of students with disabilities, including DHH students, with additional factors such as SES, gender, and race. In terms of growth, the achievement across all students increased rapidly during elementary grades but slowed down as students reached middle school, with few significant differences between disability groups and in line with hearing norms. Furthermore, there were interaction effects for gender, race-ethnicity, and SES level, with persistent gaps for students from historically marginalized communities.

In the disability research literature, particularly in deaf education and deaf studies, there is a growing interest in whether the model of academic achievement should be one that predicts a delay or a deficit trajectory relative to hearing peers. In a model that focuses on *delay*, students are assumed to have the capacity to catch up over time, even if there is a slower, longer trajectory than hearing peers. This delay may be moderated by intensive intervention or other such supports both at school or at home and assumes that the sequence of learning is largely similar for all students. In deaf education, specifically surrounding literacy, this position is based on the Qualitative Similarity Hypothesis (Andrews & Wang, 2015), and assumes that reading development trajectories are structurally the same for DHH children as their hearing peers, and that interventions should target similar strategies.

In contrast to a delay model, a *deficit* model assumes that a student, no matter what interventions or supports are available, will never be at the level of their typically developing peers due to an inherent limitation on their learning due to their disability and resultant cognitive functioning. Deficit models may be supported by data illustrating persistent, early plateaus in academic domains or subdomains. For DHH students, language delay and language deprivation can have longstanding, devastating effects on a child's academic development (Hall, 2017), which could suggest a deficit model of literacy development for at least part of this population. In a deficit model, the instructional focus may be on remediation in areas that are thought to benefit from intervention, instead of a comprehensive approach across all competencies. This would assume a different curricular approach than in the general population and an assumption of an overall lower level of achievement as an end point.

Evidence to support different literacy trajectories may be possible using longitudinal data analysis approaches to studying academic achievement. For example, Francis, et al. (1996) conducted an early study of the delay vs. deficit model for students with learning disabilities using individual growth curve analyses. This study examined student scores from third grade, about the time that many students are identified as having a reading disability, over the course of the remainder of their compulsory education. Analyses controlled for gender, race and SES status. The authors hypothesized that changes in reading ability would be nonlinear, showing an initial pattern of rapid acquisition with subsequent slowing in the rate of change, a pattern we have seen throughout the literature. Because outcome data for all students revealed a curvilinear pattern, a quadratic model was utilized to determine growth, but modified to allow for a plateau towards the end of the measurement period (instead of a downward trend). Interestingly, students identified as having a learning disability (using IQ discrepancy model) and students without a learning disability both levelled off at about the same age, around age 13. Results from these analyses indicated that students with a disability (and, in addition, in this study, all students with a lower IQ) had a performance over time reflective of a *deficit* model of reading development. The delays seen in early childhood were persistent, and students did not “catch up” over time. Furthermore, they were seen to plateau at about the same time as their typically developing peers, indicating a slowdown in the window of time where there might be expected growth with a delayed model of achievement.

Paucity of Longitudinal Research with DHH Students

Research methods within the literature have a significant impact on what we know about academic achievement. Due in part to the focus on grade-level achievement and accountability for schools, the cohort approach to tracking academic performance dominates recent research in the field (Cawthon, 2007). Sample sizes within each grade are small, limiting generalizability of analytical approaches under cohort designs. This means that we know very little about how DHH children develop over time, especially during the critical elementary and middle school years. There are few recent longitudinal data sets to be able to draw conclusions about what overall growth in academic achievement looks like, let alone what different pathways and trajectories might be for the diverse subsets of the DHH population.

Antia et al. (2009) provided a summary of early longitudinal studies in the field as well as findings from their five-year analysis of academic progress in 197 DHH students in general education classrooms. Participants were in grades 2-8 at the start of the study. This analysis is unique in that it combined the use of the state standardized academic results (for students in grades required to take them for state accountability) as well as teacher perceptions of student progress. Students also provided self-ratings on their classroom participation and preferred communication modality. Overall, at least half of DHH students performed at the average or above average range each year in reading, with the percentage increasing from 54% to 66% between the first and fifth year of the study. Further examinations of mean slopes indicated that students were making above average gains in their language and writing skills over the course of the five years. Results for mathematics, with DHH students performing at over 70% average to above average across all five study years, were stronger in terms of overall proficiency, and with equal gains per year as their hearing peers.

In a more recent study, Antia et al. (2020) examined language and reading development of over 300 children in kindergarten, first, and second grades over the course of a single year. This is often a period of rapid growth for children, making this age range particularly important to look at in terms of trajectory for later literacy development. The students in this study were divided into three groups for analysis based on their communication modalities in the classroom: spoken only, sign- only, and bimodal (acquiring both). Findings in this study were mixed. First, overall, study participants began behind the hearing norms at the time of the fall assessments in both language (English and ASL) and literacy skills. Measured again at the end of the school year, the study participants made some gains in language, with students in spoken modalities making gains in English syntax and students using sign or bimodal approaches in ASL syntax. Vocabulary gains showed no difference between the groups. Literacy development, however, was not as consistent nor demonstrative of increases over time. There were decreases in comprehension skills from kindergarten to second grade, and mixed achievement between the three study groups. Rather than results clearly supporting either a deficit vs. delay model of achievement, this study raised the possibility of a differential model, with trajectories that may vary depending on both individual and contextual (e.g., additional academic supports, home language supports, peer interaction) factors.

