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Visual Analysis Plus Hierarchical Linear Model Regressions: Morphosyntax Intervention with Deaf-and-Hard-of-Hearing Students

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Abstract

We conducted a pilot study using intentional teaching strategies with specially designed materials to improve accuracy and production of targeted English morphosyntax structures with six deaf and hard-of-hearing students (kindergarten to first grade). A multiple baseline single-case research design (SCRD) consisting of 20-minute sessions four times per week for the duration of a school year was implemented to determine the effect of the supplemental syntax curriculum. The data were inconsistent and highly variable. Visual analyses were problematic; therefore, hierarchical linear model (HLM) regression analyses were conducted with the time series SCRD data as an additional analysis. HLM regression analyses were used to interpret data that might otherwise be overlooked in SCRDs to provide specific values for the rate students were learning during the intervention phase of the study. This pilot study demonstrates that the syntax intervention produces promising results when data that are too messy for visual analysis are analyzed with HLM.

Keywords

Syntax, intervention, alternative analyses, single-case design, hierarchical linear model regression, deaf and hard of hearing

A robust knowledge of morphosyntax contributes to comprehension of spoken or written language (Brimo, 2016; Fricke et al., 2013), including children's reading comprehension (Hagtvet, 2003; Nation et al., 2004; Share & Leikin, 2004). Morphosyntax knowledge requires the child to integrate information across two components of language: morphology and syntax. *Morphology* is the study of the "internal structures or parts of words" (Paul, 2009, p. 19) while *syntax* refers to the rules that order the grammatical structure or arrangement of words (Paul, 2009). Syntactical structures assist with understanding the meaning between words (e.g., The girl kicked the ball.) and between sentences (e.g., The girl kicked the ball. She scored a goal.).

Typically hearing children in an English-speaking environment acquire English morphosyntax knowledge through repeated auditory exposure to spoken grammatical structures during interaction with communication partners. By the age of five or six, most typically developing hearing children produce adult-like grammar and do not require formal instruction in English morphosyntax (Arndt & Schuele, 2013; Bowen, 1998). Despite technological advances in hearing assistive technology, deaf and hard-of-hearing (DHH) children often have difficulty mastering English morphosyntax because of intermittent and distorted auditory access to spoken language (Nielsen et al., 2016). They may enter school with a delay in morphosyntactic knowledge (Trussell & Easterbrooks, 2015) and thus require specially designed instruction.

Effective Strategies Used in Morphosyntax Studies

Specific teaching strategies have been used to promote syntax learning in hearing children who have language impairments (Brimo, 2016; Meyers-Denman & Plante, 2016; Serratrice et al., 2015; To et al., 2015). These include focused stimulation, explicit presentations about the target structure, adult modeling followed by child imitation, and adult recasts of child utterances. These strategies also have been used when teaching morphosyntax structures to preschool- and school-age DHH students (Richels, Bobzien, et al. 2016; Richels, Schwartz, et al., 2016). Two research

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studies conducted on syntax intervention with DHH students used single-case research designs (SCRD) and visual analysis of graphed data to show individual patterns of change. Each of the intervention studies are described briefly to illustrate effective instructional strategies, examine results reported by the authors, and identify some challenges in the visual analysis (e.g., stability, trend, immediacy of effect, etc.).

Richels, Schwartz, et al. (2016) used a multiple baseline design to examine the effect of repeated story book reading on increased production of targeted morphosyntactic forms and novel vocabulary. Participants were three DHH students, ages 3.7–4.4 years, who used listening and spoken language. The intervention consisted of a teacher reading three modified children's storybooks that provided frequent exposure to the target structures (i.e., present progressive, e.g., is + verb + ing). The teacher used at least one of five strategies while reading each page: requiring individual and choral responding of the target structures; verbal expansions of the child's utterance to include the target structure; providing word definitions; using a cloze technique to elicit the structure; and modeling the target structure. Students were required to show 100% mastery by producing complete sentences with both the target structure and novel vocabulary word in two consecutive probes. The authors reported a stable baseline for all three participants across all three books, an increasing trend during intervention, and maintenance of the target structure 2–8 days following intervention.

Although the authors suggest a functional relation between the morphosyntax intervention and the students' accurate production of the target structures, a close examination of the visual analysis reveals several concerns. While baseline is stable for all participants, the immediacy of effect between baseline and mastery is highly variable across participants (ranging from 4–25 sessions). In addition, intervention data for each participant is somewhat problematic to analyze visually. For example, the intervention phase data for Child 1 Book 2 shows extremely variable data points with increasing and decreasing trends throughout the phase. This variable trend is seen across all three students for book 3 but is not addressed by the authors.