In contrast with the Antia et al. (2020) academic year time frame, Kyle and Harris (2010, 2011) provide a rare example of longitudinal analysis of early literacy development in DHH and hearing readers across multiple years. Their research examined literacy development with a total of 29 DHH children, beginning at about 7-8 years of age and following for three years. Students showed delays in their literacy outcomes, delays that grew over time, on average, but that were highly variable within the group. Interestingly, the authors suggest a possible *differential* trajectory in the relationship between phonological awareness and reading ability, with earlier reading levels predicting later phonological awareness levels in study participants, and not vice versa after controlling for other factors. This is in contrast with the typical pathway of phonological awareness as an early predictor of later reading ability. Although a small sample size is a limitation to this study that may have affected the power to detect true differences, this study contributes to the concepts of consistent themes of high inter-group variability and possible difference in literacy trajectories for DHH students (see also Andrews, et al., 2016).

The Current Study

One of the greatest barriers to measurement in deaf education research is that summative standardized assessment in educational settings is rarely designed to measure growth. Alternatively, research and intervention studies can include growth measures within their own designs, but this is a step that is not always possible nor desired given the extensive testing already present in school settings (in the US, at least). The opportunity to leverage an in situ standardized assessment is thus rare, particularly one that spans multiple grades and multiple years and sufficient sample size of DHH students across multiple school sites. Such an opportunity was afforded to this research team by the NWEA MAP® Growth™ Research Database, with five years of data for DHH students in seven elementary and middle school grades.

This study has the following objectives:

1. Compare longitudinal outcomes for reading and mathematics for DHH and hearing students participating in the NWEA MAP® Growth™ data from grades 2-8 over a period of five years.

2. Examine possible differences in developmental trajectories within a total of seven reading and mathematics subdomains.

Methods

Data Source

This collaboration represents expertise from contributors in the field of deaf education, special education, and the use of MAP® Growth™ data. MAP Growth is designed to measure progress over a student's entire school career with a single metric. MAP Growth assesses the students up to three times per year (fall, winter, and spring). School districts choose to administer MAP Growth assessments for a variety of purposes, including monitoring student achievement and growth. MAP Growth is a computer adaptive assessment designed for test items to match the ability of the student (Thum & Kuhfeld, 2020). All the items within MAP Growth are calibrated to the same scale using the Rasch one parameter logistic (1PL) item response theory (IRT). When taking a MAP Growth assessment students will receive different items based on the item difficulty and the estimates of the student's ability level. The result of the final ability estimate is a RIT score or a Rasch Unit (Thum & Kuhfeld, 2020).

We used a unique data set from NWEA Growth Research Database, which examined academic progress over time for 351 2–8 DHH students, primarily students attending schools for the deaf where the MAP Growth assessment tool is used as part of interim assessment. Across the data collection years, the number of schools for which academic data were collected for DHH students ranged from 33 to 94 schools. Although many schools for the deaf include ASL as part of their pedagogy, school-level data about language use in the classroom or student-level data regarding preferred language modalities are not available for this dataset. This data set also did not have delineation between identification of "deaf" vs. "hard of hearing" or other further breakdown within this category, such as type of amplification (e.g., hearing aids, cochlear implants, if any) used. In this study, we compared DHH students with a group of peers without disabilities, denoted as “hearing” for the purpose of this analysis. Hearing students attended school in general education settings.

Measures

Table 1 presents the descriptive statistics for the sample of students who were identified as DHH and their hearing peers. Across both subgroups, a little over half the students were males. Additionally, just over half of students identified themselves as white in the DHH (58%) and the hearing (41%) subgroups, with similar proportions of Black students (12% and 13% for DHH and hearing, respectively) but lower proportions of Hispanic students (7% and 19% for DHH and hearing, respectively) and higher percentage of American Indian/Alaska Native students (15% and 2% for DHH and hearing, respectively).

(Insert Table 1 here)

Outcome measures are disaggregated across 7 subscales:

- Math: Algebra
- Math: Geometry
- Math: Numbers and operations
- Math: Measurement and data
- Reading: Informational Text
- Reading: Literature
- Reading: Vocabulary Acquisition

Test Construction

MAP Growth assessments are aligned to 2nd through 10th grade state standards in mathematics, English language arts, and science. The standards are analyzed and reviewed by content experts organizing critical concepts and progressions within the standards into a framework for each assessment. This two-tier framework contains the instructional areas and sub-areas that form the structure of the test. For example, the reading assessment aligned to the Common Core State Standards has three instructional areas: Literary Text, Informational Text, and Vocabulary. Items in MAP Growth assessments come from the robust NWEA item bank. Items in MAP Growth tests are carefully selected and aligned to individual state standards by NWEA Content Specialists. Items are only aligned to individual standard statements when the content within the item clearly assessed the concept within the standard at the appropriate reading level, difficulty level, and level of cognitive complexity. Each item alignment is reviewed by at least one Content Specialist who was not involved in the initial alignment process. As a result of this process, each item in the assessment item pool has a confirmed alignment to a state standard. Creating tests in this manner means that they align tightly to the standards and provide an accurate measure of student achievement. For more information about the constructs measured within each subscale, see the MAP Growth website: https://www.nwea.org/map-growth/.

Analysis

Data on students' academic outcomes were collected thrice each year (i.e., during Fall, Winter, and Spring). We coded time as 0.25 (Fall), 0.50 (Winter) and 0.75 (Spring) to align with each data collection time point. For instance, data collected for student A in Grade 2 during the Fall semester was coded as 2.25 and data collected for the same student during the Spring of Grade 3 was coded 3.75. Thus, time indicates students' progression through grade-levels and timepoints when academic data were collected. Given that data were collected longitudinally, we used mixed method growth curve models to estimate academic growth in students identified as deaf compared to hearing students. More specifically, the data structure entails repeated test observations nested within students who are also nested within schools. We used the following multilevel model in Equation 1 to examine changes in each reading and math outcome from grade two to grade eight:

(1) $$Y_{ijk} = \beta_{000} + \beta_{100}TIME_{ijk} + \beta_{200}TIME_{ijk}^{2} + \beta_{300}DHH_{i} + \theta_{Y} + \tau_{0ij} + \mu_{00k} + \tau_{1ij}TIME_{ijk} + \tau_{2jk}TIME_{ijk}^{2} + \varepsilon_{ijk}$$

Y_{ijk} refers to the academic score for student *i* at time period *j* in school *k*. The academic scores are a function of time measured in the grade of students at period *j* and whether students were DHH or typically developing. We included a linear and quadratic term for time because past studies have demonstrated that students' academic growth is greatest in early elementary grades with a decrease in the level of academic growth rates as students' progress through grades (Francis et al., 1996; Wei et al., 2012). More specifically, β_{100} captures the instantaneous rate of change when *TIME* = 0, while β_{200} represents the curvature parameter, the changing rate of change. The parameter of interest, β_{300}, is the difference in academic scores between DHH and typically developing students, holding all else constant. We explored statistical interactions between the time variables and DHH status to allow the trajectories for both student groups to differ. However, we retained only the main effects in our final models as the statistical interactions were not statistically significant. Due to potential test administration differences, we also controlled for a vector of year fixed effects in θ_{Y}. Student and school-level random intercepts are included in τ_{0ij} and μ_{00k} respectively, to account for the nested data structure. We specify random slopes (τ_{1ij} and τ_{2jk}) to permit the growth parameters to vary stochastically across students and schools. Lastly, the residual in ε_{ijk} denotes time-specific deviation from a student's academic outcome score.

Missing data were detected primarily in the outcome measures as not all students were tested at each wave. Missingness range varied by measure. Of the total DHH sample, data were unavailable for 12 to 19% of the sample on various reading measures, and 23 to 53% unavailable on various math measures. The multilevel model of change, however, handles missing or unbalanced data (Singer & Willett, 2002). That is, every student record contributes the estimation, regardless of how many records are available per student. All analyses were conducted in R (R Core Team, 2017) using the lme4 package (Bates et al., 2015).

Results

Results from the mixed method growth curve modeling analyses are presented in Tables 2 and 3, respectively. As shown in Table 2, controlling for the year data were collected, and students' linear and quadratic growth rates, hearing students perform significantly better than their DHH peers in comprehension of informational text (B = 1.04, p<.05, d = 0.03), comprehension of literary text (B = 1.11, p<.05, d = 0.04), and vocabulary acquisition (B = 1.06, p<.05, d = 0.03). The one-point difference between hearing and DHH students is equivalent to about 0.03 to 0.04 standard deviations—small when compared to racial differences of 0.50 standard deviations but similar to some intervention effects (Lipsey et al., 2012). Similarly, as shown in Table 3, the results indicate that, controlling for the year data were collected, and students' linear and quadratic growth rates, hearing students perform significantly better than their DHH peers in algebra (B = 2.89, p<.01, d = 0.08), geometry (B = 3.14, p<.01, d = 0.08), measurement and data (B = 2.12, p<.01, d = 0.06), and numbers and operations (B = 2.15, p<.01, *d* = 0.05) related tasks. The standardized differences, 0.05 to 0.08, between hearing and deaf students in reading are about twice of those in math but remain small.

<Insert Tables 2 and 3 here>

<Insert Figures 1 and 2 here>

In both Table 1 and Table 2, the growth parameters show a positive instantaneous rate of change and a negative curvature estimate. In other words, the trajectory initially rises and increases but this increase does not persist. Figures 1 and 2 show the growth curve results for reading and math domains, respectively. In reading, all students on average scored approximately six standard points higher each year and their reading-related growth was curvilinear and decelerating. In Figure 2, across different math measures, all students on average scored about eight standard points higher each year as they progressed from grades 2 to 8. As hypothesized, the quadratic term in the models were significant and demonstrated that academic growth across both groups of students was curvilinear and decelerating. Finally, we fitted models to identify if an interaction existed between the two groups and their linear or quadratic growth. The interaction terms were not significant; to present parsimonious models, we dropped the interaction terms from Tables 2 and 3. Box plots of the score distributions at each grade level, for each analysis, are provided in the Appendix.