Richels, Bobzien, et al. (2016) used similar teaching strategies by implementing a multiple probe across participants' design with three preschool DHH students who used spoken English. The researchers evaluated the effectiveness of having a typically developing hearing peer-prime participant by modeling responses to wh- questions (e.g., "What is she doing?") in a play-based intervention. The target structure for the intervention included sentences with a pronoun, a progressive verb, and an object (e.g., *He is holding a dog.*). Teaching strategies included adult modeling/priming, expanding and recasting; using manipulatives to demonstrate the action in visual picture prompts; and providing children multiple opportunities for receptive and expressive practice. Richels et al. reported a stable baseline, an immediate effect during intervention, and an increasing trend for all participants achieving 100% mastery (5/5) over three consecutive sessions. However, the graphs showed variable trends not addressed by the authors in the visual analysis. The visual analysis also showed students varied widely in how many intervention sessions were required for mastery (range: 7–23). Students maintained increased production of target structures during the maintenance phase compared to their individual baselines. However, Participant 2 had a decreasing trend almost returning to baseline on the final maintenance probe. Using traditional SCRD visual analyses to report the effectiveness of an intervention could be problematic with such within-phase variability as that demonstrated by Richels, Bobzien, et al. (2016) and Richels, Schwartz, et al. (2016).

HLM as an Additional or Alternative Analysis

The SCRD morphosyntax intervention studies reveal several challenges when using visual analysis: (a) variability within and between phases and (b) delayed effect, which offers a chance to explore an alternative analysis. Visual analysis results of SCRDs only capture the most obvious effects, while more subtle, yet significant, effects may be undetected (Brossart et al., 2006; DeProspero & Cohen, 1979; Park et al., 1990). Hierarchical linear model (HLM) has been proposed as an alternative analysis for SCRD data because of the flexibility to accommodate nested data (Davis et al., 2013). Using HLM descriptively instead of inferentially allows researchers to capture numeric trends in even small samples that might otherwise be too diffuse for visual detection. Using HLM, regression lines are fit to variable SCRD data within or across phases. The results of HLM provide individual and group growth patterns to capture numeric information that may be too variable for visual analysis.

Woltman et al. (2012) provided an example research question and a step-by-step description of an HLM analysis to break down its complexity. The example used nested data to complete a two-level HLM analysis to identify the relationship between student's breakfast consumption (i.e., individual level) within classrooms in a school (i.e., group level) to students' grade points average (GPA; continuous outcome variable). In short, the HLM analysis first identified each student's GPA and breakfast consumption (i.e., Level 1) by each students' classroom (i.e., Level 2). From the results, each student's classroom slope (i.e., Level 2) was identified and analyzed individually. From this, within- and between-group regressions were used to depict the relationship between breakfast consumption and GPA. The results indicated that breakfast consumption was positively related to GPA at the student level (Level 1). In addition, the intercepts for these individual slopes were also influenced by classroom factors (Level 2).

In addition, Davis et al. (2013) used SCRD results from Alberto and Fredrick (2007) to illustrate the use of HLM in augmenting visual analysis to quantify relations at the individual and group level. As an example, Alberto and Fredrick (2007) used a multiple baseline with an embedded changing criterion design to demonstrate replication across groups (i.e., classrooms within schools) in their original literacy study. Collecting data during each intervention subphase (i.e., Noun Subphase and Adjective Subphase), each student was to have five consecutive data points with variability no more than 50% above or below the mean. Students then had to achieve 80% accuracy for two of the last three sessions in the Noun Subphase before moving to the Adjective Subphase. The Noun Subphase had 12 trials per probe and the Adjective Subphase had 16 trials per probe, allowing trials to be nested within students and nested within phase. Davis et al.'s visual analysis showed that the students met the criterion for a stable baseline; however, they varied on ranges of correct responses (Noun Subphase: 0–12 correct responses; Adjective Subphase: 4–16) and in total number of sessions required to achieve mastery (Noun Subphase: 5–21 sessions; Adjective Subphase: 4–22 sessions) which led Davis and colleagues to explore augmenting visual analysis with HLM using data from three participants.

Two HLM growth models were used to quantify and statistically test growth trajectories of the three students within and between phases (Davis et al., 2013). In addition, HLM growth modeling was used to examine which student characteristics might account for the large variance between baseline and the two subphases for sight word reading. For the purpose of this article, only the first analysis will be shared (see Davis et al. for the second analysis). The first HLM model used the three time variables (i.e., time during baseline, time during Noun Subphase, and time during Adjective Subphase) to detect growth in sight word reading during baseline and each of the two subphases. Despite significant variance between participants during baseline, $\tau_{00} = 12.088$, $\chi^2(10) = 48.265$, $p < .001$, the HLM results showed that statistically significant growth did not occur during the baseline phase, suggesting no substantial learning was taking place. There was also no significant change between the baseline and Noun Subphase. However, within the Noun Subphase, reading scores changed significantly, $t(10) = 4.640$, $p < .010$, increasing by 0.707 words per session on average. The variance of individual growth rate was also statistically significant, $\chi^2(10) = 442.648$, $p = <.010$. As anticipated by the researchers, there was a decline in reading ability between the Noun and Adjective Subphases. However, statistically significant growth was identified within the Adjective Subphase, $t(10) = 4.345$, $p < .010$, as well; scores increased by 0.600 words per session on average. Like the Noun Subphase, statistically significant variance in growth rates were observed during the Adjective Subphase, $\chi^2(10) = 103.5936$, $p < .001$. The statistical results from HLM provided information far beyond the original SCRD study, detecting numerical trends hidden from visual analysis by variability.