Discussion

Our key finding is that in both reading and mathematics, we found small but persistent gaps in growth scores between DHH and hearing students. There was, however, steady growth for both groups throughout the time period measured, findings that parallel with Antia et al. (2009) where the majority of students made at least one year's gain in math and reading. Both DHH and hearing students in this sample are making the same relative gains year to year throughout the data analysis period, a finding that holds across all domains in reading and mathematics.

This analysis largely supported a delayed model of achievement for DHH students. Perhaps because DHH students often start with delayed access to both language and learning opportunities, DHH students in this study started with second grade reading and mathematics scores behind their hearing peers. This means that there is more for them to learn within their elementary and middle school grades to reach the same level as their peers. The good news in these data is that, looking at the rate of growth, DHH students are progressing throughout the time period relative to their hearing peers, without a significant plateau that might be indicative of a deficit model of development. MAP Growth data indicates that there is much reason to be optimistic and positive about the progress DHH students are making year to year. This is very powerful information not only for English instruction, but also for subject areas that may rely on text comprehension skills—such as social studies—where students may need to access information through text-based materials.

Our encouragement to students, parents, and educators is this: What is happening within these educational settings seems to be working, and we encourage educators and families to continue to have high expectations for DHH student achievement. While our findings cannot make a causal link between specific teaching practices and student outcomes, the overall trends indicate that schools are succeeding in supporting DHH students in their growth journey through elementary and middle school grades in the key content areas of reading and math. The assumption of a fourth-grade average reading level for DHH students when they finish high school is inconsistent with the trajectories suggested by these data. Indeed, this assumption is unlikely given that the growth trajectories from grade 2 to 8 for both groups, despite the small gaps, are similar in shape and curve upward over time. However, these results also point to the critical importance of early childhood opportunities for access to the language, social, and academic experiences as DHH children enter formal education. These data indicated that DHH students are starting behind in early elementary grades, and, at least as far as achievement on standardized tests of reading and math, do not fully catch up to their hearing peers. We need to continue to improve access to both linguistically rich environments and high-quality instruction starting from early childhood.

A few limitations need consideration when interpreting the results of this study. First, our sample is not nationally representative even though drawn from schools for the deaf across the country. The majority of DHH students in the US are enrolled in general education settings, not in the schools and programs for the deaf that were sampled in this dataset. We were also unable to break the findings down by race and ethnicity, additional disability, language modality of instruction, socio economic status, or by other school factors due to either lack of data or insufficient sample size. Previous research has shown that measures of average progress masks what can be very different trajectories for DHH students with different backgrounds and intersectional identities (see slope analysis from Antia, et al., 2009; differential trajectories in Garberoglio, et al., 2021). This study cannot add insight into what kinds of teaching approaches may result in stronger achievement outcomes and/or be a better fit for diverse student populations with different developmental trajectories (Easterbrooks, et al., 2015). Finally, this study only included measures of academic achievement and does not include important linguistic and cultural factors that may either predict or co-occur with literacy and mathematics development. There is a growing area of research in the field that seeks to make more direct connections between the socio-linguistic experiences of DHH children and their academic development (e.g., Allen, et al., 2014; Andrews, et al., 2016). Conclusions about deficit vs. delay models of academic achievement for DHH students require comprehensive understanding of the familial, linguistic, social, educational, and community milieu in which development occurs (Humphries et al., 2019).

Conclusion

Results from this study indicate a continued need for robust data collection of student achievement for a diverse set of DHH students, with samples large enough to examine what may be critical disparities in opportunity for growth between student racial and ethnic subgroups that are not available in this analysis (National Deaf Center, 2017). This is a call to larger systems, either at the state or federal level, to design mindful, comprehensive ways to understand learning trajectories of disabled students, including DHH students, in ways that can be tracked over time and analyzed with intersectional identities in mind. Current assessments built into accountability reforms typically are not designed to measure diverse developmental pathways, nor are they publicly available for the kind of analyses that can reveal key patterns and current trends in learning outcomes for students. Assessment systems with multiple data points, important contextual information, and a broad range of outcomes are critical for the building of data-driven policy and practice.

The power of high expectations (Cawthon & Garberoglio, 2017), particularly from parents and teachers, encourages us to be mindful of the potential negative impact of the "fourth grade achievement level" assumption. Sustainable educational change, at the individual student, group, school levels, remains a significant challenge and essential goal for all school systems. There are still significant disparities in outcomes for DHH students, and systemic barriers to education continue to play a significant role in the lives of DHH people (e.g., Palmer, et al., 2020). Data collection and research play an important role in how well the field understands factors that support DHH students in their overall development. Each study contributes a piece of the puzzle – the variety of frameworks and approaches only enriches how we approach DHH learning trajectories.