Although Davis et al. (2013) did not identify the variability in baseline or delayed effect as reasons to proceed with HLM analyses, the purpose of their study was to show that HLM provides additional valuable and practical information when applied to SCRD data. SCRD interventions that result in variable data and delayed effects with DHH students may warrant HLM. The purpose of this pilot study was to examine the effects of a multiple-strategy morphosyntax intervention on young DHH students' production of morphosyntactic structures. In addition, in this study, we show that it is possible to use HLM to examine highly variable SCRD data, so as to capture the promise of a morphosyntax intervention to continue development and refinement. This study will answer the following research question: Will DHH children increase production of English morphosyntactic structures in single sentences when taught through this explicit syntax intervention?

Method

Research Design

A single-case multiple-probe design across content (Gast & Ledford, 2014) was used to determine if a functional relation existed between the syntax intervention and children's mastery of targeted syntactical structures. The content consisted of several syntactic structures (called set for this study). Each set was introduced and staggered over time.

Participants and Setting

Six DHH students in kindergarten through Grade 2 participated in this study. Four students attended a self-contained classroom at a center school and two attended a co-enrollment program in a public elementary school. All six participants were referred by their classroom teachers and met the following criteria: (a) had a diagnosed hearing loss (see Table 1 for student demographic information); (b) received services from a teacher of the DHH, (c) had no additional visual, cognitive, or physical disability that would inhibit their participation or use of instructional materials, (d) had a need for syntax instruction established through teacher recommendation, (e) achieved a score that was at least one standard deviation below their typical peers on standardized assessments (e.g., Clinical Evaluation of Fundamental Language, Fourth Edition, CELF-4; Test of Auditory Language Comprehension, TACL), and (f) primarily used spoken language receptively and expressively.

Table 1. Participant Demographics.

Participants	Grade	Gender	Hearing loss	HAT	Comm. mode	Educational setting
Student 1	1	M	Mild to profound	HA & CI	Speech/sign	Self-contained
Student 2	K	M	Moderate	2 HA	Speech/sign	Self-contained
Student 3	K	M	Moderate	2 HA	Speech/sign	Self-contained
Student 4	1	F	Mild to moderate	2 HA	Speech/sign	Self-contained
Student 5	1	F	Profound	2 CI	Speech/sign	Co-enrollment
Student 6	1	M	Moderate	2 HA	Speech/sign	Co-enrollment

Note. Student participant demographics for xxx pilot study intervention. HAT = type of assistive technology worn by student. Comm. mode = communication mode preferred by students—primarily spoken language with sign support.

The Institutional Review Boards of all universities involved approved this study. Appropriate parental consent for student participants was obtained.

Dependent Variable

Syntax production and accuracy was operationally defined as a spoken production of the target English syntax structure that included all obligatory components in a single sentence.

Independent Variable

The xxx (xxx) intervention. We created five syntax "sets" from stories the research group created for DHH students. The stories were engaging and included familiar topics (e.g., meeting new friends and playing with toys) along with activity cards and take-home practice sheets. Each set included 2–4 targeted syntactical structures (see Table 2) and 12 lessons with four components that were implemented as described in Table 3. The first author served as the instructor and implemented the intervention in the following order: Hear, See, Say, and Learn; Story Time; Single Sentence Drill & Practice; and Connected Language Activity. At least one effective teaching strategy (e.g., modeling, expanding, recasting, repeated opportunities) was systematically incorporated into each component. Each intervention session was video-recorded.

Table 2. XXX Target Syntax Structures by Set With Examples.

Set	Structures	Examples
1	NP +LV (am)+NP	I am a boy.
	S+V+O (a+N)	Bella is a girl.
	NP+ LV (is) +N/adj.	Jose is happy.
2	NP+LV (has) + N	Pam has a hat.
	NP (He/She) + LV+ Adj.	He is happy.
	NP (He/She) + LV+N	She is a doctor.
3	NP + (conj.) and+ N + VP	Sam and Bella like cake.
	N + VP + *N* (conj.) and N	Sam wants cake and pie.
	N+ V (said) +S	Sam said, "I want pie."
4	NP + V + PP (on)	Sam sat on the bed.
	NP + VP + O + PP (on)	Sam put the hat on the bed.
	NP (we) +VP (can+V)	We can play.
5	NP+ LV (have) + NP	We have cake.
	N (plural s)	The pals play on the hill.
	NP + LV (are) + Adj.	The pals are happy.

Note. Target syntax structures developed for the five sets used in the XXX pilot study.

Measurement

Syntax measure. To measure single-sentence syntax production and accuracy, we created a set of picture prompts for each target structure that were different than materials used during the intervention. The instructor started the probe by modeling the target structure. She then presented the picture prompts and asked the student to "say a sentence like mine." Students were given three opportunities to produce the correct structure following a system of increasing prompts. Syntax production and accuracy were scored based on the accuracy of the student's production of the target structure and the number of trials. Students received a score only when the sentence included all obligatory components. They received a score of 3 if the first attempt (following the instructor's initial model and prompt) was correct, a score of 2 if they produced correct responses after the second prompt, a score of 1 if they produced correct responses after the third prompt, and a score of 0 when the target structure was produced inaccurately after the third prompt. Students were considered to have mastered a structure if they received a score of 8 or 9 for two consecutive trials. For all probes, the instructor scored the single sentence assessments in real-time and a second observer scored probes from the video-recorded sessions.