References

Allen, T. E., Letteri, A., Choi, S. H., & Dang, D. (2014). Early visual language exposure and emergent literacy in preschool deaf children: Findings from a national longitudinal study. *American Annals of the Deaf*, *159*(4), 346–358. https://doi.org/10.1353/aad.2014.0030

Andrews, J., Hamilton, B., Dunn, K., & Clark, M. (2016). Early reading for young deaf and hard of hearing children: Alternative frameworks. *Psychology*, 7, 510-522. https://doi.org/10.4236/psych.2016.74052

Andrews, J. F., & Wang, Y. (2015). The qualitative similarity hypothesis: Research synthesis and future directions. *American Annals of the Deaf*, *159*(5), 468–483. https://doi.org/10.1353/aad.2015.0005

Antia, S. D., Jones, P. B., Reed, S., & Kreimeyer, K. H. (2009). Academic status and progress of deaf and hard-of-hearing students in general education classrooms. *Journal of Deaf Studies and Deaf Education*, *14*(3), 293–311. https://doi.org/10.1093/deafed/enp009

Antia S.D., Lederberg A.R., Easterbrooks S., Schick B., Branum-Martin L., Connor C.M., Webb M.Y. (2020). Language and reading progress of young deaf and hard-of-hearing children. *Journal of Deaf Studies and Deaf Education*, 25(3), 334-350. https://doi.org/10.1093/deafed/enz050

Cawthon, S. & Garberoglio, C. L. (2017). *Shifting the Dialog, Shifting the Culture: Pathways to Successful Postsecondary Outcomes for Deaf Individuals.* Gallaudet University Press.

Cheng, Q., Halgren, E., & Mayberry, R. (2018). Effects of early language deprivation: Mapping between brain and behavioral outcomes. *Proceedings of the 42nd annual Boston University conference on language development*, pp. 140-152, Cascadilla Press, . Somerville, MA. http://www.lingref.com/bucld/42/BUCLD42-11.pdf

Chen, L. & Wang, Y. (2021). The contribution of general cognitive abilities and specific numerical abilities to mathematics achievement in students who are deaf or hard-of-hearing. *Journal of Developmental and Physical Disabilities, 33*(5), 771-787. https://doi.org/10.1007/s10882-020-09772-8

Drasgow, E. (1998). American Sign Language as a pathway to linguistic competence. *Exceptional Children*, *64*(3), 329-342. https://doi.org/10.1177/001440299806400303

Dye, M. W., Hauser, P. C., & Bavelier, D. (2008). Visual skills and cross-modal plasticity in deaf readers: Possible implications for acquiring meaning from print. *Annals of the New York Academy of Sciences, 1145*(1), 71–82. https://doi.org/10.1196/annals.1416.013

Easterbrooks, S. R., Lederberg, A.R., Antia, S. D., Schick, B., Kushalnagar, P., Webb, M-Y., Branum-Martin, L., & Connor, C. M. (2015). Reading among diverse DHH learners: What, how, and for whom? *American Annals of the Deaf*, *159*(5), 419–432. https://doi.org/10.1353/aad.2015.0002

Francis, D. & Shaywitz, S. & Stuebing, K. & Shaywitz, B. & Fletcher, J. (1996). Developmental lag versus deficit models of reading disability: A longitudinal, individual growth curves analysis. *Journal of Educational Psychology*, *88*(1), 3-17. https://doi.org/10.1037/0022-0663.88.1.3

Garberoglio, C. L., Dickson, D., Cawthon, S., & Bond, M. (2015). Bridging the communication divide: CMC and deaf individuals' literacy skills. *Language Learning and Technology, 19*(2), 118-133. http://dx.doi.org/10125/44420

Garberoglio, C.L., Johnson, P.M., Sales, A., & Cawthon, S. W. (2021). Change over time in educational attainment for deaf individuals from 2008-2018. *Journal of Postsecondary Education and Disability (JPED)* 34(3), 253-272. https://eric.ed.gov/?id=EJ1325423

Goldstein, D. S. (2018). Mathematics identities of competence in a middle-grades d/Deaf and hard-of-hearing classroom. *Investigations in Mathematics Learning*, *10*(3), 145-158. https://doi.org/10.1080/19477503.2018.1467081

Hall, W. C. (2017). What you don't know can hurt you: The risk of language deprivation by impairing sign language development in deaf children. *Maternal and Child Health Journal*, *21*(5), 961-965. https://doi.org/10.1007/s10995-017-2287-y

Hall, M. L., Hall, W. C., & Caselli, N. K. (2019). Deaf children need language, not (just) speech. *First Language*, *39*(4), 367-395. https://doi.org/10.1177/0142723719834102

Henner, J., Pagliaro, C., Sullivan, S., & Hoffmeister, R. (2021). Counting differently: Assessing mathematics achievement in signing deaf and hard of hearing children through a unique lens. *American Annals of the Deaf, 166*(3), 318-341. https://doi.org/10.1353/aad.2021.0023

Humphries, T., Kushalnagar, P., Mathur, G., Napoli, D. J., Rathmann, C., & Smith, S. (2019). Support for parents of deaf children: Common questions and informed, evidence-based answers. *International Journal of Pediatric Otorhinolaryngology*, *118*, 134-142. https://doi.org/10.1016/j.ijporl.2018.12.036

Kushalnagar, P., Moreland, C., Simons, A., & Holcomb, T. (2018). Communication barrier in family linked to increased risks for food insecurity among deaf people who use American Sign Language. *Public Health Nutrition, 21*(5), 912-916. https://doi.org/10.1017/S1368980017002865

Kyle, F. E., & Harris, M. (2010). Predictors of reading development in deaf children: A 3-year longitudinal study. *Journal of Experimental Child Psychology*, *107*(3), 229-243. https://doi.org/10.1016/j.jecp.2010.04.011