Treatment integrity measures. The first author implemented the intervention with all six students. Treatment integrity (TI) checklists (available from the first author) were used to examine the consistency and quality of instruction using the strategies and lessons as designed. The instructor completed a daily checklist to document tasks completed during the lesson (e.g., teacher models, expands, or provides student at

Table 3. XXX Procedures.

XXX Component	Procedures
Hear, See, Say, and Learn	1. Prompt participants to attend to the target structure auditorily (Hear) 2. Present the structure in print (See) 3. Model and requested that participants' imitate the target structure (Say) 4. Give a child-friendly definition of the target structure
Story time	1. Read a researcher-created story that included target structures 2. Ask scripted questions after the story was read to elicit the target structure from participants 3. Recast, expand, and/or highlight the target structure to provide corrective feedback to the student
Single sentence drill and practice	1. Engage student in games, such as bingo or memory, which gave each participant at least two opportunities to produce the target structure 2. Model, prompt, and recast student sentences
Connected language	1. Engage student in teacher–child conversations 2. Retell or generate stories that contained the target structures with visual cues (e.g., manipulatives and character puppets)

Note. Procedures for each component of the XXX intervention.

least 3 opportunities to produce target structures). Each completed component of the checklist earned a score of 1. A trained research assistant scored at least 20% of the recorded sessions for increased prompting and number of trials to ensure implementation fidelity of the XXX intervention.

Interrater reliability. During all single sentence probe assessments, each student participant worked with the instructor in a one-to-one setting. Participant responses were scored live by the instructor and then again using a transcription of the video-recorded sessions by a second researcher. All assessments were video-recorded and interobserver agreement was completed on 100% of the assessments. Scores were compared for single sentence production. When there was any discrepancy (i.e., $\geq$ 1 point), the two researchers read the transcript, watched the video-recorded session together, discussed, and came to consensus on the final score. Typically, the second researcher's score became the participant's final score. Interrater reliability (IRI) was calculated to be .8%.

Procedures

XXX was implemented for 20–25 minutes a day, 4 days a week over the traditional 9-month school year. The research-teacher followed the school calendar and honored scheduled breaks and/or teacher-in-service days. The intervention took place in a separate but familiar location of the school. Students participated in small groups for the intervention, but assessments and probes were administered individually. Each set of structures was probed repeatedly during the baseline phase and introduced sequentially during the intervention phase in a staggered manner (i.e., Sets 1–5).

Baseline phase. Baseline data on the targeted syntactical structures in each set (see Table 2) were collected prior to intervention. We conducted a minimum of three consecutive baseline probes, one per session, over three to six consecutive school days for each targeted structure prior to the intervention. Baseline ranged from three to six probes for each structure for each participant. Structures within each set were assessed in a random sequence determined by a computer-generated list.

Intervention phase. The intervention phase included explicit and direct instruction on targeted morphosyntactic structures by implementing at least three of the four components during each session (see Table 3). During intervention, students engaged in at least three sessions of single sentence drill and practice. The Connected Language activities were conducted after students had several opportunities to practice the target structure in single sentences. Single sentence probes for the target structures within the given set occurred after each intervention session. After students mastered the target structures in the set (8/9 or 9/9 for two consecutive trials), the researcher introduced the next set of structures.

Maintenance phase. After mastery criteria were met for each structure within a set, we administered three maintenance probes between 2 weeks and 2 months after the last intervention session for the given set. During the intervening time, participants received no additional instruction on the target structures for that set. During maintenance probes, the single sentence assessments were randomized for the given set.

Data Analysis

Visual analysis. We attempted visual analysis to examine the functional relation between the intervention and increased production and accuracy of target morphosyntax structures by examining stability, trend, immediacy of effect, and percentage of nonoverlapping data (POND) (Gast, 2005; Wolery & Harris, 1982). Daily probes indicated data were variable and inconsistent. Thus, we used an alternative analysis to capture the promise of the intervention.

HLM analysis. HLMs were used to supplement visual analysis to explore level of performance and linear change in performance during baseline, intervention, and maintenance phases using the single-sentence assessment data. Given that each of the six participants were assessed on each of the five syntax sets, there were two ways to analyze the data: (a) run a separate HLM for each student across all syntax sets such that trials were nested within syntax set or (b) run a separate HLM for each syntax set across all participants such that trials were nested within student participant. To demonstrate the utility of HLM, we present one of the analyses from option 2. We conducted one HLM for the data from a single syntax set (i.e., Set 3 for all students). Thus, within that syntax set, the HLM produced two sets of results: (a) regression lines for each student's performance (i.e., one line for their baseline performance, one line for their intervention performance, and one line for maintenance performance) and (b) an average regression line for each phase across all students.