Kyle, F. E., & Harris, M. (2011). Longitudinal patterns of emerging literacy in beginning deaf and hearing readers. *Journal of Deaf Studies and Deaf Education*, *16*(3), 289-304. https://doi.org/10.1093/deafed/enq069

Lipsey, M.W., Puzio, K., Yun, C., Hebert, M.A, Steinka-Fry, K., Cole, M.W, Roberts, M., Anthony, K.S, & Busick, M.D. (2012). Translating the statistical representation of the effects of education interventions into more readily interpretable forms. (NCSER 2013-3000). Washington, DC: National Center for Special Education Research, Institute of Education Sciences, U.S. Department of Education. https://ies.ed.gov/ncser/pubs/20133000/

Lund, E. (2020). The relation between vocabulary knowledge and phonological awareness in children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 63(7*), 2386-2402. https://doi.org/10.1044/2020_JSLHR-19-00259

McLeskey, J. (2020). Reflections on future directions for including students with severe disabilities. *Research and Practice for Persons with Severe Disabilities*, *45*(1), 45-50. https://doi.org/10.1177/1540796919890924

Mitchell, R. & Karchmer, M. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the United States. *Sign Language Studies. 4*(2). 138-163. https://doi.org/10.1353/sls.2004.0005

National Deaf Center. (2017). *Research summarized! Collecting and using data for decision-making*. Washington, DC: U.S. Department of Education, Office of Special Education

Programs, National Deaf Center on Postsecondary Outcomes. https://www.nationaldeafcenter.org/resource/research-summarized-collecting-and-using-data-decision-making

National Deaf Center. (2018). *Root causes of gaps in postsecondary outcomes for deaf individuals.* Washington, DC: U.S. Department of Education, Office of Special Education Programs, National Deaf Center on Postsecondary Outcomes. https://www.nationaldeafcenter.org/resource/root-causes-gaps-postsecondary-outcomes-deaf-individuals

Palmer, J. L., Newman, L. A., Davidson, S., & Cawthon, S. W. (2020). Life after college: Employment, social, and community outcomes for young deaf adults. *American Annals of the Deaf, 165*(4), 401-417. https://doi.org/10.1353/aad.2020.0027

Paris, S. G. & Hoffman, J. V. (2004). Reading assessments in kindergarten through third grade: Findings from the center for improvement of early reading achievement. *The Elementary School Journal, 105*(2), 199-217. https://doi.org/10.1086/428865

Qi, S., & Mitchell, R. E. (2012). Large-scale academic achievement testing of deaf and hard-of-hearing students: Past, present, and future. *Journal of Deaf Studies and Deaf Education, 17*(1), 1-18. https://doi.org/10.1093/deafed/enr028

Ruben, R. J. (2018). Language development in the pediatric cochlear implant patient. *Laryngoscope Investigative Otolaryngology*, *3*(3), 209–213. https://doi.org/10.1002/lio2.156

Sarant, J. Z., Harris, D. C., & Bennet, L. A. (2015). Academic outcomes for school-aged children with severe–profound hearing loss and early unilateral and bilateral cochlear implants.

Journal of Language Speech and Hearing Research, *58*(3), 1017–1032. https://doi.org/10.1044/2015_JSLHR-H-14-0075

Simon, M., Fromont, L. A., Le Normand, M. T., & Leybaert, J. (2019). Spelling, reading abilities and speech perception in deaf children with a cochlear implant. *Scientific Studies of Reading, 23(6*), 494-508. https://doi.org/10.1080/10888438.2019.1613407

Singer, J. D., & Willet, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. Oxford University Press.

Thum, Y. M., & Kuhfeld, M. (2020). *NWEA 2020 MAP growth achievement status and growth norms for students and schools*. NWEA Research Report. https://www.nwea.org/research/publication/nwea-2020-map-growth-achievement-status-and-growth-norms-for-students-and-schools/

Tomblin, J. B., Oleson, J., Ambrose, S. E., Walker, E. A., & Moeller, M. P. (2018). Early literacy predictors and second-grade outcomes in children who are hard of hearing. *Child Development*, *91*(1) e179-e197. https://doi.org/10.1111/cdev.13158

Traxler, C. B. (2000). The Stanford Achievement Test: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, *5*(4), 337-348. http://dx.doi.org/10.1093/deafed/5.4.337

Wauters, L. N., Van Bon, W. H., & Tellings, A. E. (2006). Reading comprehension of Dutch deaf children. *Reading and Writing*, *19*(1), 49-76. https://doi.org/10.1007/s11145-004-5894-0

Wei, X., Lenz, K. B., & Blackorby, J. (2013). Math growth trajectories of students with disabilities: Disability category, gender, racial, and socioeconomic status differences from ages 7 to 17. *Remedial and Special Education*, *34*(3), 154–165. https://doi.org/10.1177/0741932512448253

Wei, X., Blackorby, J., & Schiller, E. (2011). Growth in reading achievement of students with disabilities, ages 7 to 17. *Exceptional Children*, *78*(1), 89-106. https://doi.org/10.1177/001440291107800106

Figure 1: *Reading Domain Growth Curves for Hearing and DHH Students*

The three graphs show the growth curve results for both hearing and DHH students within each of the three reading domains analyzed in this study: Informational Text, Literary Text, and Vocabulary Acquisition.