Random Coefficients Model (RCM). The model of interest, the RCM, included main effects of trial and phase (i.e., baseline, intervention, and maintenance) and an interaction between phase and trial. Phases were dummy coded into two variables. Baseline was the reference condition (0 on both dummy variables). One dummy variable represented the intervention phase and the other represented the maintenance phase. For each student, trial or time was centered around the middle of each phase. For example, if a student had three baseline trials (1, 2, 3), they were recoded as −1, 0, and 1 for the HLM. If that same student had four intervention trials (1, 2, 3, 4), they were recoded as −1.5, −0.5, 0.5, and 1.5 for the HLM. This coding centered all intercepts at mid-phase performance because the middle of each phase was coded as time zero. Fixed and random intercepts and slopes for time, phase, and the interaction (phase × time) were included. Thus, each student had their own main effect of trial (random effect of trial), their own main effects of phase (one main effect comparing the intervention to baseline and the other comparing maintenance to baseline, both random effects of phase), and their own interaction terms (trial × intervention and trial × maintenance, random interaction effects). The average of each random effect across all students was included as a fixed effect. For example, the fixed effect of intervention phase was the average of the student-specific regression weights comparing mid-phase intervention performance to mid-phase baseline performance (the average of the random effects). Model equations are given below:

Level 1 (Student):

$$\begin{aligned}\text{TotalScore}_{pt} = {} & \pi_{0s} + \pi_{1s} \times \text{Time}_{st} + \pi_{2s} \times \text{BvI}_{st} + \pi_{3s} \\ & \times \text{BvM}_{st} + \pi_{4s} \times \text{Time}_{st} \times \text{BvI}_{st} + \pi_{5s} \\ & \times \text{Time}_{st} \times \text{BvM}_{st} + e_{ps}\end{aligned}$$

Level 2 (Sample):

$$\pi_{0s} = \gamma_{00} + \zeta_{0s};\ \pi_{1s} = \gamma_{10} + \zeta_{1s};\ \pi_{2s} = \gamma_{20} + \zeta_{2s};$$
$$\pi_{3s} = \gamma_{30} + \zeta_{3s};\ \pi_{4s} = \gamma_{40} + \zeta_{4s};\ \pi_{5s} = \gamma_{50} + \zeta_{5s}$$

Combined:

$$\begin{aligned}\text{TotalScore}_{pt} = {} & \gamma_{00} + \gamma_{10} \times \text{Time}_{st} + \gamma_{20} * \text{BvI}_{st} + \gamma_{30} \\ & \times \text{BvM}_{st} + \gamma_{40} \times \text{Time}_{st} \times \text{BvI}_{st} + \gamma_{50} \\ & \times \text{Time}_{st} \times \text{BvM}_{st} + \zeta_{0s} + \zeta_{1s} \times \text{Time}_{st} \\ & + \zeta_{2s} * \text{BvI}_{st} + \zeta_{3s} \times \text{BvM}_{st} + \zeta_{4s} \times \text{Time}_{st} \\ & \times \text{BvI}_{st} + \zeta_{5s} \times \text{Time}_{st} * \text{BvM}_{st} + \varepsilon_{st}\end{aligned}$$

where *s* represents student, and *t* represents trial or time.

Results

Visual Analysis

Initially visual analyses were attempted. For purposes of illustration only, Student 1's visual analysis results for Set 3 are in Figure 1. Other sets and students yielded similar results.

Results for Set 3 show highly variable baselines for all three structures: (a) NP(NandN)+VP, (b) N+VP+NP (NandN), and (c) N+V(said)+S. The first baseline data points for all three structures ranged between 2 and 3, indicating the student was unable to accurately produce the structures without multiple prompts and models. The second data points for all three structures show an increasing trend (range: 2–9), indicating less prompting was required to produce the target structures. However, at the third baseline data points, Structures 2 and 3 had a score of 0. The first data points in the intervention phase revert to 0 for Structures 1 and 3. The second data points for Structures 1 and 3 start to show upward trends. Structure 1 is mastered; Structure 3 shows a delayed effect and only one mastery data point (9/9). Structure 2 shows an immediate effect of the intervention for the first data point but is variable to mastery. During the intervention phase, there are positive trends observed, but PNOD is only 33%. In maintenance, Structure 1, which met mastery criteria in the intervention phase, reverted to below baseline for the first maintenance data

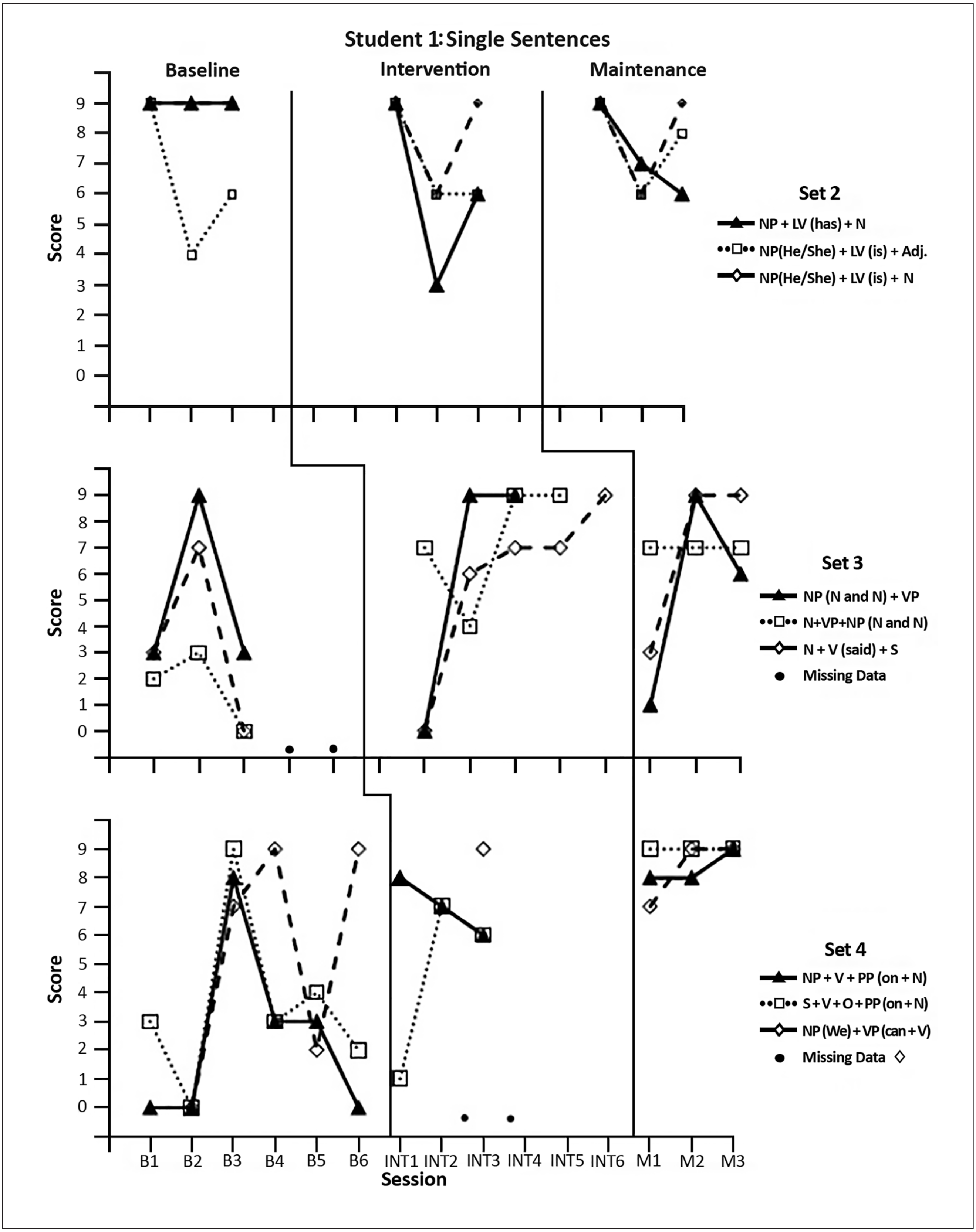

Figure 1. Student 1 Single Sentences.
Visual Analysis Results (B = Baseline, INT = Intervention, M = Maintenance).

Table 4. Participant HLM Results for Syntax Set 3.

Predictor	*B*	*SE*	*df*	*t*	*p*	95% CI
Intercept (baseline)	6.03	0.95	50	6.29	.00	[4.57, 7.45]
Trial slope (baseline)	0.44	0.58	50	0.76	.45	[0.49, 1.75]
Intervention	1.78	0.55	50	3.26	<.01	[1.66, 3.37]
Maintenance	2.09	0.74	50	2.82	<.01	[0.98, 4.29]
Intervention × trial	0.17	0.76	50	0.23	.81	[−2.10, 0.40]
Maintenance × trial	−0.16	0.70	50	−0.24	.81	[−1.78, −0.21]
Component	Variance	*SD*	95% CI (*SD*)			
Intercept (baseline)	5.15	2.27	[4.97, 4.98]			
Trial slope (baseline)	1.75	1.32	[1.55, 1.88]			
Intervention	1.31	1.15	[0.44, 0.75]			
Maintenance	2.71	1.64	[3.41, 3.83]			
Intervention × trial	3.11	1.76	[4.03, 4.20]			
Maintenance × trial	2.51	1.59	[3.16, 3.39]			
Error						

Note. LL = −91.43, AIC = 238.858, BIC = 295.063. HLM = hierarchical linear model; LL = lower limit; AIC = Akaike information criterion.

point and was not maintained at mastery. Structure 2 showed improvement above baseline but was not maintained at mastery as observed in the intervention phase. Structure 3 also reverted to near baseline scores at the first maintenance data point.

The highly variable data, unclear trend lines, and visually challenging data create concern for using visual analysis. Fortunately, the nested data structure allowed us to continue to explore the variability phenomenon of morphosyntax production and accuracy through HLM.