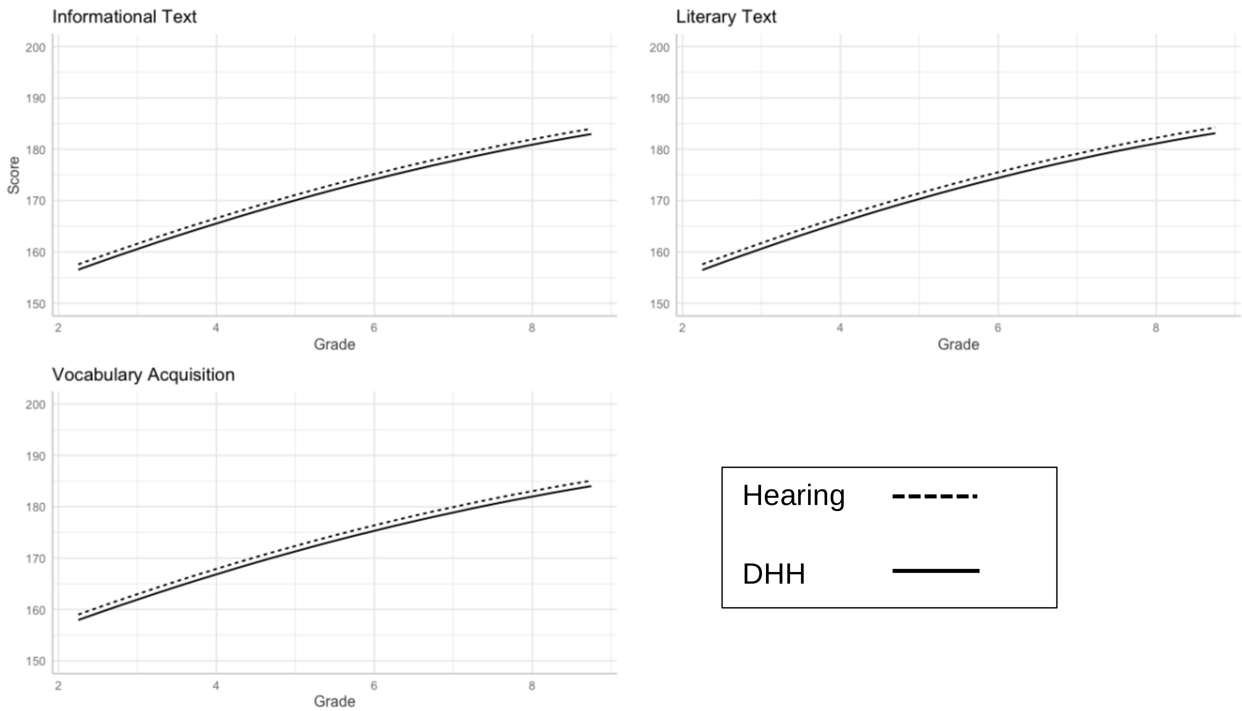

Figure 2: *Mathematics Domain Growth Curves for Hearing and DHH Students*

The three graphs show the growth curve results for both hearing and DHH students within each of the four mathematics domains analyzed in this study: Algebra, Geometry, Numbers & Operations, Measurement & Data.