HLM

Results from the RCM are reported for Set 3 in Table 4 for all students. Although all sets were analyzed with HLM, Set 3 is reported to demonstrate HLM as alternative analysis for SCRD data. HLM results for additional sets can be requested from the first author. The upper half of Table 4 represents fixed effects, the average effects across all students. The fixed intercept indicated that, on average, students earned 6.03 points out of 9 possible points in the middle of the baseline phase. The fixed main effects of phase indicated on average across students, performance was 1.78 points higher in the middle of the intervention phase compared to the mid-baseline, and 2.09 points higher in the middle of the maintenance phase compared to mid-baseline. Thus, despite the variable data points, more accuracy was demonstrated during the intervention and maintenance phases than during the baseline phase.

The main fixed effect of trial represents the linear growth trend across baseline. On average across students, from one trial to the next during the baseline phase, performance increased by 0.44 points. The trial × phase interaction fixed effects indicate the difference in linear trend (slope) between the intervention and baseline phase and the maintenance and baseline phase. On average across students, from one trial to the next in the intervention phase, performance increased by 0.17 additional points compared to the baseline slope (or 0.44 + 0.17 = 0.61 points from one trial to the next). On average across students, from one trial to the next in the maintenance phase, performance increased by 0.16 points less compared to the baseline slope (or 0.44–0.16 = 0.28 points from one trial to the next). Thus, steepest improvement occurred during the intervention phase, with some improvement present at baseline and the least improvement during maintenance, as would be expected.

The numbers in the bottom half of Table 4 represent the variance of each random effect from student to student. We can interpret standard deviations as deviations from the fixed-effect estimates. For example, the standard deviation for the intercept indicates student-specific intercept, student-specific performance at mid-baseline, was on average 5.15 points off from the fixed-effect estimate of 6.03, capturing the large variability between students in baseline performance. Similarly, student-specific intervention main effects were on average 1.31 points off from the fixed-effect of intervention, 1.78. Thus, for some students, performance at mid-intervention was only a little better than performance at mid-baseline, while for others, mid-intervention performance was much higher than mid-baseline. The random main effect of trial or time indicates that student-specific slopes across the baseline phase are on average 1.32 points off from the average of these slopes (the fixed main effect of trial at baseline), 0.44. Similarly, the random trial ×

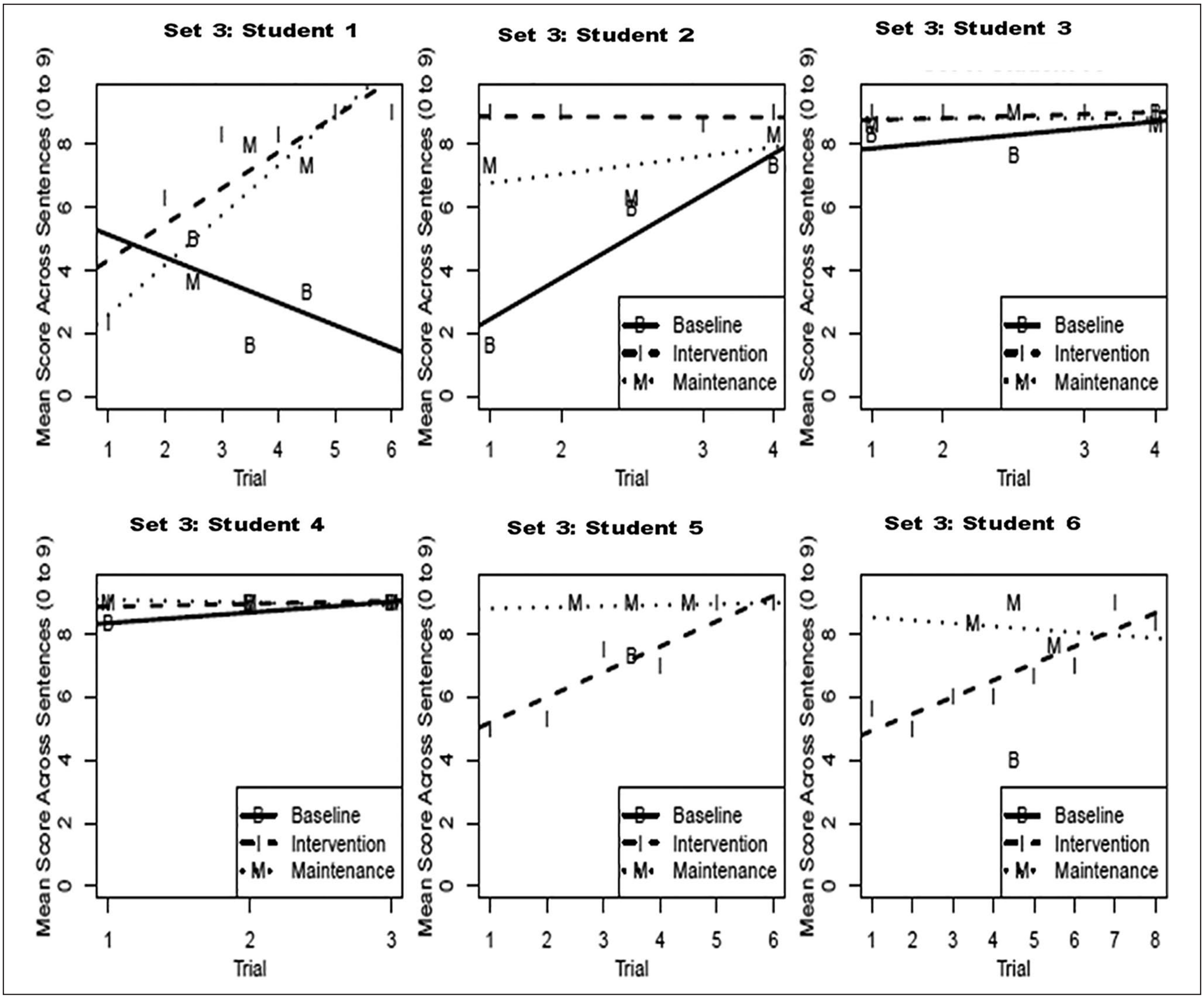

Figure 2. Set 3 individual student Single Sentence HLM regression results.

intervention interaction effect indicates the student-specific differences between intervention slope and baseline slope were on average 1.76 points off from the mean of all these differences (the fixed effect of the trial × intervention interaction), 0.17. For some students, slope or increase in performance during the intervention phase was much steeper than at baseline. For other students, slope or increase in performance during the intervention phase may have been shallower than the increase at baseline. Results indicate the variation in every random effect is substantial from student to student. Another benefit of HLM is that it provides student-specific regression weights. Thus, if desired, we could produce the top half of Table 4 for each student individually, to describe the individual trends in performance. These numbers can be overwhelming. Instead, we used these student-specific regression weights to plot regression lines on top of each student's data for Set 3 (see Figure 2). These regression lines show learning during the intervention phase which was challenging to observe in the visual analysis results.

Student 1 had a baseline regression line that was slightly decreasing over baseline trials. Student 2 learned structures during baseline trials, and Students 3 and 4 had already mastered the structures at baseline. Instruction was continued with Students 3 and 4, as they were in small groups with other participants for the intervention study. Students 5 and 6 had no baseline trend because they only had one baseline score. The intervention regression lines either have a steep positive slope or demonstrate mastery performance (high unchanging performance across the intervention) for every single participant. In addition, all students maintained high, stable performance throughout the maintenance phase, with the exception of Student 1, who relearned structures during maintenance. Overall, HLM results show a reasonably positive effect of the intervention, supplementing visual analysis as an effective tool for evaluating SCRD data. With visual analysis alone, these compelling linear trends would have remained hidden.

Discussion

Visual Analysis Challenges Made Visible With HLM

Syntax development is a contributing factor to reading comprehension and future literacy outcomes (Hagtvet, 2003; Nation et al., 2004; Share & Leikin, 2004). In addition, this is an area that DHH students may show a deficit (Trussell & Easterbrooks, 2015). The purpose of this research was to examine the promise of a syntax intervention specifically for DHH students.

Highly variable data, low PNOD, and delayed effect created challenges in examining the effect of the intervention through visual analysis. The single subject graphed data showed extreme variability and overlap, but an alternative HLM analysis indicated that the intervention had promise and would be worth pursuing further.

The HLM results indicated the intervention was effective in capturing the growth of individual students' learning within sets. Using HLM as a tool for fitting student-specific lines to each student's data (see Figure 2) allowed us to detect patterns in performance that were hidden in visual analysis. HLM results show that the participants obtained syntax scores 1.78 points higher in the middle of the intervention phase compared to the middle of baseline phase, and 2.09 points higher in the middle of the maintenance phase compared mid-baseline. In addition, on average across students, the steepest improvement occurred during the intervention phase.

The Future of HLM With SCRD

HLM may be used as an additional analysis for SCRD data when an effect is not clearly seen in the visual analysis. HLM provides additional information about students' growth trajectories with statistical evidence (Davis et al., 2013), especially when data are highly variable. In instances where visual analysis may not reveal a functional relation in an SCRD study, HLM can provide specific values for the rate at which students are learning per instructional session (Davis et al., 2013). In addition, HLM can capture variability in the rate of change, which visual analysis cannot, and researchers can even include participant characteristics that may explain some of this variability, although this was beyond the scope of the current project. Future use of HLM with SCRD nested data will allow interventions with variable data to be further examined. Without this additional analysis, otherwise compelling results from messy data may be overlooked or seen as inconclusive, discouraging an effective intervention.

Limitations

Several factors affect generalization of these results. The documented results and generalization to other DHH children is limited because of the small sample size ($n = 6$) and the use of HLM for description rather than for hypothesis testing (inference about a population). The intervention was implemented by researchers, and the results are not generalizable to classroom settings when implemented by a teacher of DHH students. In this study, we did not measure generalization of the syntactic structures to connected language. Missing data points create a limitation for visual analysis; however, HLM can handle data missing at random with a specific estimation method, full maximum likelihood estimation (Graham et al., 2007).

Conclusion

This pilot study demonstrates that the syntax intervention produces promising results when data that are too messy for visual analysis are analyzed with HLM. The DHH students improved their production and accuracy of English morphosyntactic structures within single sentences. Replication and extensions of the intervention are necessary to progress toward an evidence-based practice that can be implemented in the classroom by teachers.

Declaration of Conflicting Interests

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