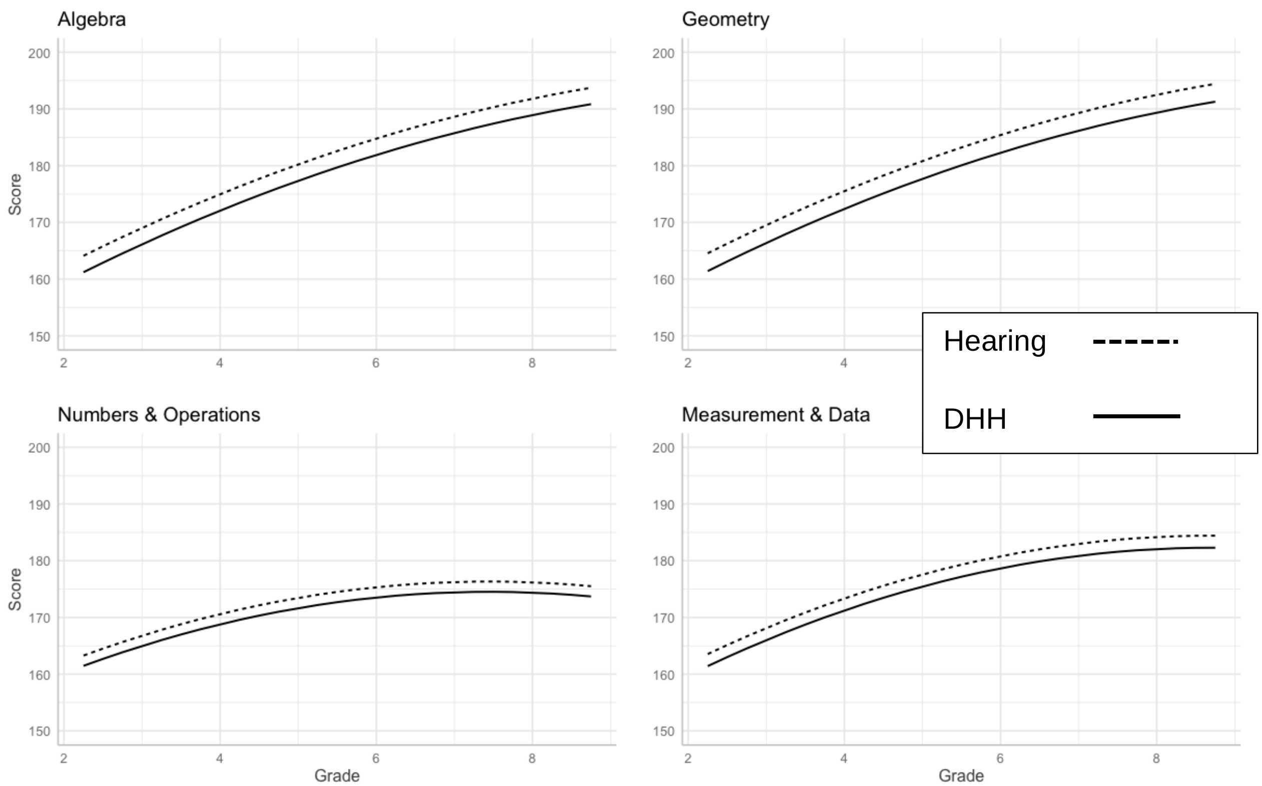

Table 1

Sample Demographic Information

Characteristics	DHH (*n* = 351)	Hearing (*n* = 6655)
Gender		
Male	201 (57%)	3566 (54%)
Female	150 (43%)	3074 (46%)
Not reported	NA	15 (<1%)
Race		
White	206 (58%)	2700 (41%)
Black	41 (12%)	845 (13%)
Hispanic	23 (7%)	1277 (19%)
American Indian/Alaska Native	52 (15%)	124 (2%)
Asian/Pacific Islander	18 (5%)	298 (4%)
Other	11 (3%)	1411 (21%)

Note. DHH = Students who are deaf and hard of hearing; Hearing = Students without disabilities

Table 2

Growth Curve Model Estimates for Reading-Related Measures

	Informational Text	Literary Text	Vocabulary Acquisition
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
Fixed Effect			
Intercept	142.93** (0.92)	142.35** (1.33)	144.45** (1.34)
Group (hearing)	1.04* (0.44)	1.11* (0.44)	1.06* (0.45)
Grade	6.56** (0.36)	6.84** (0.36)	6.51** (0.36)
Grade^2	-0.23** (0.03)	-0.25** (0.03)	-0.23** (0.03)
Year (2014)	1.56** (0.24)	1.37** (0.25)	-
Year (2015)	2.58** (0.28)	2.27** (0.30)	1.33** (0.22)
Year (2016)	4.12** (0.34)	3.70** (0.35)	2.74** (0.28)
Year (2017)	5.31** (0.42)	4.76** (0.42)	4.02** (0.35)

Year (2018)	7.04** (0.48)	6.42** (0.49)	5.74** (0.42)
Random Effect			
Student τ_{oo}	192.20	198.94	165.25
Student τ_{01}	5.27	5.21	5.19
School τ_{11}	36.81	38.20	43.05
School τ_{02}	1.69	1.60	1.61
Residual (σ^2)	35.81	36.73	35.40
N (Student)	3845	3854	3715
N (School)	91	90	92
Observations	16897	16747	15549
Conditional R^2	.931	.928	.931

Note. Comparison group is DHH students. In 2013, vocabulary acquisition data were not available for the sample.

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 3

Growth Curve Model Estimates for Math-Related Measures

	Algebra	Geometry	Measurement and Data	Numbers and Operations
	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
Fixed Effect				
Intercept	144.14** (1.46)	144.15** (1.37)	143.45** (1.89)	142.38** (1.81)
Group (hearing)	2.89** (0.54)	3.14** (0.52)	2.12** (0.62)	2.15** (0.72)
Grade	8.37** (0.37)	8.47** (0.34)	9.43** (0.35)	9.14** (0.53)
$Grade^2$	-0.36** (0.03)	-0.35** (0.03)	-0.58** (0.05)	-0.51** (0.05)
Year (2014)	0.83* (0.27)	0.40 (0.24)	-	0.91** (0.29)
Year (2015)	1.82** (0.31)	1.30** (0.27)	0.97** (0.29)	1.42** (0.36)
Year (2016)	2.72** (0.36)	2.10** (0.32)	2.92** (0.36)	3.13** (0.43)
Year (2017)	3.74** (0.42)	3.26** (0.37)	4.99** (0.44)	4.54** (0.50)

Year (2018)	6.25** (0.48)	5.68** (0.43)	8.21** (0.52)	7.55** (0.58)
Random Effect				
Student τ_{oo}	217.45	212.33	182.66	176.58
Student τ_{01}	4.81	4.75	6.39	6.18
School τ_{11}	53.53	53.55	74.42	70.06
School τ_{02}	1.92	1.82	4.31	3.90
Residual (σ^2)	44.69	44.68	47.41	46.72
N (Student)	4121	4797	2816	3017
N (School)	91	97	84	81
Observations	18430	21226	10322	11386
Conditional R^2	.910	.909	.883	.889

Note. Comparison group is DHH students.

* p < .05, * p < .01, *** p < .001